WTP 281
Feb. 1995

WORLD BANK TECHNICAL PAPER NUMBER 281
ASIA TECHNICAL DEPARTMENT SERIES

Environmental and Economic Issues in Forestry

Selected Case Studies in Asia

Edited by Susan Shen and Arnoldo Contreras-Hermosilla

RECENT WORLD BANK TECHNICAL PAPERS

No. 216 Carr, *Improving Cash Crops in Africa: Factors Influencing the Productivity of Cotton, Coffee, and Tea Grown by Smallholders*

No. 217 Antholt, *Getting Ready for the Twenty-First Century: Technical Change and Institutional Modernization in Agriculture*

No. 218 Mohan, editor, *Bibliography of Publications: Technical Department, Africa Region, July 1987 to December 1992*

No. 219 Cercone, *Alcohol-Related Problems as an Obstacle to the Development of Human Capital: Issues and Policy Options*

No. 220 Kingsley, Ferguson, Bower, and Dice, *Managing Urban Environmental Quality in Asia*

No. 221 Srivastava, Tamboli, English, Lal, and Stewart, *Conserving Soil Moisture and Fertility in the Warm Seasonally Dry Tropics*

No. 222 Selvaratnam, *Innovations in Higher Education: Singapore at the Competitive Edge*

No. 223 Piotrow, Treiman, Rimon, Yun, and Lozare, *Strategies for Family Planning Promotion*

No. 224 Midgley, *Urban Transport in Asia: An Operational Agenda for the 1990s*

No. 225 Dia, *A Governance Approach to Civil Service Reform in Sub-Saharan Africa*

No. 226 Bindlish, Evenson, and Gbetibouo, *Evaluation of T&V-Based Extension in Burkina Faso*

No. 227 Cook, editor, *Involuntary Resettlement in Africa: Selected Papers from a Conference on Environment and Settlement Issues in Africa*

No. 228 Webster and Charap, *The Emergence of Private Sector Manufacturing in St. Petersburg: A Survey of Firms*

No. 229 Webster, *The Emergence of Private Sector Manufacturing in Hungary: A Survey of Firms*

No. 230 Webster and Swanson, *The Emergence of Private Sector Manufacturing in the Former Czech and Slovak Federal Republic: A Survey of Firms*

No. 231 Eisa, Barghouti, Gillham, and Al-Saffy, *Cotton Production Prospects for the Decade to 2005: A Global Overview*

No. 232 Creightney, *Transport and Economic Performance: A Survey of Developing Countries*

No. 233 Frederiksen, Berkoff, and Barber, *Principles and Practices for Dealing with Water Resources Issues*

No. 234 Archondo-Callao and Faiz, *Estimating Vehicle Operating Costs*

No. 235 Claessens, *Risk Management in Developing Countries*

No. 236 Bennett and Goldberg, *Providing Enterprise Development and Financial Services to Women: A Decade of Bank Experience in Asia*

No. 237 Webster, *The Emergence of Private Sector Manufacturing in Poland: A Survey of Firms*

No. 238 Heath, *Land Rights in Côte d'Ivoire: Survey and Prospects for Project Intervention*

No. 239 Kirmani and Rangeley, *International Inland Waters: Concepts for a More Active World Bank Role*

No. 240 Ahmed, *Renewable Energy Technologies: A Review of the Status and Costs of Selected Technologies*

No. 241 Webster, *Newly Privatized Russian Enterprises*

No. 242 Barnes, Openshaw, Smith, and van der Plas, *What Makes People Cook with Improved Biomass Stoves? A Comparative International Review of Stove Programs*

No. 243 Menke and Fazzari, *Improving Electric Power Utility Efficiency: Issues and Recommendations*

No. 244 Liebenthal, Mathur, and Wade, *Solar Energy: Lessons from the Pacific Island Experience*

No. 245 Klein, *External Debt Management: An Introduction*

No. 246 Plusquellec, Burt, and Wolter, *Modern Water Control in Irrigation: Concepts, Issues, and Applications*

No. 247 Ameur, *Agricultural Extension: A Step beyond the Next Step*

No. 248 Malhotra, Koenig, and Sinsukprasert, *A Survey of Asia's Energy Prices*

No. 249 Le Moigne, Easter, Ochs, and Giltner, *Water Policy and Water Markets: Selected Papers and Proceedings from the World Bank's Annual Irrigation and Drainage Seminar, Annapolis, Maryland, December 8-10, 1992*

No. 250 Rangeley, Thiam, Andersen, and Lyle, *International River Basin Organizations in Sub-Saharan Africa*

No. 251 Sharma, Rietbergen, Heimo, and Patel, *A Strategy for the Forest Sector in Sub-Saharan Africa*

No. 252 The World Bank/FAO/UNIDO/Industry Fertilizer Working Group, *World and Regional Supply and Demand Balances for Nitrogen, Phosphate, and Potash, 1992/93–1998/99*

No. 253 Jensen and Malter, *Protected Agriculture: A Global Review*

(List continues on the inside back cover)

WORLD BANK TECHNICAL PAPER NUMBER 281
ASIA TECHNICAL DEPARTMENT SERIES

Environmental and Economic Issues in Forestry

Selected Case Studies in Asia

Edited by Susan Shen and Arnoldo Contreras-Hermosilla

The World Bank
Washington, D.C.

First printing February 1995

The complete backlist of publications from the World Bank is shown in the annual *Index of Publications,* which contains an alphabetical title list (with full ordering information) and indexes of subjects, authors, and countries and regions. The latest edition is available free of charge from the Distribution Unit, Office of the Publisher, The World Bank, 1818 H Street, N.W., Washington, D.C. 20433, U.S.A., or from Publications, The World Bank, 66, avenue d'Iéna, 75116 Paris, France.

ISSN: 0253-7494

Susan Shen is Senior Ecologist in the East Asia Country Department I of the World Bank. Arnoldo Contreras-Hermosilla is Senior Natural Resources Economist in the Latin America and Caribbean Country Department II of the World Bank.

Library of Congress Cataloging-in-Publication Data

Environmental and economic issues in forestry: selected case studies
in Asia/edited by Susan Shen and Arnoldo Contreras-Hermosilla.
p. cm. — (World Bank technical paper, ISSN 0253-7494 ; no. 281)
Includes bibliographical references.
ISBN 0-8213-3233-3
1. Forests and forestry—Environmental aspects—Asia—Case studies. 2. Forests and forestry—Economic aspects—Asia—Case studies. I. Shen, Susan. II. Contreras-Hermosilla, Arnoldo, 1942– III. International Bank for Reconstruction and Development. IV. Series.
SD219.E58 1995
333.75'137'095—dc20 95–13025
CIP

ASIA TECHNICAL DEPARTMENT PAPERS

No. 137 Constant and Sheldrick, *An Outlook for Fertilizer Demand, Supply, and Trade, 1988/89-1993/94*

No. 156 De Geyndt, *Managing Health Expenditures under National Health Insurance: the Case of Korea*

No. 162 Replogle, *Non-Motorized Vehicles in Asian Cities*

No. 174 Constant and Sheldrick, *World Nitrogen Survey*

No. 182 Land Resources Unit, Asia Technical Department, *Strategy for Forest Sector Development in Asia*

No. 187 De Geyndt, Zhao, and Liu, *From Barefoot Doctor to Village Doctor in Rural China*

No. 193 Braatz, *Conserving Biological Diversity: A Strategy for Protected Areas in the Asia-Pacific Region*

No. 202 Vergara, *The Materials Revolution: What Does It Mean for Developing Asia?*

No. 211 Wiebers, *Integrated Pest Management and Pesticide Regulation in Developing Asia*

No. 212 Frederiksen, Berkoff, and Barber, *Water Resources Management in Asia, Volume I: Main Report*

No. 217 Antholt, *Getting Ready for the Twenty-First Century: Technical Change and Institutional Modernization in Agriculture*

No. 220 Kingsley, Ferguson, Bower, and Dice, *Managing Urban Environmental Quality in Asia*

No, 222 Selvaratnam, *Innovations in Higher Education: Singapore at the Competitive Edge*

No. 224 Midgley, *Urban Transport in Asia: An Operational Agenda for the 1990s*

No. 233 Frederiksen, Berkoff, and Barber, *Principles and Practices for Dealing with Water Resources Issues*

No. 236 Bennett and Goldberg, *Providing Enterprise Development and Financial Services to Women: A Decade of Bank Experience in Asia*

No. 248 Malhotra, Koenig, and Sinsukprasert, *A Survery of Asia's Energy Prices*

No. 261 Lynch, *Provision for Children with Special Educational Needs in the Asia Region*

No. 272 Greaney and Kellaghan, *Equity Issues in Public Examinations in Developing Countries*

Contents

Foreword

In 1990, when the papers that make up this volume were commissioned, World Bank lending for forestry in Asia stood at nearly $2 billion. In fiscal 1994 alone, more than $300 million in lending was devoted to Asian forestry issues. As part of its responsibility for this level of investment, the World Bank has assisted the borrowing countries in their efforts to slow the rate of deforestation in the region, estimated at 3.5 million hectares a year during the 1980s, while expanding economic growth. This work has been hampered, however, by a lack of analyses of the key weaknesses in the sector—for example, low administrative capacity, inappropriate forest and other development policies, and limited knowledge of silvicultural and management systems for (tropical) forests and of the social, cultural, and environmental dimensions of forest management.

Over the last few years, the World Bank and the Asia Technical Department have provided significant guidance on reassessing and adapting approaches to these issues. The World Bank policy paper *The Forest Sector* (1991), Operations Evaluation Department Review of Forestry Lending (1991), *Strategy for Forest Sector Development in Asia* (1992), and various country-specific forest sector analyses provide the broad parameters for Bank work in forestry in Asia.

The papers presented in this volume were planned to support specific forestry programs at the country level. Toward that end, the Asia and Pacific Country Departments were invited to identify the priority issues to be studied and collaborated throughout the process of preparation and review of the reports. The resulting studies provide an overview of some of the more important forestry issues facing countries in Asia, and this volume is presented in support of all concerned policymakers, foresters, and development organizations as they balance the pressures of population and economic growth with protection of the region's critical forestry resources.

Harold W. Messenger
Director
Asia Technical Department

Abstract

Forests in Asia are under intense pressure to grow construction timber, provide trees and underbrush for fuel or leaves for crafts, and supply medicinal plants, game, fruits, nuts and so on—for one of the fastest growing populations in the world. The number of people living in South Asia alone is expected to grow by two-thirds during the next two generations, and governments across Asia are justifiably concerned about the degradation or loss this growth may mean to their forest resources and to their people. The poor in Asia particularly depend on forests as a source of protein and shelter.

But beyond the obvious, immediate causes of deforestation, it is generally recognized that other interrelated forces—economic, institutional, and technical—contribute more to forest loss. For instance, the underpricing of timber, or subsidies, will probably lead to overuse of wood and eventually to deforestation.

Recognizing that many of the immediate pressures on Asian forests were caused by the needs of growing populations and economies, in 1991 the World Bank commissioned a series of studies funded by a grant from the Government of Norway to incorporate environmental considerations into economic analyses of forestry operations. The Environment Division of the Asia Technical Department (ASTEN) coordinated the process of preparation and review, and the World Bank Country Departments for Asia were invited to identify the specific issues of concern to operations.

Each of the chapters presented in this volume represent one of those research topics—from analysis of the logging ban in Thailand to technical advice on tree improvement programs to analysis of the effect on forests of economic policy in India. Because the topics represent the interests of the Asia Country Departments, the volume provides an overview of the environmentally related priority issues in Asian forestry and contributes to the critical work of understanding their complex dynamics.

Preface

History of process

Forests are a major resource of nearly every country and provide many services such as cleaning the air, stabilizing the soil, and moderating runoff. But in Asia they also have important second and third jobs—growing construction timber, providing trees and underbrush for fuel or leaves for crafts, and supplying medicinal plants, game, fruits, nuts and so on—for one of the fastest growing populations in the world. The number of people living in South Asia alone is expected to grow by two-thirds during the next two generations, and governments across Asia are justifiably concerned about the degradation or loss this growth may mean to their forest resources and to their people. The poor in Asia particularly depend on forests as a source of protein and shelter.

The growing population in Asia is expected to exacerbate the usual causes of deforestation—conversion to agricultural uses, demand for fodder and fuelwood (four-fifths of Asia's timber demand), and logging. The Food and Agriculture Organization of the United Nations has estimated that forests disappeared in Asia at the rate of 3.5 million hectares a year during the 1980s, and already this historically wood-exporting region is showing a wood deficit. In fact, imports of timber and forest products will cost the region an estimated $20 billion annually by 2000.

But beyond the obvious, immediate causes of deforestation, it is generally recognized that other interrelated forces—economic, institutional, and technical—contribute more to forest loss. For instance, the underpricing of timber, or subsidies, will probably lead to overuse of wood and eventually to deforestation.

Environmental economists, extending these lines of argument, are now recognizing that an even more basic factor than any of these may be what lies behind those forces—that is, what happens, or does not happen, in the economic valuation of natural resources or the services they provide. What is the economic chain of cause and effect that is set in motion when, for example, a lake is polluted and the loss of its fish or surrounding vegetation is ignored as a cost and the service is considered "free"? It is now recognized that the destruction of environmental resources or services is never without cost. One of the main messages of this publication is that when forest resources are destroyed, whether through logging, agricultural activities, or exploitation for fuelwood, the loss is not free and if the full costs of the use—erosion, loss of biodiversity, or release of carbon dioxide into the atmosphere—are not borne by the private or public user, they will be paid by society as a whole, or future generations.

The social, political and economic dynamics that cause the environmental costs of overuse, degradation or destruction to be overlooked by national planners are of course very complex. But this report describes a number of common interlinked actions (or results of inaction) that can be identified and addressed. For instance, when degradation or depletion is not reported in national income indicators, policymakers receive a badly skewed picture of income generation (chapter 2). And as noted earlier, the institutional and policy structures of many countries muddle the environmental management picture even further and create conflicts in objectives (as when programs for intensifying agriculture production encourage the clearing of forests) or unwanted incentives (usually through subsidies) to overuse natural resources (chapters 3 and 4).

Recognizing that many of the immediate pressures on Asian forests were caused by the needs of growing populations and economies, in 1991 the World Bank commissioned a series of studies funded by a grant from the Government of Norway to incorporate environmental considerations into economic analyses of forestry operations. The Environment Division of the Asia Technical Department (ASTEN) coordinated the process of preparation and review, and the World Bank Country Departments for Asia were invited to identify the specific issues of concern to operations. A steering committee selected proposals for funding, and after the research topics were refined through discussions within the departments, the papers were submitted to rigorous peer review and revision. Several seminars were held to allow further discussion and to make tighter application to Bank experience.

Another part of the exercise funded by the Norwegian grant and participated in by Bank staff was a multilateral effort under the direction of the Food and Agriculture Organization of the United Nations. Two publications have already been published from that effort, *Economic Assessment of Forestry Project Impacts* and *Assessing Forestry Project Impacts: Issues and Strategies.*

In the Foreword to *Strategy for Forest Sector Development in Asia*, published by the World Bank in 1992, Daniel Ritchie wrote, "More than perhaps any other sector, forestry captures the interrelationships between economic growth, environmental preservation, and poverty alleviation." This volume that is based on research developed and carried out by World Bank staff and consultants—and representing the interests of Asia Country Departments—is presented here to provide an overview of the environmentally related priority issues in Asian forestry and contribute to the critical work of understanding their complex dynamics.

Tools, policies and institutions, and technologies

Chapter 1 addresses the economic issues in conserving biodiversity in West Kalimantan, the third largest Indonesian province, which is rapidly losing many of its highly diverse ecosystems—an estimated 50 percent of the original forest, for example—and the rich biodiversity they support. Conserving biodiversity in West Kalimantan, or anywhere else, is an economic proposition because alternative land uses are considered economically attractive. The authors, William B. Magrath, Charles M. Peters, Nalin Kishor, and Puneet Kishor, describe their preliminary work in organizing data on these costs in the form of a schedule of the marginal costs of habitat preservation, or a *biodiversity supply curve.* The supply curve is then used in a preliminary exploration of a number of policy issues such as biodiversity valuation and the justification for international compensation for biodiversity compensation. These experiments give rise to additional questions, which will be explored in future work.

In chapter 2, Claudia W. Sadoff addresses the issue of not reflecting the cost of environmental degradation or resource depletion in national income indicators. While recognizing that measurement of the interdependence of economics and ecosystems is complex, the author nevertheless considers the exercise critical to sound environmental management if, as the celebrated economist

J.R. Hicks suggested, income is a "guide for prudent conduct." The author applies two natural resource accounting methodologies, user cost and depreciation, to Thailand's forestry-related income between 1970 and 1990 to assess the effect of the country's logging ban on its forests. According to Sadoff's estimates of forest depletion-adjusted income, the average annual cost of deforestation in Thailand over the past two decades has been roughly 2 percent of the country's real gross domestic product (GDP). The annual losses of forest assets have been, on average, equivalent to more than 20 percent of the total manmade capital depreciation that is currently recorded in Thailand's national income accounts. None of these costs are reflected in the standard calculations of GDP. Clarifying what the variables mean to the computation, the author discusses the policy implications of these and other results of the application of the two natural resource accounting methodologies for Thailand and for environmental economics in general.

Government policy that has negative impacts on forests in India is the focus of chapter 3. The author, Arnoldo Contreras-Hermosilla, sets the discussion in a worldwide context, however, by describing the policies of other governments that have unintended negative impacts on forestry, such as the policies in Costa Rica on livestock and trade that have encouraged the conversion of forests. In India government policy has an especially powerful effect on forests, because they are mainly the property of the state. This and the following chapter on institutions together provide a clear analysis of how policies and the procedures of government agencies can inadvertently work at cross-purposes to the goal of sound management of India's forest resources.

In chapter 4 Augusta Molnar, Malcolm Jansen, and J. Gabriel Campbell analyze the current status of India's forests and wastelands (defined according to the National Wasteland Development Board as lands that are used far below their productive potential). The authors describe the potential for developing these resources and discuss the key environmental and economic issues underlying various alternatives. Institutional arrangements that show promise for the development of forests and wastelands by user groups are examined. And finally the authors outline a potential strategy for biodiversity conservation. The chapter was one of three background papers for India for the World Bank Forest Sector review (1991). There are overlaps among the three background papers, and the complementarity between this chapter and another of the papers, included here as chapter 5, is particularly strong.

Vast areas of forest land worldwide have been degraded and are unproductive, and many countries raise forest plantations on these sites. The Food and Agriculture Organization of the United Nations reports an increase in plantation forest in the tropics of 18 million–44 million hectares over the decade 1980–1990. Not all of these plantations, however, are as productive as they could be. G. Sam Foster, Norman Jones, and Erik D. Kjaer point out in chapter 5 that although people have reaped enormous benefits from domesticating annual plants such as wheat and rice and perennial plants like apples, mangoes, tea, and coffee, they have not made much headway with the process of domesticating tree species. The authors describe how domestication might be attempted through careful attention to germination and nursery practices and through genetic identification and manipulation, or tree "improvement." They outline the basic components of a tree improvement program, describe various common trade-offs necessary when these programs are established or redesigned, and examine the opportunity costs when stock quality is compromised in an attempt to economize on nursery or seed stock. This practical discussion is expanded further by an examination of how the appropriate intensity of a tree improvement program is decided by comparing the value of quick, medium results with the larger but delayed gains that can be achieved through a more intensive and systematic program. Fortunately, as the authors point out, this is not necessarily an either/or decision as there are some simple steps that can be taken to generate gains quickly and these can be followed by a more-sophisticated, yet economically viable, improvement program.

Structure of publication

To prepare the papers for this combined volume several adjustments were required. Where an appendix was attached to the papers, it has been included as the last section to the chapter, followed by the endnotes. The authors had different methods of citing literature and these are reflected as either references or a bibliography at the end of each chapter. Otherwise, except for chapters 2 and 5, the chapters are as they appeared as papers. Chapter 2 was originally two papers that were rewritten into one draft by the editor and substantially updated by the author. Chapter 5 was revised significantly by the authors to reflect advancements in technology.

Acknowledgments

Many World Bank staff were instrumental in bringing this volume to publication. As Division Chiefs of the Environmental Division of the Asia Technical Department, both Gloria Davis, who spearheaded the initial project, and Maritta Koch-Weser, who supported the publication of the findings in this volume, recognized the significance of the close collaboration with the Country Departments this research represents. The contributions of the Country Departments in identifying issues and sharpening the focus is greatly appreciated for helping to make the research and this publication more practical and useful.

The authors of the chapters also wish to acknowledge special contributions to their work: Andrew Parker, Wayne Luscombe, Pietr Nyborg, John Dixon, Kenneth Chomitz, and Susan Shen of the World Bank (chapter 1); Michael Ward and Arnoldo Contreras-Hermosilla of the World Bank and Albert Fishlow and Jeff Romm of the University of California, Berkeley (chapter 2); N.C. Saxena of the Oxford Forestry Institute and Hans Gregersen of the University of Minnesota (chapter 3); Ben Van De Poll and Ann Clark of the World Bank (chapter 4); and J. Williams, a private consultant, and Arnoldo Contreras-Hermosilla of the World Bank (chapter 5).

Finally, a number of people have helped prepare the papers for this publication. Charlotte Maxey edited the volume and coordinated its production. George Parakammanil designed the cover, and Cynthia Stock produced the desktopped version.

Contributors

J. Gabriel Campbell is an anthropologist and Director of Asian Environmental Programs for Woodlands Mountain Institute, a nongovernmental organization.

Arnoldo Contreras-Hermosilla is Senior Natural Resources Economist in the Latin America and Caribbean Country Department II of the World Bank.

G. Sam Foster is Director of the Southern Research Station of the United States Department of Agriculture Forest Service.

Malcolm Jansen is Environmental Specialist in the Asia Environment and Natural Resources Division of the World Bank.

Norman Jones is Senior Forestry Specialist in the Agriculture and Natural Resources Department of the World Bank.

Nalin Kishor is Economist in the Environmental and Natural Resources Division of the Asia Technical Department of the World Bank.

Puneet Kishor is GIS Specialist in the Public/Private Sector and Technology Development Division of the Asia Technical Department of the World Bank.

Erik D. Kjaer is Research Assistant with the Danish International Development Agency.

William B. Magrath is Senior Economist in the Agricultural Policies Division of the Agriculture and Natural Resources Department of the World Bank.

Augusta Molnar is Natural Resources Management Specialist in the Natural Resources Management and Rural Poverty Division of the Latin America and Caribbean Country Department II of the World Bank.

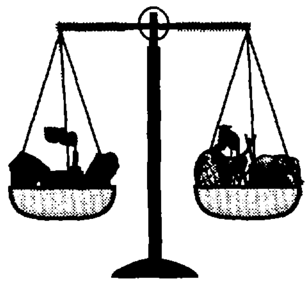
Charles M. Peters is the Kate E. Tode Curator of Botany at the Institute of Economic Botany of the New York Botanical Garden and currently lives in West Kalimantan, Indonesia.

Claudia W. Sadoff is a Young Professional with the Infrastructure Operations Division in the Middle East and North Africa Region of the World Bank.

Abbreviations and Data Note

AC1	LANDSAT satellite
BI	Biodiversity Index
CPI	Conservation Priority Index
CPR	Common property resources
ENDAF	Endemism Adjustment Factor
ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
f.o.b.	Free on board
FAO	Food and Agriculture Organization of the United Nations
FIO	Forest Industries Organization (Thailand)
FPC	Forest Protection Committee (India)
G&E	Genotype x environment (interaction)
GDP	Gross domestic product
GIS	Global Information Systems
GNP	Gross national product
IPAS	Integrated protected areas system
IRR	Internal rate of return
LANDSAT	Type of U.S. satellite
NDP	Net domestic product
NGO	Nongovernmental organization
NNP	Net national product
NTFP	Non-timber forest products
NWDB	National Wasteland Development Board (India)
ODA	Overseas Development Administration (United Kingdom)
PA	Protected area
PNW	Present net worth
RFD	Royal Forest Department (Thailand)
ROI	Rate of return
SEEA	System of Economic and Environmental Accounts (United Nations)
SNA	System of National Accounts (United Nations)
SPRICH	Index species richness
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
WRI	World Resources Institute

Note: *Dollars* are U.S. dollars unless otherwise specified.



1

The Economic Supply of Biodiversity in West Kalimantan: Preliminary Results

William B. Magrath, Charles M. Peters, Nalin Kishor, and Puneet Kishor

West Kalimantan, the third largest Indonesian province on the island of Borneo (see inset map 1), with a total land area of almost 147,000 square kilometers, is facing the rapid disappearance of many of its highly diverse ecosystems and the biodiversity they support. Although reliable data on forest clearing are difficult to obtain, recent estimates suggest that almost 50 percent of the original forest has already been lost and the destruction of lowland dipterocarp forests and mangrove areas has been especially pronounced. Extensive logging, establishment of large-scale industrial crop plantations, and increasing agricultural demands of a growing rural population appear to be the major factors responsible for this alarming reduction in forest area. The environmental impacts of these developments will come under increasing scrutiny in the future.

Conserving biodiversity is an economic proposition. Alternative land uses are being pursued aggressively in West Kalimantan because of their financially attractive returns. Efforts to introduce land use policies aimed at biodiversity conservation would benefit from explicit information on the size of these rents. This chapter describes preliminary work in organizing data on these costs in the form of a schedule of the marginal costs of habitat preservation, or a *biodiversity supply curve.*

The protection of natural areas implies foregoing other socially valued land uses and may require additional resources to ensure that protected areas are actually protected. Exploration of these opportunity costs can provide crucial data to policymakers and others interested in biodiversity loss or degradation. Building on the opportunity cost concept, this chapter uses Geographic Information Systems (GIS) technology to illustrate estimation of the economic supply of biodiversity in West Kalimantan.

West Kalimantan presents an interesting and important opportunity to study the costs of conserving biodiversity. It offers both the availability of fairly detailed information on the economics of various land uses and reasonably well-documented biological resources. The natural vegetation of the region is characterized by a variety of forest types including mangroves, peat forest, freshwater swamp forest, heath forest, and lowland or hill mixed dipterocarp forest. Some of these forests are reputed to be the oldest and most species-rich in all of Southeast Asia (FAO 1981). Floristic studies of the province suggest that the forests of this region are exceptionally rich in edible fruits, rattan, oil seeds, medicinal plants, resins, and other useful plant products (Padoch and Peters 1993). Leighton (1990), for example, reports that the forests at Gunung Palung in the Ketapang district contain 21 species of wild mangosteen (*Garcinia* spp.), 8 species of rambutan (*Nephelium* spp.), 7 species of durian (*Durio* spp.), 4 species of mango (*Mangifera* spp.), and a host of lesser known fruits such as rambai (*Baccaurea*, 23 species) and cempedak (*Artocarpus*, 13 species). Small tracts of forest may also exhibit a high abundance of useful plants. A 1.0 hectare plot of hill dipterocarp forest inventoried in the Sambas district was found to contain 3 species of illipe nut (*Shorea* spp.), 25 species of edible fruits and nuts, 35 timber species, 5 species producing damar (oleo-resin) or other useful exudates, 2 species of rattan, 3 species whose leaves or bark are used medicinally, and 1 species used locally as a fish poison (Peters 1991).

The chapter begins with a brief and selective review of literature on biodiversity, calling attention primarily to the relative neglect, despite its conceptual and methodological appeal, of an opportunity cost approach and to some specific problems of definition that hamper its use. Several pioneering studies of conservation that do apply an opportunity cost approach are reviewed providing a basis for their extension in later sections.The paper then turns to a detailed discussion of the estimation of the economic supply of biodiversity in West Kalimantan.

An index of biodiversity quantity is proposed to link data on ecosystems with data on alternative land uses. Because some of these data are spatially related, the use of GIS techniques to generate the supply curve is then described. Finally, the estimated supply curve is used to explore a number of policy issues including biodiversity valuation, the justification for international compensation for biodiversity conservation, and an assessment of the impact of various economywide variables such as interest rates and foreign exchange rates on biodiversity. These experiments give rise to additional questions, and possible directions for further work are explored.

Economic perspectives on biodiversity

Biodiversity refers to the totality of biological life. The term includes plants, animals and microorganisms together with the ecosystems and ecological processes to which they belong (see, for example, Ehrlich and Wilson 1991; Wilson 1988; McNeely and others 1990) and even extends to the genetic information from which this diversity results. From a conceptual standpoint, the term is an eloquent expression for highlighting the rapid and irreversible species loss now occurring throughout the world, and it provides a useful framework for orienting and promoting conservation activities. From a practical perspective, however, the term remains essentially undefined, and there is probably no spot on earth—certainly no spot lying between the Tropics of Cancer and Capricorn—for which all the constituent biodiversity has been quantified. So poor is knowledge of the biome that current estimates of the number of species on the planet can only be narrowed to a range of 2–100 million (Reid 1992). Fewer than 1.5 million of these species have been named, much less studied, counted or described in terms of their ecology or ecosystems requirements (see table 1.1).

While in principle species can be counted, it is not clear that species number is an appropriate measure of biodiversity. Other quantification schemes have been attempted varying from simple subjective description to complex multivariate assessment. The desired result is usually a single value that can be used to rank different habitats in terms of their potential, predicted or relative biological diversity. Essentially all available measures are imperfect as they may reflect only a small de-

Table 1.1 Estimates of species number by taxa

Group	Number of described species
Bacteria and blue-green algae	4,760
Fungi	46,983
Algae	26,900
Bryophytes (moses and liverworts)	17,000
Gymnosperms (conifers)	750
Angiosperms (flowering plants)	250,000
Protozoans	30,800
Sponges	5,000
Corals and jellyfish	9,000
Roundworks and earthworks	24,000
Crustaceans	38,000
Insects	751,000
Other arthropods and minor invertebrates	132,461
Mollusks	50,000
Starfish	6,100
Fish (Teleosts)	19,056
Amphibians	4,184
Reptiles	6,300
Birds	9,198
Mammals	4,170
Total	1,435,662

Source: McNeely and others 1990.

Table 1.2 Estimates of species extinction

Estimate of species loss	Percentage of global loss per decade	Method of estimation
1 million species 1975–2000	4	Extrapolation of past exponentially increasing trend
15–20 percent of species 1980–2000	8–11	Species area curves
25 percent of species 1985–2015	9	Loss of half of species in area likely to be deforested by 2015
2–13 percent of species 1990–2015	1–5	Species area curves

Source: Reid 1992.

gree of biological reality, may be based on weak assumptions, or may give undue weight to certain habitats or species while ignoring others.[1] Were it not for the conflicts that arise over the measures taken to preserve biodiversity, the difficulties in expressing quantitative dimensions would mainly be of academic interest. However, assessment schemes are needed to provide a means of identifying areas of particular conservation importance, and some have been used effectively in planning and establishing protected areas in many tropical regions.

The need for protected areas derives from the pressures being placed on natural habitats by population growth, open access to land resources, development demands from other sectors and other sources.[2] Estimates of the resulting species extinction vary widely (see table 1.2), but it is generally agreed that the rate of loss is high and is primarily due to destruction of habitat. Only to a very limited extent—for example, as required by legislation on endangered species protection—are biodiversity concerns explicitly considered by policymakers. The world's current stock of biodiversity is thus not the result of carefully weighed valuation of the consequences of alternative land uses. It is rather the result of myriad market-based and other demands for land that aggregate to the observed rates of extinction.

While numerous attempts have been made to estimate the local and global values of biodiversity (see the appendix table),[3] only a relatively few studies have explicitly and systematically addressed the values of alternative land uses. This is somewhat surprising in view of the relatively greater tractability of costs compared with benefits, as well as the conceptual appeal of a cost-based approach.[4] These advantages are well demonstrated by studies conducted by Hyde (1989) on the redcockaded woodpecker, by Montgomery, Brown and Adams (1994) on the northern spotted owl, and by Ruitenbeek (1992) on the Korup National Park in Cameroon.

In his study of mechanisms for promoting rainforest conservation, Ruitenbeek (1992) developed the notion of rainforest supply price (RSP) and applied it to estimate the requirements for international transfers to protect the Korup National Park. Conceptually, RSP is essentially the annual rental value of 1 hectare of rainforest. Ruitenbeek treated the entire park as a project, calculated the present value of the project, and estimated the compensation needed to offset the present value of net losses associated with conservation. He developed scenarios for conversion of park land to secondary forest through agriculture and for timber harvests in the absence of park development and considered the possible benefits from park development, including tourism, fisheries protection, flood control, and soil fertility maintenance. His model estimated that park development would cost CFAF 5,051 million (communauté financière Africaine franc, approximately US$1=524 CFAF), return direct benefits of CFAF 3,199 million, and provide protection, in present value terms, to 513,800 hectares. This generated an estimated RSP of CFAF 3,605 per hectare per year, which compared favorably with values implied by actual debt for nature swaps and other international transactions for compensating for natural area protection.

Ruitenbeek's work treated the existing park and its surrounding areas as an indivisible unit. Hyde (1989), in his consideration of the marginal costs of managing the red-cockaded woodpecker in forests in the southern United States treated habitat area as a choice variable and examined the opportunity costs of different levels of protection. The woodpeckers nest in cavities they build in live pine trees, and their protection requires maintenance of adequate old growth trees. Biologists recommend average age stands of 75–90 years for woodpecker habitat, as opposed to standard multiple use criteria that specifies rotations of 70 years.[5] Each colony of birds requires approximately 4.8 hectares (12 acres) of territory. Therefore, Hyde considered two management alternatives: (a) permanent cessation of harvesting on currently occupied sites and (b) extended rotations and harvests on a sequence of timber stands recruited as colony sites.

By assembling data on land quality (site index), growth rates, costs of operations and timber prices, Hyde was able to determine that the costs, in terms of annual rents, of preserving existing nesting sites varied from $10 to $2,261 per site and that expansion of habitat would result in costs of $473–$4,734 per site. However, when the costs of access (road construction) were taken into account, because the existing nesting sites were generally undeveloped for logging, for much of the area under consideration there was essentially no conflict between logging and woodpecker habitat.

Montgomery, Brown and Adams (1994) extended the use of opportunity cost concepts to analyze species preservation by relating area protected to the probability of species survival. Focusing on a single species, the northern spotted owl (*Strix occidentalis caurina*), they characterized forest tracts in the United States Pacific Northwest by their potential contribution to owl habitat capacity, which they denote c_i, and by their potential contribution to annual public stumpage supply, q_i. The ratio, c_i/q_i, provided an estimate of the physical (wood volume) "price" per owl nesting pair for each tract. Ranking the tracts by physical price and summing give them habitat capacity as a function of the area allocated to protection and the reduction in annual stumpage supply associated with a particular level of protection.

This approach was used to estimate the marginal costs of protecting the northern spotted owl and to evaluate protection proposals. In addition to showing that serious proposals varied in their marginal costs of protection from $0.6 billion to $3.8 billion per percentage point increase in survival probability, Montgomery, Brown and Adams were also able to analyze the distributive impact of owl protection on local communities and producers.

West Kalimantan case study

Extending the opportunity cost approach to West Kalimantan required five basic steps: (a) modelling biodiversity quantity; (b) modelling opportunity costs; (c) spatially associating the distribution of biodiversity with that of alternative opportunities to rank specific areas by both parameters; (d) arraying the results in the form of a supply curve; and (e) utilizing the formulation to evaluate selected policy problems. The essential techniques underlying the methodology used in this study is well established in applied economics. First developed in classic studies in economic theory by Marshall (1947) and Viner (1932), they have been used in forestry by Hyde (1980), in studies of air pollution in Mexico City by Eskeland (1994), and in numerous other applications. In all these studies, average costs and outputs for discrete production units are observed and supply is modelled as an increasing function of average cost.[6]

Modelling biodiversity quantity

The conservation problem faced in West Kalimantan differs significantly from the work described above. Unlike Hyde (1989) and Montgomery, Brown and Adams (1994), who were concerned with the protection of a single species, or Ruitenbeek (1992), who was concerned with a discrete land unit, anyone concerned with biodiversity protection in West Kalimantan must choose both how much land area should be preserved and what kind of land. This problem of which ecosystems and which diversity may actually be the most common form of biodiversity conservation problem, but it has largely been ignored. Consequently, it is necessary to develop a quantitative measure of biodiversity that can be used to rank and compare different units of land. Although there is no entirely satisfactory method for this kind of modelling, there is broad scientific agreement on the essential parameters for developing biodiversity priorities.[7]

A procedure was developed to use insights from the field of island biogeography,[8] and data from the Regional Physical Planning Project for Transmigration (RePPProT) (1987) Land Use map series (scale 1:250,000) for West Kalimantan to calculate a Biodiversity Index (BI) value for specific land units covering the entire province. This series of eighteen maps, which was prepared to assist the Indonesian Ministry of Transmigration in land development site selection, provides the most comprehensive representation of the distribution and extent of land use, land capability, habitat and other features. The vegetation and land use determinations are based largely on interpretation of satellite imagery (LANDSAT-MSS) and aerial photography with limited ground truthing and are therefore subject to considerable margins of error. The eighteen map sheets describe 2,610 geographic units (polygons in GIS parlance) pertaining to forty-five different habitats or land use types. These types conform to the classification scheme proposed for Indonesia by Malingreau and Christiani (1981) and are summarized in table 1.3.[9] A simplified version of the RePPProT data is shown in map 1 in which land use categories have been aggregated for clarity of illustration.

The Biovalue Index used in this work incorporates data from the RePPProT series on (a) the area of each of the 2,610 land use

Table 1.3 Biogeographic description of Indonesia by habitat or land use type

Habitat or land use	*Code*[a]	*Area (ha)*	*SPRICH*	*ENDAF*	*Notes*
Lowland forest	Hh	5,091,950	16	1	Mixed dipterocarp forest 100 meters above sea level (masl)
Swamp forest	Hr	269,080	12	1	Variable flooding by freshwater, *rawa*
Riparian forest	Hs	6,671	11	1	Gallery forest along river meander
Heath forest	Hk	462,645	10	1.02	Forest on white sand; *kerangas*
Peat forest	Hg	1,617,477	6	1	Forest on peat of variable depth; *gambut*
Tidal forest	Ht	208,641	5	1.02	Saltwater tolerant mangroves, palm species
Coastal forest	Hc	23,603	5	1	Beach and/or dune vegetation
Submontane forest	Hf	397,829	5	1.02	Mixed dipterocarp forest; 1,000–2,000 masl
Logged primary forest	Hx	445,998	4	0.9	Selective timber harvest of variable intensity
Lowland forest+Bush	HhB	88,566	3.5	0.8	Forest mixed with secondary vegetaion
Peat forest+Bush	HgB	47,001	3.5	0.8	Forest mixed with secondary vegetation
Lowland forest+Swidden	HhL	1,409	3.5	0.6	Forest mixed with shifting cultivation; *ladang*
Bush	B	875,138	3.5	0.7	Secondary vegetation of varying age
Swamp vegetation	Rr	66,606	3	1	Swamp grassland with sedge and *Pandanus*
Rubber+Lowland forest	PkHh	974	3	0.6	Rubbler plantation mixed with forest
Bush+Rubber	BPk	23,276	3	0.6	Secondary vegetaion mixed with rubber
Rubber+Bush	PkB	36,887	3	0.6	Rubber mixed with secondary vegetaion
Bush+Swidden	BL	1,403,252	2.5	0.6	Secondary vegetation and swidden plots
Bush+Wetland rice	BS	543	2.5	0.6	Secondary vegetation with rice; *sawah*
Tree Crops	P	118,644	2	0.5	Mixed tree crops
Plantation	PLNT	14,346	2	0.5	Unidentified estate crops
Coconut plantation	Pc	74,827	2	0.5	Mostly coconut monocultures
Rubber plantation	Pk	11,793	2	0.5	Mostly rubber monocultures

polygons, (b) habitat type of each polygon, (c) number and type of different habitats adjacent to each polygon, and (d) adjustment to account for rarity, exhaustion rate and protection status. The Biodiversity Index is a weighted measure that integrates information about the species richness, endemism (or number and kind of species that are unique to the region), and heterogeneity of the landscape surrounding a site. The Biodiversity Index provides a representation of the total variety of plants and ani-

Habitat or land use	*Code*[a]	*Area (ha)*	*SPRICH*	*ENDAF*	*Notes*
Oil palm plantation	Pp	11,032	2	0.5	Intensively managed monocultures
Grassland	R	134	2	0.5	Unidientified grassland
Alang-alang	Ra	343,620	2	0.5	Imperata grassland
Wetland rice	S	38,438	2	0.5	Permanent rice cultivation; sawah
Rainfed rice	Sr	139,200	2	0.5	Permanent rice cultivation; no irrigation
Swidden	L	839,929	2	0.5	Shifting cultivation; ladang
Tree crops+Settlements	PK	2,737	2	0.5	Agroforestry fields mixed with villages
Reforested areas	Fr	20,203	2	0.5	Replanted forestry concessions
Settlements+Swidden	KL	1,275	2	0.5	Villages mixed with swidden plots
Swidden+Bush	LB	1,355,453	2	0.5	Swidden plots and secondary vegetation
Swidden+Settlements	LK	1,064	2	0.5	Swidden plots mixed with villages
Swidden+Rubber	LPk	37,031	2	0.5	Swidden plots and rubber plantations
Coconut+Rubber	PcPk	4,918	2	0.5	Coconut and rubber plantation
Coconut+Rainfed rice	PcSr	5,365	2	0.5	Coconut plantation mixed with rice planting
Coconut+Swidden	PcL	3,981	2	0.5	Coconut plantation and swidden plots
Alang-alang+bush	RaB	3,452	2	0.5	Imperata grassland and secondary vegetation
Alang-alang+Swidden	RaL	737	2	0.5	Imperata grassland mixed with swidden plots
Wetland rie+Swidden	SL	48,717	2	0.5	Sawah and swidden plots
Rainfed rice+Coconut	SrPc	279,676	2	0.5	Rice plantings and coconut plantations
Unvegetated	T	427	1	0.5	River bed, rock outcrops, etc.
Settlements	K	18,989	1	0.5	Cities, towns, villages, etc.
Transmigration Area	TRMI	180,947	1	0.5	Existing or planned transmigration site

a. RePPProT map code.
Source: Adapted from Malingreau and Christiani 1981.

mals in a given habitat and is only part of what should be considered in selecting areas for conservation. Since the overall goal of biodiversity conservation is protection of a representative sample of the indigenous flora and fauna of an area (Soulé 1991), a Conservation Priority Index was therefore calculated to avoid a bias toward large species-rich tracts at the expense of smaller but rarer areas.

Arithmetically, the Biodiversity Index (BI) value of polygon i is expressed by equation 1:

$$BI_i = (HD_i + ND_i) \times ENDAF_i \quad (1)$$

where,
HD_i = Habitat Diversity of polygon i
ND_i = Neighborhood Diversity, around polygon i, and
$ENDAF_i$ = Endemism Adjustment Factor of the habitat of polygon i.

The Habitat Diversity (HD_i) value is calculated as:

$$HD_i = \log_{10} (SPRICH_i, A_i) \qquad (2)$$

where,
$SPRICH_i$ = Species Richness of Habitat i, and
A_i = Area of Polygon i in hectares.

Data on the distribution and abundance of tree species in different forest habitats were used as the basis for estimating SPRICH (the values are summarized in table 1.3). While data on which to estimate SPRICH are limited, important sources of general information include Ashton (1964) and Whitmore (1984). A basic assumption, which has a strong empirical basis, is that tree species richness is a reliable surrogate for the total biological diversity of a given site. Cranbrook (1982), for example, reports that the richest assemblage of birds (171 species) at Gunung Mulu in Sarawak occurs in lowland dipterocarp forest. Only about half this number were found in the less peat forests. Whitmore's data (1984) suggests that the relatively diverse lowland dipterocarp forest contains about twice the amphibian species found in heath forest. Similarly suggestive data on mammalian diversity can be found in Payne and others (1985) and Marsh and Wilson (1981). These, and many other reports, suggest that habitat type is a useful and easily defined surrogate for the indirect assessment of total biological diversity.[10] Table 1.4 summarizes the diversity of tree species found in different forest types on the island of Borneo.

Because area is perhaps the single most important consideration in ranking sites for biodiversity preservation, equation 2 also factors polygon size into the calculation. As

Table 1.4 Summary of diversity of tree species found on Borneo

Site	*Sample area (hectares)*	*Number of tree species*	*Source*
Lowland dipterocarp forest			
Lempake East Kalimantan	1.6	209	Riswan (1987a)
Wanariset, East Kalimantan	1.6	239	Kartawinata and others (1981)
Lambir, Sarawak	1.0	283	Ashton (1984)
Andulau Resesrve, Brunei	2.0	222	Ashton (1964)
Sandakan, Sabah	2.0	198	Nicholson (1965)
Gunung Mulu, Sarawak	1.0	225	Proctor and others (1983)
Hill dipterocarp forest			
Raya-Pasi, West Kalimantan	1.0	148	Peters (1991)
Kuala Belalong, Brunei	2.0	125	Ashton (1984)
Andulau Reserve, Brunei	2.0	144	Ashton (1964)
Heath forest			
Gunung Mulu, Sarawak	1.0	125	Proctor and others (1983)
Badas, Brueni	1.0	72	Ashton (1984)
Samboja, East Kalimantan	0.5	24	Riswan (1987b)
Peat forest			
S. Durian, West Kalimantan	0.2	26	Anderson (1976)
S. Durian, West Kalimantan	0.2	37	Anderson (1976)
S. Durian, West Kalimantan	0.2	55	Anderson (1976)

was first observed by Arrhenius (1921) and Gleason (1922) large areas have more species than smaller ones. This pattern has been found to hold at almost every scale, whether comparing arthropods in caves (Culver, Holsinger, and Baroody 1973), small tracts of tropical forest (Gentry 1988), or islands of increasing size (Diamond and Mayr 1976). Although the slope and intercept of the species-area curve can vary with habitat, the relationship between these two parameters usually takes a logarithmic form (McGuinness 1984).

Numerous hypotheses have been advanced to explain the species-area effect. Williams (1943) suggested that species numbers increase with area because larger areas usually contain more habitats or available niches. MacArthur and Wilson (1967) theorize that larger areas have more species because populations increase and species interactions decrease with increasing area.

In addition to size and habitat type, the heterogeneity of different habitats (edges or ecotones) surrounding a site has also been shown to have a notable influence on diversity (see, for example, Noss 1983; Harris 1988; Yahner 1988). This effect apparently is because sites contain species from all the adjacent habitats, as well as those species specifically adapted for growth and survival at the edge itself. In addition, the constituent species diversity of the adjacent habitats plays a role as well. A site adjacent to highly diverse communities will usually be subjected to a larger degree of species immigration and colonization than one surrounded by species-poor habitats (MacArthur and Wilson 1967, Stamps and others 1987, Shafer 1990). To account for all of this, a second parameter, Neighborhood Diversity (ND_i) attempts to account for landscape heterogeneity and edge effect by summarizing the variety and biological richness of the different habitats adjacent to each polygon. The parameter is derived by:

$$ND_i = \log (\sum SPRICH_j) \qquad (3)$$

The last parameter included in the Biodiversity Index is the Endemism Adjustment Factor (ENDAF). This value serves a dual purpose: (a) it provides a rough estimate of the level of endemism characteristic of each habitat, and (b) it serves to adjust or "fine tune" the habitat and neighborhood diversity parameters by accounting for the degree to which the original vegetation in each habitat has been disturbed. This adjustment is needed because of the strong influence that forest type and land use appear to exert on the specificity or endemism of local species. Although the entire island of Borneo is thought to contain a large percentage of endemic species,[11] heath forests, tidal or mangrove forests and submontane forests have been found to be especially rich in endemism (Brunig 1974; Kartawinata 1980; Anderson and Chai 1982; Whitmore 1984). Intensively used, highly disturbed, or artificially revegetated habitats may exhibit a very low level of endemism. Forest habitats with high levels of endemism, such as heath forest (Hk) and mangrove swamp (Ht) were assigned a value of 1.02. Undisturbed forest habitats were given a score of unity, mixtures of secondary vegatation received scores of 0.9 or 0.8, and intensively managed habitats from which natural vegatation has been completely removed were assigned an adjustment factor of 0.5. ENDAF values are shown in table 1.3.

The Conservation Priority Index (CPI) is intended to add consideration of the relative abundance of a particular habitat, rate at which habitat is being destroyed or transformed, and extent to which similar representatives of similar habitat have already been selected for protection (PROTAREA). The derivation of this index requires information about the original area (ORIGAREA), the remaining area (REMAREA), and the area currently protected in reserves of different forest habitats. ORIGAREA data were taken from MacKinnon and Artha (1982) or estimated based on average rates of deforestation in West Kalimantan (FAO 1989). REMAREA and PROTAREA were obtained directly from RePPProT. Based on these data,

Table 1.5 Derivation of Conservation Priority Index for selected forest types

Habitat	*Code*	*Original area (hectares)*	*Remaining area (hectares)*	*Protected area (hectares)*	*Rarity*	*Exhaustion rate*	*Protection status*	*CPI*
Lowland forest	Hh	7,020,000	5,091,950	901,200	0.146	1.139	0.892	0.148
Swamp forest	Hr	1,305,000	269,080	110,800	0.164	1.686	0.385	0.106
Riparian forest	Hs	12,060	6,671	1	0.245	1.257	3.824	1.178
Heath forest	Hk	1,845,000	462,645	13,600	0.160	1.601	1.532	0.391
Peat forest	Hg	2,201,000	1,617,477	58,500	0.158	1.134	1.442	0.258
Tidal forest	Ht	425,000	208,641	7,600	0.178	1.309	1.439	0.335
Coastal forest	Hc	42,697	23,603	3,100	0.216	1.257	0.882	0.239
Submontane forest	Hf	1,800,000	397,829	252,800	0.160	1.656	0.197	0.052

coefficients of rarity, exhaustion rate and protection status were calculated for each forest habitat according to the following:[12]

$$\text{Rarity} = 1 / \log(ORIGAREA) \qquad (4)$$

$$\text{Exhaustion Rate} = \log(10 \times ORIGAREA/REMAREA) \qquad (5)$$

$$\text{Protection Status} = \log(ORIGAREA/PROTAREA) \qquad (6)$$

The results of these calculations are summarized in table 1.5, which gives CPI as the product of equations 4–6. CPI is then added to the Biodiversity Index to calculate the final Biovalue for each polygon. CPI is set at zero for deforested or otherwise altered polygons and can thus be interpreted as a premium given to rare, threatened or unprotected habitats.

$$\text{Biovalue}_i = BI_i + CPI_i \qquad (7)$$

The resulting Biovalue Index produces a score for each polygon ranging from 10.4 for a large tract of lowland forest to 0.84 for a small swidden plot among human settlements. While it is difficult to quantitatively test the validity of this modeling procedure, the results and other considerations of the relative scores of specific polygons yield a surprisingly accurate reflection of biological realism. In the absence of quantitative forest inventories and detailed species counts, the index seems to provide an acceptable interim criteria for ranking different habitats and types of land use in terms of their potential biological richness.

Table 1.6 Input and output prices and economy-wide variables

	Unit	*Rp*
Interest Rate	%	0.1
Exchange Rate	Rp/US$	2,000
Wage Rate	day	2,000
Rice	kilogram	200
Coconut	kilogram	250
Oil Palm	kilogram	60
Rubber	kilogram	1,350
Chemicals	unit	1
Rice Seed	kilogram	384
Rubber Stock	unit	296,000
Rubber Tax	per hectare	20,000
Oil Palm Stock	per hectare	184,000
Oil Palm Tax	per hectare	20,000
Coconut Stock	per hectare	531,000
Coconut Tax	per hectare	20,000

Note and source: Basic information used in preparing the rice budget came from the most recently available edition of the annual provincial statistics (BPS 1990: 1589). Modification of these data was needed to properly account for family labor, which is a major source of labor but which is generally excluded from Indonesian official statistics. Information for the three tree crops (coconut, palm, and rubber) was derived from World Bank project and sector work, revised according to information from the provincial office of the Directorate-General of Estate Crops.

Table 1.7 Net revenue from selected alternative products

Inputs	*Upland rice*	*Lowland rice*	*Rubber*	*Oil palm*	*Coconut*
Labor	258,000	278,000	90,266	64,474	39,239
Chemicals	—	11,450	43,393	73,364	40,024
Seeds/planting material	13,056	13,056	8,970	5,576	17,066
Machinery rental	—	—	3,931	5,536	5,647
Other	21,000	17,000	1,811	0	0
Taxes	—	—	6,051	6,158	6,107
Cost of production	292,056	319,506	151,786	155,156	105,768
Value of output	320,000	513,600	278,522	166,633	135,121
Net return per hectare	27,944	194,094	126,736	11,477	29,353

— Data not available.
Source: BPS 1990 and World Bank project and sector studies.

Modelling opportunity costs

Much of the area of West Kalimantan has the potential of supporting a variety of commercial uses. Modelling the opportunity costs of land involved the construction of a series of budgets for various land uses and spatially referencing this data with respect to the potential of sites for supporting alternative uses. This potential was assessed by RePPProT (1987) on the basis of technical criteria that considered the requirements of different crops, soil type and other site factors such as slope, rainfall and elevation. In all, the RePPProT system identified thirty-seven "Land Systems" on the basis of different combinations of limiting factors and matched these with the requirements of twenty-two industrial and estate crops.[13] The Land Systems version of the RePPProT data identifies 1,682 polygons each associated with a set of limitations and suitabilities. A simplified version of the Land Systems data is given in map 2 in which land uses have been aggregated for clarity.

Budgets for alternative land uses were compiled by reference to literature, project proposals and other sources. Based on a common set of input and output prices (see table 1.6) scaled to 1991 prices, input and output coefficients were reconciled to generate the budgets for dryland rice, wetland rice, oil palm, coconuts, and rubber. Although an exhaustive list of activities was not undertaken, the table does cover the most important crops in terms of areal extent and production.

While most smallholder cultivation of the oil palm, coconuts, and rubber has been carried out, to date, on a relatively informal basis in West Kalimantan, future expansion of production is likely to be more organized. Palm oil and rubber production is being developed increasingly along the nucleus estate and smallholder model, and hybrid coconuts are being encouraged for copra production. The budgets for the three crops summarize present valued (at 10 percent) annual cash flows for a 31-year period on a per hectare basis. Thus, they represent the annualized flows from the equivalent of one representative hectare in a fully established plantation.

Net revenues of Rp. 28,000 and Rp. 194,000 per hectare per year for dryland and wetland rice, respectively (see table 1.7), do not appear out of line with returns to rice in some of the less advantageous rice-growing regions in Indonesia reported in Pearson and others (1991). Similarly, estimated returns for rubber, oil palm and coconut, also appear reasonable. The range of crops and land uses is somewhat limited, and a priority for further development of the model is specification of additional alternatives and introduction of transport costs and forest management options (see below). Despite these weaknesses, these five crops do provide an economic option for a significant portion of the total area of the province and also correspond well to observed land uses.

Geographic analysis and supply curve construction

After the modelling of the magnitude and distribution of both biodiversity and land development opportunities in West Kalimantan, the next step in the analysis was to determine the spatial correspondence between the two. This was calculated by using a the Arc-Info GIS system (Environmental Systems Research Institute, Inc.). Digitized versions of the Land Systems and Forest/Land Use Map were superimposed on each other to generate a new map. This new map, generated by the 2,610 Forest/Land Use polygons and the 1,682 Land Systems polygons, consisted of 22,656 polygons representing 1,761 combinations.

Because the Biovalue Index was calculated from the physical parameters of the Forest/Land Use polygons, they were treated as indivisible "biodiversity production unit." Each Forest/Land-Use Polygon was then assessed on the basis of its Biovalue and the sum of the profits of the different land uses it was capable of supporting.[14] Because Biovalue is an index and therefore not an additive value, each polygon area was adjusted by a factor equal to its Biovalue divided by the area weighted average Biovalue for the entire 2,610 polygons. This yielded a Biodiversity Adjusted Area for each polygon and a total adjusted area equal to the real area of the province. The total opportunity cost for each polygon was then divided by its Biodiversity Adjusted Area to yield an average cost per biodiversity adjusted hectare. Average costs varied from zero for 555 polygons totaling about 500,000 hectares to a maximum of Rp. 12,000 per hectare per year. Arraying polygons from the lowest average cost to the highest and mapping out the running total generated a "particular expenses" approximation to a biodiversity supply curve (map 3). The supply curve maps out the areas that would be preserved as a function of the amount that would need to be paid as an annual rent, or price. The cartographic equivalent to figure 1.1 is presented in map 3, showing spatially conservation priorities as a function of price.

The supply curve suggests that for a considerable portion of the area of West Kalimantan there is little or no trade off between economic development of land and protection of biodiversity. Nearly 3.7 million hectares of land in the province could be set aside for biodiversity conservation purposes at a cost or price of less than Rp. 400 per hectare per year (approximately $0.20). This is quite consistent with the aggregate results of the planning process of the Indonesian Forest Land Use by Consensus, which allocated 3.71 million hectares to conservation and protection status. Since considerations other than biodiversity preservation figured into this allocation, it is suggestive of a relatively low valuation of biodiversity. The curve also suggests that if a market existed for the province's biodiversity, a relatively small increment in the current implicit willingness to pay for biodiversity could make competitive the allocation of a significant additional amount of land away from alternative uses. Examination of additional policy questions are taken up in greater detail in the next section.

Map 3 shows how the production schedule implied by the supply curve translates into priorities for land management. As discussed below, because this preliminary application has not considered transportation costs, forestry options, and other concerns, the geographic priorities shown in the map cannot be recommended for actual land use planning. They do serve to illustrate the economic dimensions of biodiversity policy. The white and pink areas indicate the areas where the opportunity costs of biodiversity conservation are lowest. These areas, largely in the northeast corner of the province, are predominantly forested areas with relatively high levels of biodiversity and limited capacity to support alternative land uses. Even if forestry alternatives were considered, as is planned for future investi-

Figure 1.1 Marginal costs of conservation

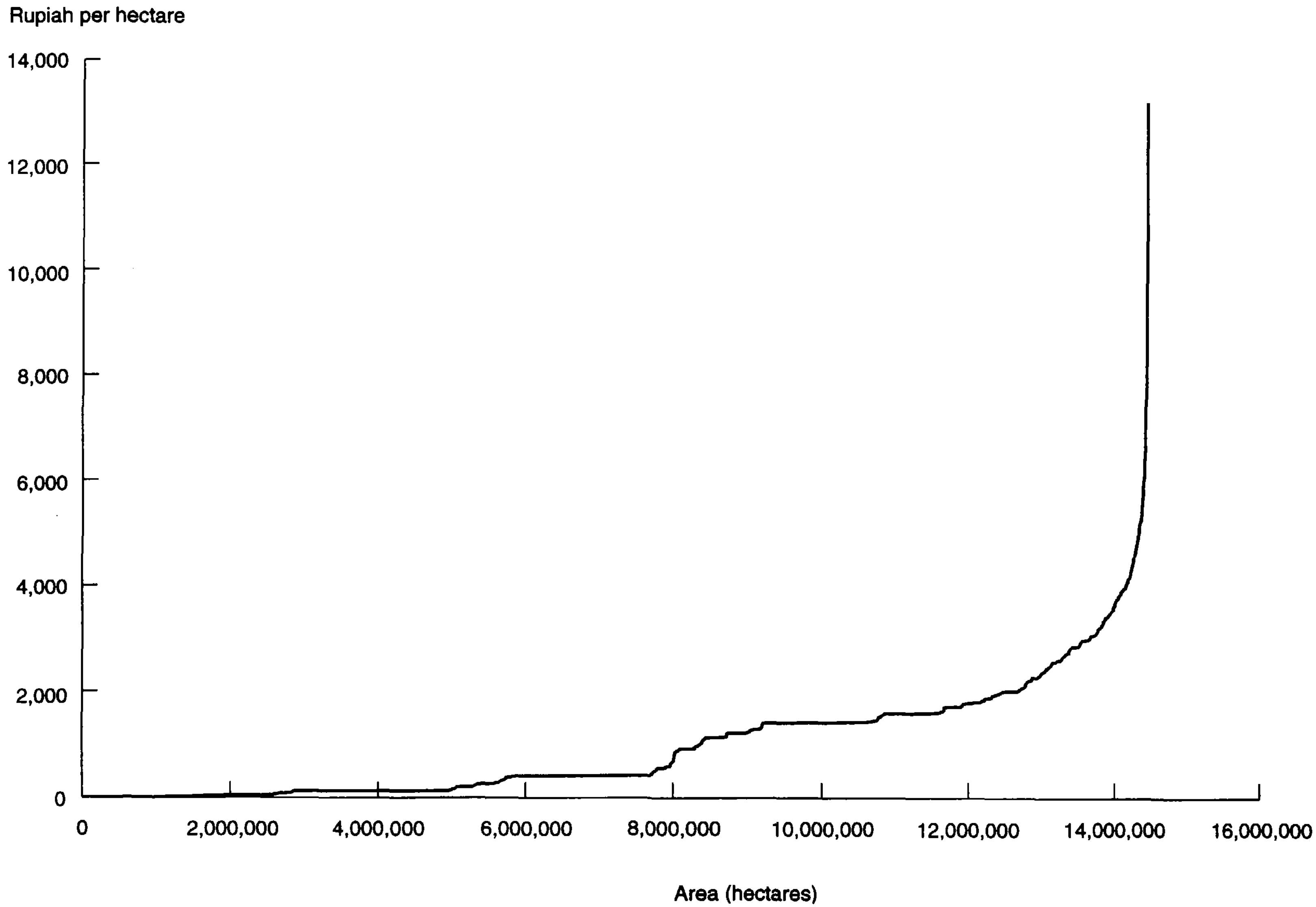


Table 1.8 Spearman's Rank Correlation Coefficient (alternative scenario against base case)

Scenario	*Base value*	*Alternative value*	*Correlation coefficient*
Devaluation	US$1 = Rp. 2,000	US$1 = Rp. 4,000	0.934167*
Low Wage	Wage = Rp. 2,000/day	Wage = Rp. 0/day	0.789914*
Increased Wage	Wage = Rp. 2,000/day	Wage = Rp. 4,000/day	0.909885*
Low Discount Rate	i = 0.10	i = 0.03	0.915311*
High Discount Rate	i = 0.10	i = 0.13	0.966867*

* Indicates significance at the p = 0.90 level.
Source:

gations, because these areas are remote from transportation infrastructure, it is likely that a similar result would be obtained.

On the other hand, the darker areas, along the west coast and in the southern corner of the province, indicate areas where biodiversity can only be preserved at relatively high cost. This includes areas already heavily alterred by human activity, such as developed agricultural lands and tree crop plantations, urban development around the capital of Pontianak, and human settlement along the major rivers.

Policy experiments

With an explicit estimate of biodiversity supply, it is possible to quantitatively explore a number of biodiversity policy issues. In view of the preliminary nature of this model and the need to extend and deepen the model in a number of directions, only two questions were explored, but these indicate the range of questions appropriate. First, because there is significant interest in the question of how relative prices and economywide policies can influence environmental concerns, a sensitivity analysis was conducted to illustrate the impacts of these variables. Among the key prices that seem to influence pressures on natural environments are interest rates, wages and foreign exchange rates. To examine the effects of changes in these variables, the model was recalculated with values given in table 1.8. The results of these trials are summarized in figure 1.2. Qualitatively, the results are highly intuitive. Changes in prices that make land development more profitable (decreases in wages) shift the supply curve up and to the left, while cost increases shift the curve down and to the right.

The movements shown in figure 1.2 could be the result of changes in relative prices with essentially the same land use priorities or the result of changes in the underlying conservation production schedule that result from a different constellation of prices. To explore this question, it is possible to employ Spearmans Rank Correlation Coefficient. In this test, the rank of each of the land use polygons in the base case is compared with its rank in an alternative scenario. If the order of the polygons is identical, the rank correlation coefficient between the two scenarios will be equal to 1, lower values indicate that the ordering of polygons is affected by the change in prices. As shown in table 1.8, there are significant differences between the orderings for all scenarios. This preliminary finding provides quantitative support for arguments that macroeconomic policy can have strong influence on incentives affecting biodiversity.

A second use of the model is for exploring possible compensation needs if, for example, international willingness to pay for biodiversity exceeds the implicit preferences of Indonesian policymakers. In the absence of an estimate of local and interna-

Figure 1.2 Impact on biodiversity supply of economy-wide variables

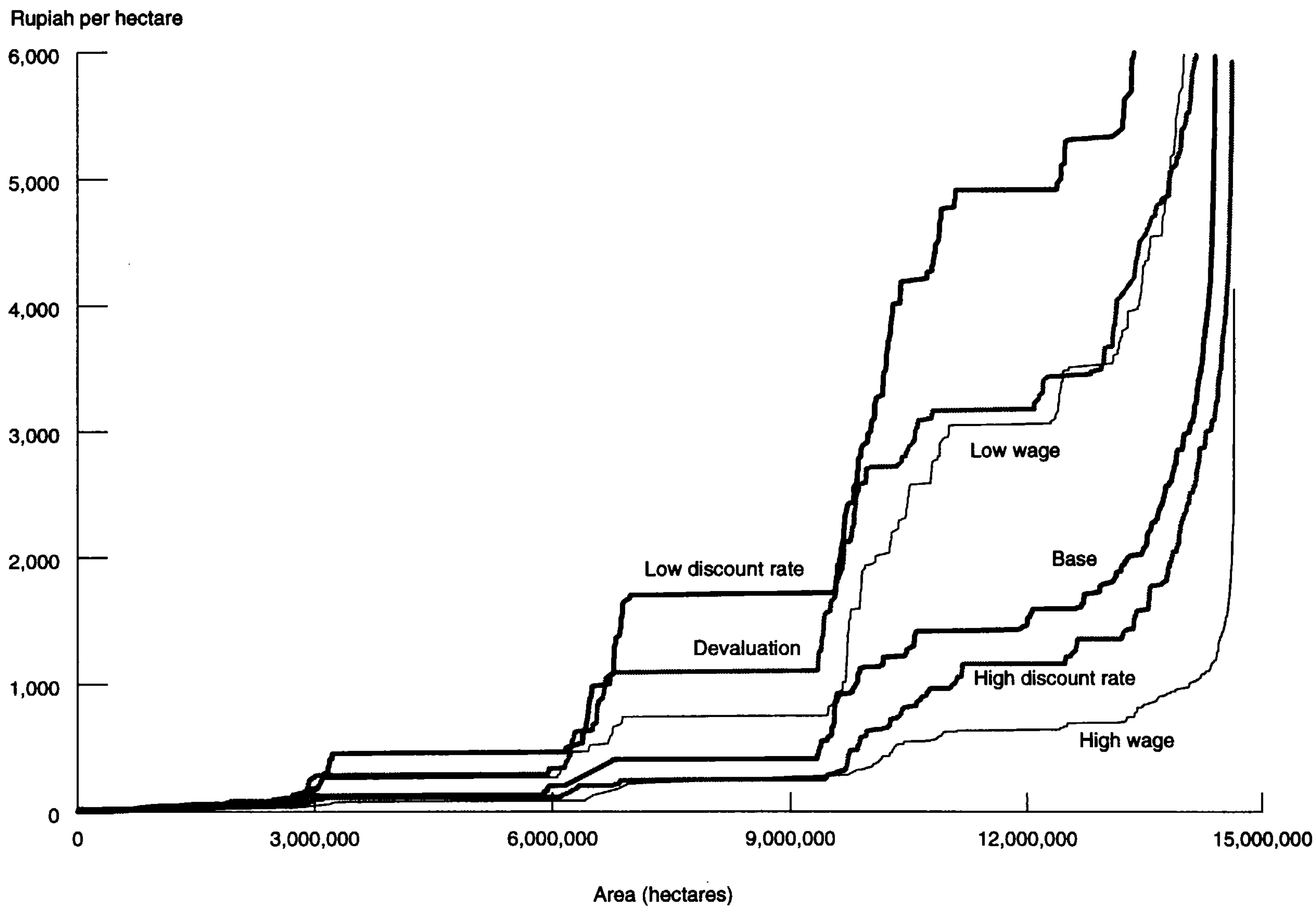


Table 1.9 Model calculation of total costs for conservation of biodiversity

Price	*Cummulative real area (hectares)*	*Cummulative biodiversity adjusted area (hectares)*	*Total cost (Rp/biodiversity adjusted hectares)*	*Producer surplus (Rp. millions)*	*Opportunity cost (Rp. millions)*	*Elasticity of supply (Rp. millions)*
0	296,305	184,105	0	0	0	
102	2,830,425	2,881,993	295	220	75	0.88
200	5,065,796	5,955,636	1,193	734	459	1.08
300	5,649,910	6,550,414	1,965	1,364	601	0.24
398	5,868,301	6,749,167	2,689	2,014	674	0.11
499	7,747,200	9,367,899	4,675	2,926	1,749	1.45
598	7,957,424	9,518,301	5,688	3,855	1,833	0.09
697	8,006,919	9,554,714	6,662	4,804	1,858	0.02
800	8,014,577	9,559,539	7,650	5,789	1,861	0.00
900	8,080,394	9,610,120	8,653	6,748	1,905	0.04
989	8,334,372	9,821,066	9,714	7,613	2,101	0.23
1,100	8,416,536	9,878,905	10,865	8,704	2,161	0.06
1,187	8,709,314	10,171,765	12,071	9,578	2,494	0.38
1,301	9,178,106	10,563,501	13,742	10,766	2,976	0.41
1,404	9,209,162	10,587,106	14,866	11,858	3,008	0.03
1,500	10,770,176	12,008,637	18,012	12,991	5,022	1.91
2,001	12,455,375	13,304,515	26,629	19,423	7,206	0.36
3,000	13,647,487	14,092,916	42,273	33,164	9,109	0.14
4,001	14,157,280	14,343,791	57,391	47,421	9,970	0.06
5,002	14,323,063	14,409,670	72,072	61,813	10,259	0.02

tional demand for biodiversity in West Kalimantan, the analysis presented here took a number of prices and to calculate costs, producer surplus and compensation requirements.

Total costs were calculated (table 1.9) as the product of the average cost or price and the corresponding biodiversity adjusted area (from figure 1.1). Producer surplus is the area above the supply curve and below the price, and opportunity cost is the area beneath the supply curve. A conservation compensation system could be structured in a variety of ways that can be linked to these values. Total cost, for example, corresponds to a conservation advocate setting a target for conservation and acting as a price taker. Under such a system, the rent, or producer surplus, accrues to the land owner. Alternatively, the conservation advocate could attempt to discriminate along the particular expenses curve, offering only the actual marginal cost to each land owner. In this system, surplus accrues to the conservation land owner, and a given conservation budget could yield a higher level of protection.

Conclusions

Because of benefits that may accrue to the global community, many tropical developing countries are being asked to undertake special efforts to conserve biodiversity. There are costs, however, to the land use restrictions that conservation implies, and a conceptually sound approach to the estimation of these costs is needed to aid in the design of land policy and in the negotiation of compensation and side payments. The methodology discussed in this chapter can contribute to better understanding of the economic consequences of biodiversity policy and provide specific and quantitative insights into land use policy.

More than the usual disclaimers and cautions are necessary with respect to interpretation of the results of this exercise. In addition to the preliminary nature of these results, the underlying data and assumptions described and used gloss over important gaps in understanding and representativeness. The land resource maps and derived biodiversity indices, for example, are subject to significant margins of error. Additional work is needed before this model can be used to develop implementable policy interventions. In particular, more effort is needed to explicitly incorporate transportation costs, forestry land use options, and multiple use alternatives into the model.

Despite its preliminary nature, this work does make several important contributions to discussions of biodiversity policy. Perhaps most important, it demonstrates the significance of, and scope for, clarity on the objectives of conservation policy. Biodiversity conservation does have costs, and priorities needs to be established on the basis of defined and measurable objectives. This chapter offers one characterization of biodiversity that is soundly based on ecological principles. While other ways of modelling biodiversity quantity can be proposed, and an important priority for further testing and development of this model is sensitivity analysis of the parameters used here, policy will inevitably reflect a set of weights that compare the importance of different elements of the ecosystem. An explicit formulation such as provided here allows for identification of areas of agreement and disagreement on priorities and determination of their policy significance. This work thus has significant scope for replication in other areas by interdisciplinary teams.

With respect to land use and conservation priorities in West Kalimantan, the analysis also makes clear that a significant share of the biodiversity in the province can be conserved at very low opportunity cost. This is an important finding and one that is consistent with the reality of natural areas preservation in many developed countries (see Krutilla and Fisher 1985). With modest levels of additional conservation compensation, the high elasticity of supply over a wide area revealed by this model can be taken by conservation advocates as encouraging evidence of good chances for introducing policies and practices to protect the resources of the province.

Appendix table. Summary of studies on the economic value of biodiversity

Value category:	Direct use	Indirect use	Non-use values *option, quasi-option,* bequest, existence	Total economic value	Benefit (sustainable use) /opportunity cost ratio
Ecosystem type: **Tropical forest** *Sources:* (1) Peters, Gentry and Mendlesohn (1989) (2) Gutierrez and Pearce (1992) (3) Ruitenbeek (1989a) (4) Mendelsohn and Tobias (1991) (5) Pearce (1991d) (6) Schneider et al. (1991) (7) Mendelsohn and Balick (1992) (8) Pearce (1990) (9) Watson (1988) (10) Kramer et al. (1992) (11) Guttierez and Pearce (1992) (12) Pinedo-Vasquez et al. (1992) (13) Solorzano and Guerrero (1988) (14) Schneider (1992)	(1) Sustainable harvesting in 1 hectare of Peruvian Amazon, (timber, fruit and latex 1987$). NPV hectare[1] $6,820 (local market values) relative to a net revenue $1,000 h[1] from clear-felling which risks uncertain regeneration, $3,184ha[1] plantations for timber and pulpwood or $2,960ha[1] from cattle ranching. (2) Estimated contribution of direct use to Brazilian GNP—$15b (3) Medicinal/genetic Net Present Value $7/ha over 126,000 ha (park area) or 426,000ha (with the additional buffer zone) This represents a minimum expected genetic value. Estimates depend on i) the probability of an area yielding a drug base ii) the method of valuation iii) an assumed extent of rent capture by local authority. Under certain assumptions the genetic/ medicinal NPV of tropical forest could be as high as $420 ha (See Appendix 1). (4) Travel cost valuation of tourist trips to Costa Rica's Monteverde Cloud forest. Average visitor valuation $35 (1988), producing a present value for trips assuming constant flows of $2.5m or extrapolating for foreign visitors, $12.5m. This gives a value per hectare in the reserve of $1,250 relative to the market price of local non-reserve land of $30–$100/ha. (7) Sustainable harvesting of medicinal plants in Belize *(local market values alone)* NPV $3,327per ha compared to $3,184 from plantation forestry with rotation felling. (9) Forest production (Malaysia) $2,455/ha compared with $217/ha from intensive agriculture. (3) Tourism value from the Korup $19/ha (10) Annual value of fuelwood to Malagasy households about $39 per annum	(3) Arising from sustained use of the Korup forest: Existence of Watershed functions affording protecton to Nigerian and Cameroonian fisheries: NPV (1989£) £3.8m (approx $6.8m) or $54ha, assuming that the benefit starts to accrue in 2010 and beyond (2010 represents the time horizon by which the continued use of the forest resources (in the absence of protection) would start to exhaust resources. The imputed benefit stream therefore represents the continued existence of resources. An imputed value of the expected loss from flooding resulting from alternative land use from 2010 onwards: NPV of expected value of loss by 2040 is £1.6m ($2.84m) or $23 ha Soil fertility maintenance. Benefit imputed based on crop productivity decline from soil loss which would take effect from 2010 onwards (the without project scenario) NPV £532,000 ($958,000) or $8ha. (5) (6) Valuing Carbon sequestration; crediting standing forest with damage avoided from adverse climate change: $1.2b–$3.9b/year, depending on assumptions of: i) Damage estimate per tonne carbon estimated range $5–13 tonne. ii) amount released, itself dependant on assumptions of per hectare sequestration and annual deforestation rates. (8)(14) Carbon storage $1,300–5,700/ha/year (11) Total carbon storage value Brazilian Amazon $46b (13) Rio Macho Preserve, Costa Rica. Evaluates the replacement cost in terms of water services and energy generation resulting from reserve conversion to agricultural use.	Lower bound option value may be inferred from the current market value or foreign exchange earning potential of plant based pharmaceuticals, (See Appendix 1) Attempts to gauge existence values in other contexts, rely on CVM to report WTP/willingness to accept compensation (WTA). To date only one study relating directly to tropical forests is available (10), although this does not report any foreign (explicitly non-use) WTP. However (2) set the existence value for the Brazilian Amazon at $30b, calculated using an arbitrary WTP figure (observed from various CVM studies), aggregated across the OECD adult population. Donations to charitable funds may be one possibility to place CV evaluations in context; however, adichotomy exists between the observed reason for giving and actual use of funds. Problem of identifying organizations involved uniquely in forest protection. (3) Value of debt-for-nature swaps may provide an estimation of a WTP, reflecting a non-use value. Varying implicit valuation of different sites is reflected in the price paid by conservation bodies involved. Some swap transactions have aimed to preserve tropical forest ecosystems,(see Appendix 3). (10) Foreign visitor's WTP for the creation of the Mantadia National Park (1991). Bids ranged $75–$118 p.a., with sums being *additional* to existing prices paid. Multiplying these sums by the number of annual foreign visitor s to a neighbouring park (3,900) resulted in an annual WTP of $292,500–460,000, a PV of $3.64m–$5.73m (at 5% and 20 years) or $364–573/ha (10,000ha). These sums might represent use values as tourists were actually in the area.	(2)Brazilian Amazon ($1991) Direct Use $15b Indirect $46b Existence $30b Total $91b/year NPV (using Krutilla & Fisher) $1,296b (10) CVM survey of villagers' WTA, to forego use benefits in the newly created Mantadia National Park (Madagascar). Implicitly their valuation will reflect a total economic value of the resource foregone. The survey revealed a per household sum of $13.91 per annum, which is aggregated over the affected number of households (347) to give $4,827 per annum PV (assuming payments for 20 years and discounted at 5%) $60,141 or $6/ha over 10,000 ha of park.	(1), Implicit ratios of 6.82, 2.14 or 2.3 depending on alternative use, but subject to qualifications regarding local elasticity of demand for harvested forest products. A similar exercise (12) *in another area of Peruvian* Amazon contradicts these estimates with a ratio of about 30 in favour of logging and rotation cropping (2) Total present value $1296bn over 3.6b ha–$360/ha relative to a net revenue from clear felling of $1000/ha. The implied ratio of 0.36 will not be strictly representative since the calculation of Total economic value is not necessarily based on the assumption of sustainable use. (4) Implied for Costa Rica 12.5 which is the ratio of recreation value per hectare of protected area to the highest estimated price of land outside the park. (7) On the basis of local medicinal plant harvesting only, the implied ratio of 1.04 (9) Determination of market prices in this study is uncertain (ie world or local) implied ratio 11.3 (3) 1.07 total project ratio or 1.94 *from the perspective of* Cameroon when indirect project adjustments are included. These include figures for project related aid flows and value for uncaptured genetic and watershed values. (13) Implied ratio of 2

Value category:	Direct use	Indirect use	**Non-use values** **option, quasi-option,** bequest, existence	Total economic value	**Benefit (sustainable use)** /opportunity cost ratio
Ecosystem Type: **Wetlands (Floodplains, Coastal wetlands, Wet meadows, Peatlands)** *Sources:* (1) Barbier, Adams and Kimmage (1991) (2) Semples et al. (1986) (3) Costanza et al. (1989) (4) Thomas et al. (1990) (5) Bergstrom et al. (1990) (6) Thibodeau and Ostro (1981) (7) Ruitenbeek (1991) (8) Hamilton and Snedaker (eds.) (1984) (9) Hanley and Craig (1991) (10) Van Diepen and Fiselier (1990) (11) Fiselier (1990a) (12) Danielson and Leitch (1986) (13) Turner and Brooke (1988) (14) Mcneely and Dobias (1991)	(1) NPV per acre ($1990) from the preservation of the Hadejia-Jama'are floodplain, Nigeria Agriculture $41 Fishing $15 Fuelwood $7 Discounted at 8% Other floodplain benefits: livestock and grazing non-timber forest products tourism, recreation, (including hunting), educational and scientific benefits (genetic and information value) (3) Louisiana. WTP PV at 8% ($1990) per acre. Commercial fishery $400 Fur trapping $190 Recreation $ 57 Storm protection $2,400 Total $3,047 (5) Louisiana. WTP PV at 8% ($1990) per acre Recreation $103 (6) Charles River, Massachusetts PV (1990$) per acre at 8%. Recreation $3400 Water supply $80,000 (8) Present Value per acre (at 8%) of Mangrove systems. Direct use from fisheries, forestry and recreation. Trinidad $15,000 Fiji $11,000 Puerto Rico $13,000	(1) Ground water recharge function for surrounding areas, potentially measurable by either WTP or using costs of ground water depletion on local agriculture—ie a *production function* approach—as a minimum benefit approximation. Other important functions: Flood Control and Storm Protection can in theory be approximated estimating alternative *preventative expenditure* or *replacement costs* for sea defences and dykes. In Malaysia the cost of rock escarpments to replace eroded mangrove fringe is typically around $300,000/km ($1990) (11). The same study quotes a 1987 E.C. estimate of the "inherent" value of mangrove protection to Guyana as $4bn, though there is no indication of how the figure is derived. Nutrient cycling will normally have a measurable effect on fishing and agricultural yields (in deltaic areas) the value of which might also be approximated by *replacement expenditures* on nutrients and compensating technologies. The value of wildlife habitats and life support functions will be reflected in the value placed on the continued existence of dependant species, (see under Existence values for some estimates) (14) Sustainable charcoal production from mangrove (Thailand) generates an annual national income of approx. $22.4m Net profits are nearly $4,000/ha for forests with average productivity of 230m³/ha.	Significant option values fom future tourism, educational and scientific uses. existence values of wetland wildlife probably high although no explicit studies exist. (2) Some non-use values for wildlife (CVM estimates) 1990$/annum/person: brown bear, wolf, wolverine (Norway) 15 bald eagle (US) 12.4 emerald shiner 4.5 grizzly bear 18.5 bighorn sheep 8 6 whooping crane 1.2 blue whale 9.3 bottlenose dolphin 7.0 california sea otter 8.1 (9) Revealed WTP (CVM) for preservation benefits of blanket bog area in Scotland (1990) (once and-for-all payment) PV £164.68/ha (approx. $296.50/ha) implicitly representing the discounted future stream of user and non-user benefits. As such the value is interpreted as an option value. (See Smith [1987]) (12) An average annual amount ($343/acre) paid (by the US Fish and Wildfowl Service in 1980) to owners of wetlands in Massachusetts for *preservation easements*, can be taken to represent a minimum option Value for the ecosystem in an unaltered state. Similar conclusions could be inferred by looking at the average value of *management agreements* negotiated between conservation bodies and land owners in the UK. Such an *alternative cost approach* has revealed a value of £70/ha/per annum for coastal marsh and.	(7) Bintuni Bay mangrove ecosystem, Irian Jaya. NPV of whole system ($1991 discount rate 7.5%) $961–$1,495m, of which direct-use probably $152–534m. This value does not account for the high *cultural value* placed on the bay by the Irarutu tribe (10).	(1) Benefit/cost ratio expressed in terms the relative benefits accruing from alternative water use: $45 per 1,000m³ of water maintained in the floodplain as opposed to *4 cents* per 1,000m³ from diverted water. (4) From a similar analysis of the Ichkeul National Park, Tunisia, direct-use benefits amounted to $134 per 1,000m³ compared to *negative returns* from diversionary use. Given the difficulty of generalizing with respect to alternative uses for wetland areas, informative cost-benefit ratios are difficult to provide. Where non-use values have been inferred from costs of imposing or agreeing land use constraints (the cost of which represent a discounted future benefit stream), the implicit cost-benefit ratio will normally be at least 1, because the compensatory payment from the recipient's perspective will have to be at least equal to the perceived opportunity cost.

Value category:	Direct use	Indirect-use	**Non-use value** **option, quasi-option,** bequest, existence	Total economic value	**Benefit (sustainable use)** /opportunity cost ratio
Ecosystem Type: **Rangelands (semi-arid) and wilderness areas** *Sources:* (1) Brown and Henry (1989) (2) Western and Thresher (1973) (3) Dobias (1988) (4) Child (1984)(1990) (5) Coulson (1991) (6) Dept. of National Parks, Zimbabwe (1991) (7) Jansen (1990) (8) Barnes (1990) (9) Imber (1991)	(1) Wildlife tourism. Viewing value of Elephants in Kenya $25m/per annum. The same study gives an indication of the extent of revenue forgone through sub-optimal park entrance pricing. A rough WTP survey revealed a potential consumer surplus as high as $25m/per annum (a sum almost 10 times the value of poached ivory exports and at least a 10% increase in actual expenditures). Since people were only asked their WTP to preserve elephants, consumer surplus for all wildlife viewing is presumably higher. (4) *Wildlife utilization:* Non-consumptive game viewing, lightly consumptive safari hunting and live animal trade, consumptive meat and hide production. **Zimbabwe:** illustrative examples: *Non-consumptive use:* Direct and indirect income accruing to the Matusadona National Park (1991) US$10.3m, 66% of which foreign currency (5). *Safari hunting:* Value for foreign visitors in 1990 was US$9m of which, trophies accounted for US$4m (6). *Consumptive value* Zimbabwe estimates it makes $4.7m/annum from the sale of elephant goods and services, a return of \$75/km^2 over approx 74,000km^2 of elephant habitat. The proportion attributed to sale of goods has fallen significantly since the imposition of an international ban on ivory sales.	Indirect benefits from sustainable wildlife management: *Distribution of benefits to local communities* as a result of sustainable wildlife management schemes. (7) The Nyaminyami Wildlife Management Trust, Zimbabwe channeled approx Z$198,000 (1989) of wildlife revenues into local projects for health, housing, education and recreation. In addition the project was able to compensate local farmers for any damage incurred and offer cropped wildlife products for sale locally at subsidiized prices. Direct and indirect provision of employment. Improvements in local infrastructure and potential increases in land and property values. Significant saving in the hidden costs of land degradation and soil erosion arising from agricultural production in marginal areas. The role of elephants as keystone species diversifying savannah and forest ecosystems. Value added retained in the host country consists of net revenues accruing to: local airlines, tour operators, hotels, transport and cottage industries.	(3) Beneficial use project for Khao Yai National Park surveyed user WTP for continued existence of elephants at approx $7. Under certain assumptions of population and park use, the option and existence value of Khao Yai to Thai residents (for elephant preservation) may be as high as $4.7m/year . The extent of existence values might be approximated from the value of *vicarious tourism*—the consumption of books, films and TV programmes —particularly in developed countries, or from observed *charitable donations* to organizations involved in wildlife preservation. More crudely we might extrapolate on the basis of WTP information of visitors to wildlife sites in substitute countries like Kenya. In 1990 56% of overnight visitors to wildlife areas in Zimbabwe were foreign, of which 26% originated in Europe or North America (approx 151,000 visitors). Assuming 50% of these visitors reveal a similar WTP *in addition to* entry fees (in much the same way as in (1) i.e. a $100 permit for elephant preservation), extra revenue generated might amount to $7.5m per annum. (9) CV study preserve the Kakadu Conservation Zone (from mining development) revealed that Australians were willing to pay A$124/annum for ten years to avoid a major impact scenario and A$53 to avoid the minor scenario. Extrapolated to the whole population produced a total WTP range of A$650m–$1,520m , or a PV at 5% of between A$1m/ha and A$2.3m/ha over 5,000 ha. Both cultural and bequest values are likely to be significant in wildlife valuation although as yet few WTP studies reveal specific motivations.		(2) Ratio of wildlife tourism revenue per ha ($40) to income from extensive pastoralism ($0.80) 50. This ratio has probably increased significantly due to increasing value added in tourism. (4) Ratio of value of wildlife production (Z$4.20/ha) to Cattle Ranching (Z$3.58/ha in Zimbabwe 1.17. Calculation based on *economic rates of return* (as opposed to financial rates), and accounting for the relative environmental costs would in certain areas of the country produce ratios of between 2 and 5. (8) Provides PVs for returns from game viewing combined with some form of elephant cropping and for viewing alone in Botswana (1989). The ratio of the former to the latter range from 2.63 to 1.8 (depending on whether a 5 or 15 year horizon is considered) demonstrating the earning potential of consumptive uses. Comparison with the economic rate of return from cattle production on a per hectare basis could show ratios similar to those in Zimbabwe.

Value Category:	Direct use	Indirect use	Non-use values option, quasi-option, bequest, existence	Total economic value	Benefit (sustainable use) /opportunity cost ratio
Ecosystem Type: **Marine/coastal systems, heritage sites** (1) Carter et al. (1987) Hundloe (1990) (2) de Groot (1992) (3) Marcondes (1981) (4) Posner et al. (1981) (5) Schulze et al. (1983) (6) Hausman, Leonard, McFadden (1992)	(1) Estimating the socio-economic effect of the Crown of Thorns starfish on the Great Barrier Reef. A travel cost approach provided estimates of consumer surplus of A$117.5m /year for Australian visitors and A$26.7m/year for international visitors. The study showed that tourism to the reef is valued (in NPV terms) over and above current expenditure levels by more than $A1b. (2) Total direct use valued at $53/ha/year, comprising ($/ha/year): Recreational use 45 food/nutrition 0.7 Raw materials for construction 5.2 Energy resources 1.5 Ornamental resources 0.4 Biochemical and genetic resource values are also thought to be significant though no estimates are provided. Provision of employment directly or indirectly related to the National Park is a considerable benefit to the Galapagos economy (60% of 2,500 workforce). Tourism is the most important activity, contributing an estimated $26.8m to the local economy. (3) A form of Travel cost appraisal of the recreational value of the Cahuita National Park, Costa Rica. Consumer surplus estimates were derived from observed wage equivalent travel time net of transport costs multiplied over a visitor population. The resulting benefit-cost ratio demonstrated that the park is economically beneficial. (4) Conventional benefit-cost analysis of the Virgin Islands National Park, St John, identified significant direct and indirect benefits associated with the park, particularly tourist expenditures and the positive effect on land values in proximity to the designated area. Little information is available on the environmental effects of alternative land uses or the extent of visitor's consumer surplus. Total benefit ($1980) approx. $8,295/ha over approx 2820ha of National Park on St. John. (6) Recreation demand study to value recreation use loss caused by the Valdez oil spill in Alaska; about $3.8m (1989)	(2) Estimates provided for the Galapagos National Park, Ecuador: $/ha/year Maintenance of biodiversity 4.9 Value of fish breeding (nursery function) 0.07 (applicable to 430,000 ha of marine zone). Watershed and erosion prevention functions 0.3 (applicable to terrestrial area of 720,000ha)	(2) Option value for the Galapagos National Park set arbitrarily at $120/ha/year which is the approximate sum of direct and indirect use values from the park. The uniqueness of the Galapagos ecosystem suggests that existence values are likely to be significant. (5) Describes a CV survey to value visibility improvements at the Grand Canyon (from reduced sulphur dioxide emissions). Mean bid ($1990/person/year) $27. A high level of familiarity may explain the high value respondents seem to have been willing to pay in this study (compared to bids for endangered species—see table 5.3). Higher WTP bids in habitat valuation studies have generally revealed a preference for protection of a perceived array of benefits rather than for a targeted species. As with other CV studies the Grand Canyon case has been the subject of much debate, particularly with respect to the levels of information and framing (hypothetical) bias (see Schulze et al. [1981]).	(2) Total annual monetary returns from direct and indirect use approx $120/ha. In present value terms this represents $2,400/ha (at 5% discount rate) or almost $2.8b for the entire study area.	(3) Cahuita National Park ratio 9.54* (4) Ratio of total (direct and indirect) benefits to total cost 11.5* * A conventionally assessed ratio rather than one based on opportunity cost.

Source: Pearce, Moran, and Fripp 1992.

Notes

1. For an interesting discussion of the ways in which conservation policy in the United States has emerged to favor "charismatic megafauna," see Metrick and Weitzman 1994.

2. For a review of the direct and indirect causes of biodiversity loss in developing countries, see McNeely and others 1990 (especially chapter 3).

3. In addition, see de Beer and McDermott 1989; Aylward 1993; Aylward and others 1993; McNeely and others 1990 (especially chapter 2).

4. Attempts to estimate theoretically defensible and policy relevant shadow prices for biodiversity, such as those summarized in the appendix, have shown considerable promise. However, as compared with techniques to measure, say, willingness to pay for recreation or the benefits of watershed management, biodiversity values can be approached from the consumption perspective only with great uncertainty.

5. Age is not the only criterion by which woodpeckers select trees. Heartwood and fungus attack are also factors, but these are also correlated with age and age is the key management variable.

6. Marshall (1947) introduced the term "Particular Expenses Curve" for this approximation of a supply curve.

7. For a recent discussion, which is generally consistent with the formulation proposed here, see Reid and others 1993.

8. The classic work is MacArthur and Wilson 1967.

9. The eighteen map sheets were digitized for this work by the World Bank's Asia Region Information Technology Lab.

10. With respect to tree species: Nicholson (1965), Kartawinata and others (1981), Proctor and others (1983), Riswan (1987a), Ashton (1984) provide data on lowland dipterocarp forests; Ashton (1964 and 1984) and Peters (1991) report on upland or hill dipterocarp forest; and Proctor and others (1983), Ashton (1984), Riswan (1987b) describe kerangas or heath forest. Anderson (1961, 1976) provides thorough descriptions of the ecology and floristics of peat swamp forest, and Corner (1978) reports on freshwater swamp forests.

11. An estimated 33 percent of the plant species, 24 percent of the reptiles, 18 percent of the mammals, and 6 percent of the birds of Borneo are thought to be endemic to the island (MacKinnon and Artha 1982). Similarly, 82 of the 130 local species of *Shorea*, an important genera of timber trees, are found nowhere else in the archipelago (Ashton 1982).

12. These formulas are essentially the same as those used by MacKinnon and Artha to calculate what they called "Habitat Product."

13. The "Land Suitability" methodology employed by RePPProT is limited by both (a) the accuracy and precision with which sites can be assessed and the requirements of different uses established and (b) the neglect of economic considerations such as market size, price, and other considerations.

14. In some cases, a particular land system is capable of supporting more than one land use. Where this occurred, the model allocated land to the option yielding the highest return.

Bibliography

Aylward, Bruce A., J. Echeverria, L. Fendt, and E.B. Barbier. 1993. *The economic value of species information and its role biodiversity conservation: Costa Rica's National Biodiversity Institute.* London Environmental Economics Center Discussion Paper DP 93-06, December. London.

Anderson, J.A.R. 1961. *The ecology and forest types of the peat swamp forests of Sarawak and Brunei in relation to their silviculture.* Ph.D. thesis. Edinburgh, Scotland: Edinburgh University.

———. 1963. The flora of the peat swamp forests of Sarawak and Brunei including a catalogue of all recorded species of flowing plants, ferns and fern allies. *Gardens Bulletin Singapore* 20:131–228.

———. 1976. Observations on the ecology of five pear swamp forests in Sumatra and Kalimantan. *Soil Research Institute of Bogor Bulletin* 3:45–55.

Anderson, J.A.R., and P.P.K. Chai. 1982. Vegetation formations. In J.A.R. Anderson, S.C. Hermy, and Earl of Cranbrook, eds., *Gunung Mulu National Park: A management and development plan.* Royal Geographic Society, London.

Arrhenius, O. 1921. Species and area. *Journal of Ecology* 9:95-99.

Ashton, P.S. 1964. Ecological studies in the mixed dipterocarp forest of Brunei State. *Oxford Forestry Memoranda* 12.

———. 1982. *Flora Malesiana.* Series I, Volume 9, Part 2. Martinus Nyjoff Publishers.

———. 1984. Biosystematics of tropical woody plants: a problem of rare species. In W.F. Grant, ed., *Plant biosystematics.* Academic Press.

Balick, M.J., and R.O. Mendelsohn. 1992. Assessing the economic value of traditional medicine from tropical rainforest. *Biodiversity Conservation* 6(1).

BAPPENAS National Development Planning Bureau. 1991. *National Biodiversity Action Plan for Indonesia.* Jakarta.

Barbier, E., Adams, and Kimmage. 1991. *Economic valuation of wetland benefits: The Hadejiia-Jam'are Floodplain, Nigeria.* London Environmental Economics Centre Paper 91–02. London.

Barnes, J. 1990. *Wildlife values.* Gaborone, Botswana: Department of Wildlife and National Parks.

Bergstrom, J. 1990. Economic value of wetlands-based recreation. *Ecological Economics* 2(2): 129–48.

Biro Pusat Statistik (BPS). 1990. *Kalimantan Barat Dalam Angka.* Jakarta.

———. 1990. *Statistik Lingkungan Hidup Indonesia* (Environmental Statistics of Indonesia). Jakarta.

———. 1991. *Statistik Indonesia.* Jakarta.

Brown, G., and W. Henry. 1989. *The economic value of elephants.* London Environmental Economics Centre Discussion Paper 89–12. London.

Brown, K., D. Pearce, C. Perrings, and T. Swanson. 1993. *Economics and the conservation of global biological diversity.* Global Environment Facility Working Paper No. 2. Washington, D.C.: UNDP, UNEP, and World Bank.

Brunig, E.F. 1973. Species richness and stand diversity in relation to site and succession of forests in Sarawak and Brunei (Borneo). *Amazoniana* 4:293–320.

———. 1974. *Ecological studies in the Kerangas Forests of Sarawak and Brunei.* Kuching, Indonesia: Borneo Literature Bureau.

Carter, K. 1987. *Economic and socioeconomic impacts of the Crown of Thorns Starfish on the Great Barrier Reef.* Report to the Great Barrier Reef Marine Park Authority, Institute of Applied Environmental Research. Brisbane, Australia: Griffith University.

Child, C. 1990. Economic analysis of Buffalo Range Ranch. In A. Kiss, ed., *Living with wildlife—Wildlife resource management with local participation in Africa.* Washington, D.C.: World Bank.

Child, G. 1984. Managing wildlife for people in Zimbabwe. In J. McNeely and K. Miller, eds., National parks, conservation and development. Washington, D.C.: Smithsonian Institution.

Conover, W.J. 1971. *Practical non parametric statistics.* New York: John Wiley & Sons Inc.

Corner, E.J.H. 1978. The freshwater swamp forest of south Johore and Singapore. *Gardens Bulletin* (Singapore Supplement) 1.

Costanza, R. 1989. Valuation and management of wetland ecosystems. *Ecological Economics* 1(4): 335–62.

Coulson, I.M. 1991. *Tsetse fly eradication in Matusadona National Park—Integrated environmental planning to reduce conflicts with conservation and tourism.* Harare, Zimbabwe: Department of National Parks and Wildlife Management.

Cranbrook, Lord. 1982. The significance of the vertebrate fauna. In J.A.R. Anderson, A.C. Jermy, and Earl of Cranbrook, eds., *Gunung Mulu National Park: A management and development plan.* London: Royal Geographic Society.

Culver, D., J.R. Holsinger, and R. Baroody. 1973. Toward a predictive cave biogeography: The Breenbrier Valley as a case study. *Evolution* 27:689–695.

Danielson, L.E., and J.A. Leitch. 1986. Private versus public economics of prairie wetland allocation. *Journal of Environmental Economics and Management* 13(1).

de Beer, J.H., and M.J. McDermott. 1989. *The economic value of non-timber forest products of Southeast Asia.* Amsterdam, The Netherlands: Netherlands Committee for IUCN.

de Carvalho, J.O.P. 1981. *Distribucao diametrico de especies comercais e potencias em floreste tropical umida natural na Amazonia.* Bol. Pesq. No. 23. Belem, Brazil: EMBRAPA.

de Groot, R. 1992. *Functions and values of protected areas: A comprehensive framework for as-*

sessing the benefits of protected areas to human society. Wageningen, The Netherlands: Agricultural University, Climate Change Research Centre.

Department of National Parks and Wildlife Management. *Annual report of the Warden for Tourism.* Harare, Zimbabwe.

Diamond, J.M., and E. Mayr. 1976. Species-area relation for birds of Solomon Archipelago. *Proceedings of the National Academy of Sciences* 73:262–266.

Dobias, R.J. 1988. *Influencing decision makers about providing enhanced support for protected areas in Thailand.* Beneficial Use Project, World Wildlife Fund Contract 3757 Interim Report. Bangkok: World Wildlife Fund Thailand.

Ehrlich, P.R., and E.O. Wilson. 1991. Biodiversity studies: Science and policy. *Science* 253:758–762.

Eskeland, G.S. 1994. A presumptive pigovian tax: Complementing regulation to mimic an emission fee. *World Bank Economic Review* 8(3): 373–94.

Fiselier, J.L. 1990. *Living off the tides.* Leiden, The Netherlands: Environmental Database on Wetlands Intervention.

Food and Agriculture Organization of the United Nations (FAO). 1981. *National Conservation Plan for Indonesia: Kalimantan* (Vol. V). Field Report 17 INS/78/061. Bogor, Indonesia.

———. 1989. *Forest management for sustainable production and conservation in Indonesia.* UTF/INS/065/INS: Forestry Studies. Jakarta: FAO and Directorate General of Forest Utilization.

Gentry, A.H. 1988. Tree species richness of upper Amazonian forests. *Proceedings of the National Academy of Sciences* 85:156–159.

Gleason, H.A. 1922. On the relation between species and area. *Ecology* 3:158–162.

Gutierrez, B., and D.W. Pearce. 1992. *Estimating the environmental benefits of the Amazon forest: An international valuation exercise.* Centre for Social and Economic Research on the Environment (CSERGE) Policy Paper. London: University College London Press.

Hanley, N., and S. Craig. 1991. Wilderness development decisions and the Krutilla-Fisher Model: The case of Scotland's Flow Country. *Ecological Economics* 4(2): 145–62.

Harris, L.D. 1988. Edge effects and conservation of biotic diversity. *Conservation Biology* 2:330–332.

Hausman, J.A., Leonard, and McFadden. 1992. *Assessing use value losses due to natural resource injury.* Cambridge, Massachusetts: Cambridge Economics, Inc.

Hundlow. 1990. *Measuring the value of the Great Barrier Reef.* Australian Parks and Recreation 26(11).

Hyde, W.F. 1980. *Timber supply, land allocation and economic efficiency.* Baltimore, MD: Johns Hopkins University Press.

———. 1989. Marginal costs of managing endangered species: The case of the red-cockaded woodpecker. *The Journal of Agricultural Economics Research* 41(2).

Imber, D. 1991. *A contingent valuation survey of the Kakudu Conservation Zone.* Resource Assessment Commission Research Paper No. 3. Canberra.

Jansen, D.J. 1990. *Sustainable wildlife utilization in the Zambezi Valley of Zimbabwe: Economic ecological and political tradeoffs.* World Wildlife Fund Multispecies Project, Project Paper No. 10. Harare, Zimbabwe.

Kartawinata, K. 1980. A note on kerangas (heath) forest at Sebulu, East Kalimantan. *Reinwardtio* 9:429–447.

Kartawinata, K., R. Abdulhadi and T. Partonmihardjo. 1981. Composition and structure of lowland Dipterocarp forest at Wanariset, East Kalimantan. *Malay Forester* 44(2-3):397–406.

Krutilla, John V., and Anthony C. Fisher. 1975. *Studies in the valuation of commodity and amenity resources: The economics of natural environments.* Washington, D.C.: Resources for the Future.

———. 1985. *The economics of natural enviroments: Studies in the valuation of commodity and priority resources.* Washington, D.C.: Resources for the Future.

Leighton, M. 1990. *Seed dispersal syndromes of Bornean fruits: The dependence of plants on birds and mammals for seed dispersal and forest regeneration.* Research Report. Jakarta: Jakarta Center for Research and Development in Biology, LIPI nd Subdirectorate of Nature Conservation.

MacArthur, R.H., and E.O. Wilson. 1967. *The theory of island biogeography.* Princeton, New Jersey: Princeton University Press.

MacKinnon, J., and B. Artha. 1982. *National Conservation Plan for Indonesia.* 8 volumes. FAO/FS/INS/78/061. Bogor.

Malingreau, J.P. and R. Christiani. 1981. A land cover–land use classification for Indonesia: First revision. *The Indonesian Journal of Geography* 11(4) 13–47.

Marcondes, M. 1981. *Adaptacion de une metodolgia de evaluacion economica, aplicada al Parque Nacional Chuita, Costa Rica.* Centro Agronomica Tropical de Investigacion y Ensenanze (CATIE) Serie Tecnica No. 9. Turialba, Costa Rica.

Marsh, C.W., and W.L. Wilson. 1981. *A Survey of Primates in Peninsulat Malaysian Forests.* Universitas Kebangsaan Malaysia and University of Cambridge.

Marshall, Alfred. 1947. *Principles of economics.* 8th edition. London: Macmillan and Co.

McGuiness, K.A. 1984. Equations and explanations in the study of species-area curves. *Biological Review* 59:423–40.

McNeely, J.A., and R. Dobias. 1991. Economic incentives for conserving biological diversity in Thailand. *Ambio* 20(2): 86–90.

McNeely, J.A., K.R. Miller, W.V. Reid, R.A. Mittermeier, and T.B. Werner. 1990. *Conserving the world's biological diversity.* Washington, D.C.: International Union for Conservation of Nature and Natural Resources, World Resources Institute, Conservation International, World Wildlife Fund-US, and the World Bank.

Metrick, A., and M.L. Weitzman. 1994. *Patterns of behavior in biodiversity preservation.* Policy Research Working Paper 1358. Washington, D.C.: World Bank.

Montgomery, C.A., G.M. Brown, Jr., and D.M. Adams. 1994. The marginal cost of species preservation: The northern spotted owl. *Journal of Environmental Economics and Management* 26: 111–28.

Nicholson, D.I. 1965. A review of natural regeneration in the dipterocarp forests of Sabah. *Malaysian Forestry* 28:4–26.

Noss, R.F. 1983. A regional landscape approach to maintain diversity. *BioScience* 33:700–706.

Padoch, C., and C. Peters. 1993. Managed Forest Gardens in West Kalimantan, Indonesia. In C.S. Potter, J.I. Cohen, and D. Janczewski, eds., *Perspectives on biodiversity: case studies of genetic resource conservation and development.* Washington, D.C.: American Association for the Advancement of Science.

Payne, J., C.M. Francis and K. Phillips. 1985. *A Field Guide to the Mammals of Borneo.* The Sabah Society and World Wildlife Fund, Malaysia.

Pearce, D.W. 1991. An economic approach to saving the tropical forest. In D. Helm, ed., Economic policy towards the environment. Oxford, United Kingdom: Blackwell.

Pearce, D.W., Moran, D., and Fripp, E. 1992. The economic value of biodiversity. Report to IUCN, Gland, Switzerland.

Pearson, S., and E. Falcon. 1991. *Rice Policy in Indonesia.* Ithaca, New York: Cornell University Press.

Peters, C.M. 1991. *Illipe nuts in West Kalimantan: Use ecology and management potential of an important forest resource.* Paper presented at the Conference of Interactions of People and Forests in Kalimantan. New York: New York Botanical Garden.

Peters, C.M., A.H. Gentry, and R.O. Mendelsohn. 1989. Valuation of an Amazonian rain forest. *Nature* 339:655–56.

Pinedo-Vasquez, M., D. Zarin, P. Jipp, and J. Chota-Inuma. 1990. Use values of tree species in a communal forest reserve in northeast Peru. *Conservation Biology* 4: 405–16.

Potter, C.S., J.I. Cohen, and D. Janczewski, eds. *Perspectives on biodiversity: Case studies of genetic resource conservation and development.* Washington, D.C.: American Association for the Advancement of Science.

Proctor, J., J.M. Anderson, P. Chai, and H.W. Vallack. 1983. Ecological studies in four contrasting lowland rain forests in Gunung Mulu National Park, Sarawak, *J. Ecol.* 71:237–260.

Reid, W.V. 1992. How many species will there be? In T.C. Whitmore and J.A. Sayer, eds., *Tropical deforestation and species extinction.* London: Chapman and Hall.

RePPPorT. 1987. *Regional Physical Planning Programme for Transmigration, Review of Phase I Results, West Kalimantan.* Land Resources

Development Centre, ODA, Foreign Commonwealth Office, London and Direktorat Bina Program, Departmen Transmigrasi, Jakarta.

Riswan, S. 1987a. Structure and floristic composition of mixed dipterocarp forest at Lempake, East Kalimantan, pp. 435–457 *in* A.J.G.H. Kostermans (ed.), *Proc. 3rd Round Table Conference on Dipterocarps*. MAB, UNESCO.

———. 1987b. Kerangas forest at Gunung Pasir, Samboja, East Kalimantan. I. Its structure and floristic composition, pp. 471–494 *in* A.J.G.H. Kostermans (ed.), *Proc. 3rd Round Table Conference on Dipterocarps*. MAB, UNESCO.

Ruitenbeek, J.H. 1989. *Social cost benefit analysis of the Korup Project, Cameroon*. London: World Wide Fund for Nature.

———. 1991. *Mangrove management: An economic analysis of management options with a focus on Bintuni Bay, Irian Java*. Jakarta: Ministry of State for Population and Environment.

———. 1992. The rainforest supply price: A tool for evaluating rainforest conservation expenditures. *Ecological Economics* 6: 57–78.

Schneider, R. 1992. *Brazil: An analysis of environmental problems in the Amazon*. Report No. 9104-BR. Washington, D.C.: World Bank.

Schulze, W. 1983. Economic benefits of preserving visibility in the national parklands of the southwest. *Natural Resources Journal* 23.

Semples, K. 1986. Information disclosure and endangered species valuation. *Land Economics* 62(3).

Shafer, C.L. 1990. *Nature Reserves: Island Theory and Conservation Practice*. Smithsonian Institution Press.

Soulé, M. 1991. Conservation: Tactics for a constant crisis. *Science* 253:744–750.

Stamps, J.A., M. Buechner and V.V. Krishnan. 1987. The effects of edge permeability and habitat geometry on emigration from patches of habitat. *American Naturalist* 129:533–552.

Thibodeau, F., and B. Ostro. 1981. An economic analysis of wetland protection. *Journal of Environmental Management* 12(1).

Thomas, D. 1990. *Use value and non-use values in the conservation of Ichkeul National Park, Tunisia*. London: University College, Department of Geography.

Tobias, D., and R. Mendelsohn. 1990. The value of recreation in a tropical rainforest reserve. *Ambio* 20:91–3.

Turner, K., and K. Brooke. 1988. Management and valuation of an environmentally sensitive area: Norfolk Broadland case study. *Environmental Management* 12(3).

van Diepen, P., and J. Fiselier. 1989. The Bintuni Case: Nature under siege. In *Proceedings of the International Conference on Wetlands: The people's role in wetland management*. Leiden, June 5–8. Leiden, The Netherlands: Centre for Environmental Studies.

Viner, J. 1932. Cost curves and supply curves. In Zeitschrift Fur Nationalokonomie 3, reprinted in R.V. Clemence, *Readings in Economic Analysis* (vol 2). Cambridge, United Kingdom: Addison-Wesley Press.

Watson, D. 1988. The evolution of appropriate resource management systems. In F. Berkes, ed., *Common property resources: Ecology and community based sustainable development*. London: Belhaven.

Western, D., and P. Thresher. 1973. *Development plans for Amboseli*. Nairobi: World Bank.

Whitmore, T.C. 1984. *Tropical forests of the Far East*. Oxford, United Kingdom: Clarendon Press.

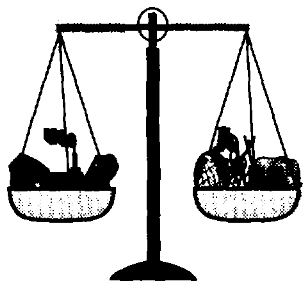
Williams, C.B. 1943. Area and number of species. *Nature* 152:264–267.

Wilson, E.O. 1988. The current state of biological diversity. In E.O. Wilson, ed., *Biodiversity*. Washington, D.C.: National Academy Press.

World Bank. 1985. *Indonesia, The Major Tree crops: A Sector Review*. Washington, D.C.

———. 1988. *Indonesia: The transmigration program in perspective*. Washington, D.C.

Yahner, R. H. 1988. Changes in wildlife communities near edges. *Conservation Biology* 2:333–339.



2

Natural Resource Accounting: A Practical Comparison of Methodologies and Application to Thailand's Logging Ban

Claudia W. Sadoff

Introduction

All countries rely to some degree on natural resources and the environment for their long-term economic and social well-being. Yet national income indicators, the usual measures of economic performance, do not generally reflect the costs of natural resource depletion and environmental degradation. By ignoring these costs national income indicators mislead policymakers and present environmental disinvestment as income generation.

While the interdependence of economics and the ecosystem is undeniable, measurement is complex. As inputs, natural resources are generally priced according to their extraction costs, without taking into account their inherent value or the value of their *in situ* functions. As a receptacle for waste, the services of the ecosystem are rarely priced at all. Though many countries have established fees and fines for waste disposal, the majority of the world's waste is released into the ecosystem at no cost whatsoever to the polluter. As productive capital, natural assets are in effect assumed to be limitless. Their depletion is therefore unrecorded in national asset balance sheets and unnoted in the calculation of a country's capital stock.

Measuring environmental costs is not solely an academic exercise. The trade-offs between economic production and environmental degradation cannot be fully understood or managed unless their costs and benefits can be measured by a common yardstick. Proper measurement is crucial also because so long as the environment is undervalued, or unvalued, it will be overexploited. If environmental concerns are to be taken seriously, they must be explicitly incorporated into economic evaluations and included when calculating the true gains from economic production. The way in which the environment is treated or, more accurately, neglected in the context of national income accounting must therefore be reassessed. Particularly in resource-dependent developing countries, trade-offs and environmental costs must be clarified before long-term development policies can be conscientiously evaluated.

Natural resource accounting offers a means of modifying national income calculations to more fully reflect the cost of natural resource depletion and environmental degradation. The United Nations System of National Accounts (SNA), which sets the international guidelines for income accounting, has recently been revised to recommend the compilation of satellite accounts that incorporate natural resource accounting. The methodology by which natural resources will be valued, however, has not been specified, though several techniques have been proposed. Each methodology necessarily introduces biases that will affect the adjusted income levels and hence policy recommendations. A standardized system of valuation would lend comparability and credibility to natural resource accounting.

J.R. Hicks (1939) suggested that income should be a "guide for prudent conduct." A comparison of the policy implications arising from different valuation techniques might therefore be a good place to begin examining the practical strengths and weaknesses of various methodologies.

Therefore, to assess their relative feasibility and usefulness, two natural resource accounting methodologies, user cost and depreciation, were applied to the same task—modifying Thailand's forestry-related income between 1970 and 1990 to account for the value of forest asset loss. Both approaches attempt to redress the uneven treatment of natural and manmade capital in calculating national income, and incorporate the environmental costs of production into economic indicators. The case study highlights some of the difficulties of definition and data availability that are inevitable in natural resource accounting.

The case study also illustrates the importance of natural resource accounting for policymaking. The adoption of legislation to protect Thailand's forests presupposes that those forests embody social value. Current calculations of national income, however, assign no value to standing forests. Value is assigned only to wood removed from the forest. Standard economic indicators are thus misleading tools for analyzing the economic effects of such policies because they tally only the costs (forgone timber earnings) and none of the benefits (the value of forest preservation) associated with such policies. Natural resource accounting can be used to impute values for standing forests, and incorporate these values into modified measures of national income.

Natural resource depletion-adjusted measures provide a more complete accounting of the ecological costs of economic production, but even these modifications are not comprehensive. Substantial nonmarket forest products and services remain outside the scope of this assessment. The value, for example, of soil stabilization, biodiversity, and water regulation, as well as the effects of forest management on agricultural production,[1] are not captured here. Economic costs are narrowly defined as the costs of forest timber losses and clearly understate the true loss in value to society.

Estimates of forest depletion-adjusted income suggest that over the past two decades the average annual cost of deforestation in Thailand has been roughly 2 percent of the country's real gross domestic product (GDP). Annual forest asset losses, on average, have been equivalent to more than 20 percent of the total manmade capital depreciation that is currently recorded in the national income accounts. None of these costs are reflected in the standard calculations of GDP.

Natural resource-related production in national income accounts

Measures of national income are quoted so regularly that their definitions are assumed to be understood and are rarely explicitly stated. This can be problematic. The GDP, for example, is derived from a country's national income accounts and constructed as a measure of economic activity. Yet, in practice, the GDP is frequently used to compare the wealth and welfare of different nations and to record their trends over time. While academicians are well aware of the caveats associated with various interpretations of the GDP, many policymakers are not. Few understand the history and construction of this indicator and hence its suitability for such applications.

Current calculations of the national income accounts

The national income accounts are designed to register a systematic and consistent set of data of the production, distribution and use of goods and services during a specified time. The SNA was first standardized by the United Nations in 1968 and, with some slight modifications, has been almost universally adopted.

The 1968 SNA recommends the compilation of both flow accounts and balance sheet accounts, which are related through capital finance accounts. Flow accounts receive by far the most attention at a national level, and nowhere are natural resources and the environment explicitly included in them. Balance sheets, which are compiled under separate cover, do not include any entries for stocks of natural and environmental assets.

The gross *national* product (GNP), which is calculated from the national income accounts, is defined as the market value of newly-produced final goods and services of a country, *without* deduction for capital consumption. Final goods and services are those that are not resold in the specified accounting period. The gross *domestic* product (GDP) reflects only that production taking place *in* the country, in contrast to the GNP that includes output produced abroad but owned by a country's residents. For instance, remittances from nationals working abroad are included in the GNP but excluded from the GDP; remittances from foreign workers in the country are included in GDP but not GNP.

To avoid double counting, only "value added" is used in the national income accounts: defining the income generated by each economic activity as the value of its output, minus the value of all intermediate inputs. In natural resource exploitation, however, income is recorded as total revenues less only the cost of extraction. No intermediate costs are registered for the inherent value of the resource; the resource itself is therefore treated in the production process as a free, "costless" good.[2] Failing to subtract the value of natural resource inputs exaggerates the value added of resource-related sectors (relative to other sectors) and translates the sale of a resource into income generation.

The national income accounts are limited primarily to recording the formal market transactions of enterprises, households, and government. In general, the output of an economic activity will be recorded without regard for the actor involved. In the case of environmental defense or cleanup costs, however, the economic significance of the activity will be determined by the actor rather than the action performed. If, for example, a government or household makes expenditures to combat environmental degradation, the outlays will be recorded as income and increase GDP. If, on the other hand, an enterprise makes similar expenditures, the outlays will be classified as intermediate costs and decrease GDP.

Some activities outside the formal market are imputed in national income, generally those with clear market proxies. The decision to include imputations and the methodologies employed vary by country. For example, subsistence farming is often, but not necessarily, included. Some significant activities, however, are explicitly excluded from the GDP, for example, household services performed by family members. On the other hand, the value of the same services rendered by a household employee *are* included. This inconsistency in treatment is based on the argument that the level of family-rendered services would reorient the system away from its current purpose as a record of monetary transactions (UN 1990).

To the extent that nonmarket production, or other goods such as leisure, are excluded, national income is likely to be understated. By neglecting the role of natural resources in the economy, however, sustainable income will be overstated by an amount equal to the consumption or depreciation of natural capital. The policy implications in the latter case are serious: by overstating income from natural resource-related activities, policies that draw down natural assets, degrade the environment, and decrease future productive capacity appear to have exactly the opposite effect—to be particularly profitable and productive.

Capital depreciation is the most commonly imputed measure in the national income accounts. In order to measure net national income, depreciation must be deducted from total income; the net national product (NNP) is thus the GNP less capital depreciation. Likewise net domestic product (NDP) is GDP less capital depreciation. Depreciation does not record an economic transaction but is imputed to capture the declining income-generating potential of an asset over time and to indicate the level of investment necessary for a country to maintain its productive capacity.

Yet, until recently, depreciation was imputed and deducted only for wear and tear on reproducible, manmade capital. When natural assets were depleted—when forests were cleared, waters overfished, or nonrenewable mineral deposits mined—no analogous depreciation was recorded. The exploitation of resources and degradation of the environment undoubtedly lessen an economy's productive capacity, particularly developing economies that rely heavily on resource-extracting industries. It is clearly inconsistent and misleading to deduct depreciation for productive manmade capital, while ignoring the analogous depreciation of productive natural capital.

In 1993 the United Nations presented guidelines modifying the 1968 SNA for natural resource–related activities. These revisions preserve the integrity of the GDP as a time series, where a more radical adjustment would cause discontinuity and confusion. For example, the revisions address the way in which environmental defense expenditures are recorded in national income accounts and recommend that the NDP be given greater emphasis in policy analysis. The revised system recommends greater integration of flow accounts and balance sheets—but emphasizes balance sheets. In the 1968 version of the SNA, balance sheets were provided under separate cover but not incorporated in the main accounts. The revised balance sheets will include two new accounts for explaining natural resource use and the environment, areas inadequately addressed in the 1968 SNA.

In addition to the SNA revisions, the United Nations has created an extended satellite System of Economic and Environmental Accounts (SEEA) to explicitly recalculate modified indicators. The SEEA will be more broad than the SNA and will record all assets, such as air and water, that are affected by human activities.

Income, wealth and policy signals

The practice of excluding natural resource and environmental costs from calculations of national income is rooted in the neoclassical tradition. The classical economists defined revenue or income as rent, wages and profit—or the returns on land, labor and capital (Smith 1776). This definition also reflects what is most likely to be the popular understanding of income. The neoclassical economists, however, defined income differently in two important respects.

First, income was defined as only that portion of gross revenues that could be spent while keeping capital intact. J.R. Hicks defined income broadly as that which we can consume today without becoming less well-off tomorrow. This corresponds to Adam Smith's notion of "neat revenue," which subtracts the cost of capital maintenance from the gross receipts of production in order to establish the amount that can be spent on "...subsistence, conveniences, and amusements" without depleting the capital stock (Smith 1776).[3]

The second way in which the neoclassical economists modified their calculation of income was to minimize the role of natural resources in their analyses. The earlier classical economists, Malthus and Ricardo,[4] predicted that population would outstrip nature's power to provide sustenance and that widespread famine would result. They wrote, however, at a time when commodity prices were at an historic high.[5] Conversely, the neoclassical economists of the late nineteenth century worked in a time of unprecedented international trade as transport costs fell and inexpensive grains were imported from the British colonies.

For the neoclassical economists of the late nineteenth and early twentieth centuries, labor and capital were the constraints on growth. Thus, the productive role of natural resources was largely ignored, and the marginal product of natural capital was assumed to be zero. Circumstances have now changed. Rapidly growing populations and advanced technologies have eased the constraints of labor and capital, while accelerated growth and the exploitation of natural resources have caused natural resource and environmental constraints to become binding.

Income in the context of the GDP does not precisely correspond to either the classical economists' definition of income, or to the Hicksian definition. The SNA, from which the GDP is derived, is claimed to be theoretically neutral and not aligned with any particular school of economic thought.[6] In the SNA, much of the cost of capital maintenance is subtracted from total revenues as intermediate expenditures, and depreciation of manmade capital is imputed to arrive at NDP. The resulting figures will not correspond to the revenue or income of classical economics, but will rather reflect "neat revenue." To the extent that natural resource depletion or environmental degradation erode productive capacity and wealth, the GDP will not reflect Hicksian income either.

To measure Hicksian income, the portion of revenues derived from the consumption or sale of capital must be charged against total revenues. If GDP is interpreted as a measure of Hicksian income that can be consumed entirely without cost in terms of future production, then GDP calculated as gross of capital consumption will give entirely the wrong economic signals. The result likely will be unsustainable overconsumption and an erosion of the country's productive assets.

Besides overstating the economy's output and future capacity, the failure to account for natural resource depletion will make the GDP a skewed indicator of welfare as well. Environmental degradation often decreases social welfare in immediate ways. Deforestation limits access to fuelwood and forest products, and increases soil erosion. Perversely, the economic hardship created by removing informal sources of forest products and forcing households to purchase the goods they had previously gathered will translate into increased market activity and GDP growth.

Natural resource accounting

Natural resource accounting incorporates natural resource management into macroeconomic analyses by calculating the cost of resource depletion and degradation and constructing income indicators to reflect these capital costs. Such costs must be accounted for to reveal what is truly sustainable income and economic production. If a country is to maintain its wealth and productive capacity after natural resource exploitation, provision must be made to restore the environment to its previous productivity or to invest a part of the activities' proceeds to compensate for the income that could have been generated from later resource exploitation.

To keep the general framework of the SNA, most proposed natural resource accounting methodologies calculate or impute only the commercial losses associated with natural resource depletion or degradation. This is an extremely conservative way to adjust national income, and none of the externalities and nonmarket values of natural resource–related activities will be accounted for in the adjustments.

The two most commonly discussed methods of natural resource accounting are the user cost and the depreciation approaches. As yet, no consensus has been reached concerning a standard methodology for valuing resources in the United Nations' new SEEA.

The user cost approach

The user cost approach is based on the premise that the consumption of natural capital should not be included as value added in national income. When natural assets are depleted in the process of economic production, revenues include not only value added but also a component of capital consumption or user cost. User cost reflects future income that is necessarily forfeited as a result of current natural resource exploitation.

The user cost component of natural-resource related production must therefore be separated from the income stream and subtracted from standard calculations of national income in order to arrive at resource depletion-adjusted national income. The basic equation of the user cost approach is thus:

$$\text{GDP} - \text{User Cost} = \text{Resource Depletion–Adjusted GDP} \tag{1}$$

User cost represents forgone future income, or the difference between total revenues and Hicksian income (El Serafy 1989). It can also be thought of as that portion of current earnings that must be set aside for reinvestment to maintain an income stream that will no longer be available because of natural asset erosion.[7] El Serafy (1989) presents models for separating user cost from value added both in the case of nonrenewable and renewable resource exploitive production.

For income derived from nonrenewable resources, user cost and value added components are separated in the following manner. The finite series of revenue from resource sales is first converted into an infinite series of real income. The capitalized values of the two series are then set equal so that a user cost or depletion factor can be derived from the permanent stream of income.

$$\frac{X}{R} = 1 - \frac{1}{(1+r)^{n+1}} \tag{2}$$

where,

X = value added or true income
R = total receipts, net of extraction costs
r = the discount rate
n = the number of periods of exploitation
X/R = the ratio of real value added to total receipts
$(1 - X/R)$ = the user cost.

One advantage of El Serafy's approach is that it requires minimal data: total receipts, extraction costs, the time period over which the resource is fully exploited, and the social discount rate. The model, however, is extremely sensitive to changes in the discount and extraction rates. For example, if a discount rate of five is assumed, and the resource is exhausted over five years, the user cost will represent 75 percent of revenues. If, however, a discount rate of ten is assumed over the same five year extraction period, only 56 percent of revenues will be defined as user cost. Similarly, if a discount rate of five is assumed but the time horizon of extraction is extended from five years to ten years, the user cost component of revenues will fall from 75 percent to 58 percent.

In the case of renewable resources, El Serafy argues that an appropriate maintenance cost, the cost to sustain the productivity of natural capital, should be charged against the gross revenues of those activities that deplete or degrade natural assets. If the asset is not sufficiently maintained, the cost that would have been incurred to maintain the asset's productivity should be charged nevertheless. Such costs must be subtracted from revenues to isolate the activity's true value added.

Calculations will differ by resource, and difficulties in defining maintenance will certainly arise. To maintain forest resources, for example, what is the appropriate criterion for measuring depletion and hence replacement—the area of forest or the volume of wood? Similarly, must overfished waters be restocked to replace specific species and population sizes, or simply to maintain average catches by weight? Furthermore, if there are numerous technically acceptable means of maintenance—with widely varying costs and benefits—what criteria should be used to choose among them? In most cases, data availability will be the practical arbiter of such questions, but standardization and comparability would be compromised as a consequence.

The depreciation approach

The depreciation approach to natural resource accounting emphasizes actual depreciation, in contrast to the user cost approach that focuses on the discounted value of forgone future income. Standard calculations of national income impute and subtract the depreciation of manmade capital from GDP to arrive at NDP. The rationale behind imputing depreciation is that the wear and tear of usage today will decrease the productivity of capital in the future and that this decreased future productivity should be reflected in net national income. While the same logic clearly applies to the degradation of natural assets, no decrease in productivity is reflected in the accounts when, for example, forests are cleared or soil is eroded.

When a country clears its forests or extracts its minerals, it is reaping benefits at the cost of its future options. If the country is to be as well-off after such activities occur, the environment should be restored to its previous productivity, or some portion of current proceeds should be invested to generate the income that could be derived from later resource exploitation. Depreciation should indicate the reinvestment necessary to maintain economic productivity. Stocks of natural assets should therefore be compiled and depreciated in the same manner as manmade capital, to more accurately reflect a country's declining productive capacity.

This methodology, as applied by Repetto and others (1989, 1991), requires that the amount by which natural assets are depreciated in a given accounting period be charged against the current revenues of the depleting activities. The basic equation is the following:

$$\text{GDP} - D_s - D_{nr} = \text{Resource Depletion–Adjusted NDP} \tag{3}$$

where,

D_s = the standard manmade capital depreciation
D_{nr} = the monetized value of natural asset depletion.

The depreciation approach offers a modified calculation of the NDP. These depreciation-adjusted NDP measures, however, might in themselves provide misleading signals. The technique excludes the total value of extracted resources from the NDP by defining depreciation as the value by which resource stocks decline over a given period, which is precisely the value extracted. It therefore negates the real advantages of resource endowments by effectively erasing all resource-exploitive activities from net national income.[8] The depreciation approach not only nullifies the advantages of resource exploitation in measures of NDP, it also fails at the same time to address the fact that in measures of GDP natural resources are treated as costless. The full revenue of resource sales, less only the cost of their extraction, continues to be recorded as current production or value added.

Thailand's logging ban

Background

In January 1989, Thailand became the first country to institute a nationwide ban on commercial forest logging. The legislation followed two decades of rapid deforestation and a final monsoon season of catastrophic floods and mud slides. The severity of the 1988 floods was believed to be caused by deforestation and soil erosion in the country's hillsides and watersheds.

The logging ban was welcomed as a bold measure to protect Thailand's remaining forests and allow the country to reassess and restructure its forest management policies. The rate of forest loss in Thailand has declined since passage of the ban, while the economy apparently enjoys unimpaired growth. Yet illegal logging continues in the country's most commercially valuable forests, and Thailand's demand for imported logs contributes to accelerated cutting in other Southeast Asian nations.

Thailand's exceptional income growth seems to suggest that the kingdom's exploitation of natural resources has been economically sound. The standard tools with which environmental and economic gains are judged, however, fail to provide a framework in which the trade-offs between them can be measured. Both the effectiveness of Thailand's logging ban in preserving the country's forests and the implications of the ban for regional forest management and trade in timber are important. To analyze the economic effects of the ban, natural resource accounting can be used to quantify the trade-off between Thailand's forest policy choices and economic performance.

Economic growth and forest management in Thailand

Thailand has followed a textbook development path from reliance on subsistence agriculture and natural resource exploitation, toward a more complex industrializing economy based increasingly on manufacturing, trade and services. In the 1980s Thailand's economic growth rate was among the highest in the world. Projections for the country's current five-year development plan (1991–1996) suggest this trend will continue. Industry is expected to grow over the period at an average annual rate of 9.5 percent, while agriculture will grow at a considerably lower rate of 3.4 percent.

Growth in the Thai economy has thus been accompanied by a clear structural shift away from agriculture. The relative contribution of agricultural income to total GDP dropped sharply during the decade of the 1980s, from more than 23 percent to roughly 15 percent. The share of labor employed in agriculture, however, remained at more than 65 percent. These percentages are due to the fact that per capita income in agriculture has remained fairly static, while productivity in other sectors has improved markedly. Agricultural gains in Thailand have been largely the result of crop area expansion, at the cost of forests, rather than intensification of production.

The forestry sector, defined to include the production of timber and major forest products, produces a small and declining portion of the country's output. Even in the 1970s when the timber industry was at its peak, the forestry sector contributed just 2.5 percent of real GDP. Before the logging ban in 1988 this share had fallen to 0.37 percent of total real GDP, and in 1990 to 0.16 percent. This is not to say that forest resources have not proved a significant source of wealth for the Thai economy, but rather that their services have often been undervalued or fallen outside the scope of recorded market activities. The exploitation of forests and other natural resources has provided Thailand with the economic base necessary for its remarkable development.

The broad environmental and economic implications of forest management have made forest policy an important issue in the larger context of Thailand's development. The country's seven National Economic and Social Development Plans (1961–1996) have all specified target levels for the proportion of total land area to remain under forest cover. Actual forest area, however, has consistently fallen below these targets.

All forest lands and resources in Thailand have been property of the government since the turn of the century. This state ownership of the country's forests means that the government has control over commercial logging. Only private, artificially established tree plantations exist outside the state-owned forests, and they are generally managed for rubber, fruits and oils rather than timber. Virtually all of Thailand's commercially marketed timber was removed from natural forests under fixed-term government concessions and from reforested timber plantations in state-owned forest areas leased from the Royal Forest Department (RFD). Noncommercial forest felling was illegal, whether for household use, land clearing, or sale in informal markets.[9]

Despite a long history of forest management, deforestation has been significant in Thailand. In the beginning of the twentieth century, over 75 percent of the country was covered with forest. By the time of the First National Economic and Social Development Plan in 1961, 53 percent of the country remained forested. Since then, the forest has shrunk at an average annual rate of roughly 2.5 percent, with considerably higher rates in the 1970s. Official estimates claim that less than 27 percent forest cover remains. Unofficial estimates suggest the actual figure may be closer to 18 percent.

Causes of deforestation include logging, infrastructure development, and land conversion. What usually happens is that commercial logging ventures enter a forest area and create access for settlers that convert the land to agriculture. Cultivation of cleared forest land inhibits natural regeneration and the establishment of forest villages make official large-scale reforestation efforts considerably more complicated. An estimated 8–10 million people live and farm in the forest. Nearly all are illegal encroachers.[10]

In the mid-1970s the annual rate of deforestation in Thailand peaked at roughly 3.3 percent. At that time two important shifts in government policy occurred. First, long-term logging concessions were granted, which dramatically increased the total number of concessions in operation. In addition to increasing the area where forest was legally cleared, the logging concessions facilitated illegal encroachment as well. By building roads and felling the largest trees, the logging concessionaires effectively subsidized the conversion of forest land to agriculture.

A second shift involved government operations to suppress the guerrilla activities of the Communist Party of Thailand. The mid-1970s were the years in which the most aggressive anticommunist campaigns were carried out, primarily in the forest areas of the northeast. Government counter-insurgency programs cleared land for strategic roads and facilities in the dense forests that had provided cover for the rebels. These programs, like the concessions, encouraged illegal encroachment. New roads provided access, while the government tacitly condoned the establishment of "strategic" forest villages.

Deforestation rates in Thailand remained relatively high well into the 1980s. The United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) reported that in the early 1980s Thailand's rate of forest loss was nearly two and a half times the Southeast Asian average (ESCAP 1990), and according to the World Resources Institute (WRI), nearly five times the average rate for the tropics as a whole (WRI 1988). Over 130,000 square kilometers have been lost since 1960; an area only slightly larger—roughly 140,000 square kilometers—now remains.

In the fall of 1988, southern Thailand experienced floods and mud slides that killed more than 370 people and caused $240 million worth of property damage. The intensity of the floods was blamed on the area's severely deforested surroundings and watershed. Two villages were reportedly buried under tons of uprooted and illegally cut logs that had been swept down the hillsides by the storms.

A nationwide logging ban was issued in 1989 in response to the lethal floods and growing public concern for Thailand's forests. The ban itself is not totally restrictive. It allows, for example, the felling and sale of trees in privately operated forest plantations, harvests of designated species and trees that have been damaged by age or natural disasters, and the clearing of forests for infrastructure projects. At the time of its passage, the logging ban was characterized as a temporary measure to allow for reforestation and an overhaul of the forest management system, although no time frame was given. There are still no stated plans to revoke the ban.

Effect of the logging ban on forest harvest in Thailand and neighboring countries

PROTECTION OF THAILAND'S FORESTS. Thailand is unusually well-positioned to sustain and enforce a logging ban. The legislation was passed following a catastrophic event that raised both public awareness and broad-based support. The ban required no extension of state authority, because all forests in the country had been state-owned and managed for nearly a century. Thailand's economy was afforded significant insulation by cheap imports and opportunities for Thai logging companies to operate abroad. But perhaps most importantly, the economy, even with the ban, is growing stronger.

Official data reported by the RFD showed a significant decline in forest area loss following the ban. The rate of deforestation fell from 1.7 percent in the 1980s before the ban, to less than 0.3 percent after 1989; a decline of nearly 86 percent below projected trend levels.[11] The success of the ban, however, is not as clear as these numbers make it appear. Each year since the establishment of the ban an average of over 300 square kilometers of forest have been cleared. In addition, the ban has been considerably less successful in slowing the actual volume of commercial wood removed from the forests.

Since the ban, the estimated annual volume of commercial wood losses has fallen just 26 percent from projected trend levels. The forests that have been illegally logged since the 1989 ban must, therefore, be significantly more dense or support a higher percentage of commercial species than those previously logged. In other words, forest loss has been successfully slowed only in those areas where it is least profitable.

Furthermore, if the government-awarded concessions had been optimally managed to maximize wood extraction and minimize environmental damage, then this shift from previous patterns implies a more ecologically harmful system of forest logging. While the present preservation of the overall forest cover area is essential to conserving the ecological functions of the forest, the smaller areas now logged are likely to be more pristine and of greater importance to Thailand's ecological balance.

Early indications suggested that the increase in illegal logging might negate entirely the gains of banning the government logging concessions. Five months after the ban was implemented a ground and aerial survey conducted by the RFD reported that forest encroachment had actually increased 54 percent over the comparable period in the previous year. The agriculture minister expressed doubts about the study's reliability when it was released, but the study was never officially repudiated.

Illegal logging is not a new phenomenon in Thailand. One of the primary functions of the state-run Forest Industries Organization is to hold regularly scheduled auctions of confiscated, illegally cut timber. The RFD annual statistical reports of timber production even has a separate category for confiscated wood. A ban on legal logging could only serve to increase the well-established demand for illegally procured logs. In 1990 the volume of confiscated timber was five and a half times the 1988 pre-ban level, and of course only a small portion of illegally felled logs are confiscated. In 1980 the total illegal harvest was estimated at twice the legal cut (Bangkok Bank 1980). In 1991 it was believed to be more than six times as high (RFD 1991).

Enforcement of the ban is complicated by various legislative loopholes that allow the legal sale and purchase of illegally felled logs. House construction, for example, legalizes wood. Villagers can build new houses supported by ten to twenty large logs, and after a period of time, legally sell the structures to timber merchants. Processing also legalizes wood, so many logs are carved or processed right where they fall and then removed from the forest—legally.

There are many examples of authorized loggers "pushing the envelope" around legal cutting areas. For instance, the Chiew Larn Dam in Southern Thailand was exempt from the ban on concessions, and logging firms were authorized to clear the area flooded by the dam. Evidence of significant illegal logging along its perimeters, however, caused the contracts to be revoked. Similar difficulties were encountered when a group of firms were contracted to remove the trees damaged by Typhoon Gay in late 1989. A different way of crossing the legal cutting lines occurs along the national borders. Particularly along the Myanmar and Cambodian borders, Thai logs are felled and dragged out of the country, only to be re-imported as legal timber.

More direct violations also occur. In some villages where government officials exercise their full authority and where powerful political and business interests are absent or uninvolved, the ban has been successful in halting deforestation. In many areas, however, losses of legitimate logging employment and rising log prices have led to actual increases in cutting (MIDAS 1991).

Logging therefore occurs in virtually every forest in Thailand, despite the ban. While much of the felling is ad hoc, the profitability of illegal logging has spawned highly sophisticated operations. Equipped with radios, specially modified heavy logging equipment and firearms, some operations have become extremely effective and dangerous. Armed confrontations between officials and log poachers have resulted in loss of life on both sides. A further complication is that corrupt officials are assumed to be involved in the majority of clandestine logging operations. Thus, while it is widely believed that the logging legislation is sufficiently stringent, full enforcement is simply not feasible. The government's infamously low salary scale provides a powerful incentive for complicity in the lucrative illegal timber trade.

Enforcement of Thailand's logging ban is likely to become even more difficult in the future. The countries that supply Thailand's log imports have begun to raise prices and tighten export controls. The upward pressure this action will exert on the market price of logs will in turn bolster the demand for, and profitability of, illegally procured logs.

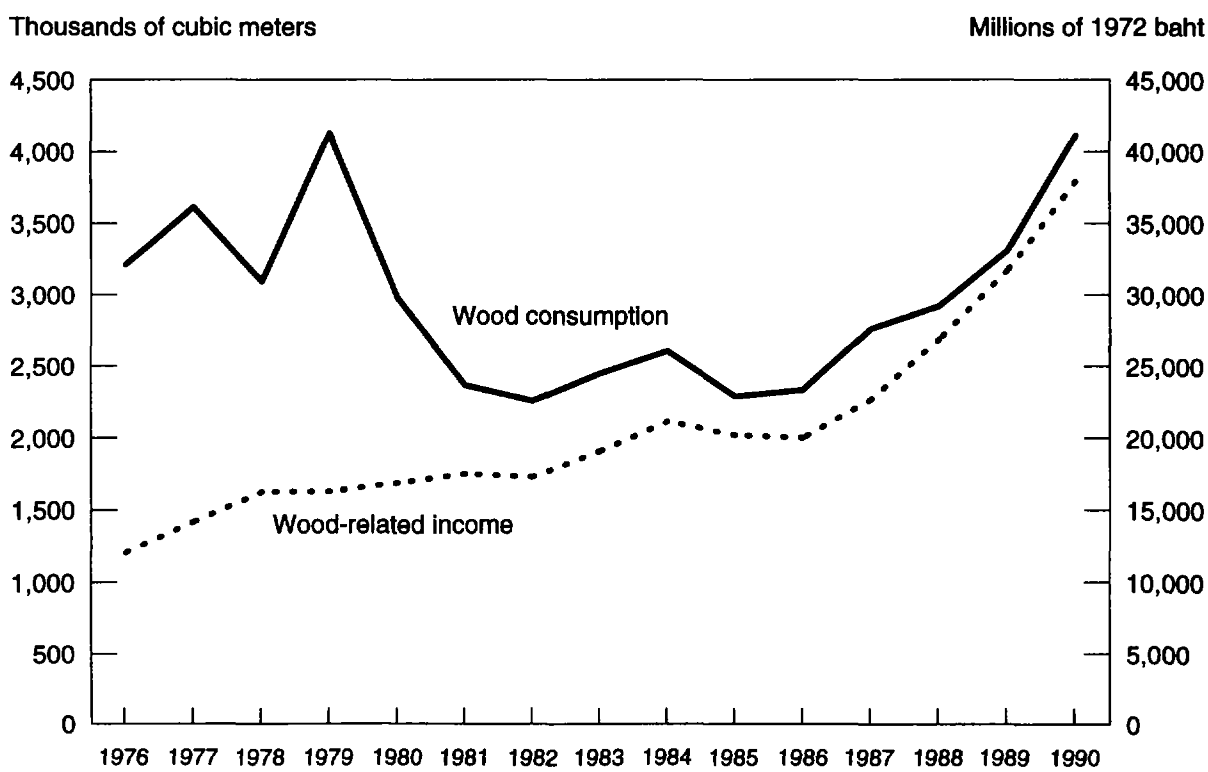
TIMBER SUPPLY AND FORWARD LINKAGES. A severe timber shortage was expected to follow imposition of the logging ban in 1989. Demand for timber was growing quickly at the time. The construction sector, which consumes the majority of domestic and imported logs, boomed in 1988, growing at nearly twice the rate of the overall economy. Within four months of the ban, however, sawmills reported an oversupply of logs. A combination of relaxed import restrictions and increased illegal cutting succeeded in flooding the Thai log market and highlighting its adaptability.

Thailand's timber production has shrunk considerably since the logging ban. Only about 40 percent of the country's sawmill capacity was utilized in 1991. The balance of timber supply cannot be explained by the sufficiency of domestic wood supplies to meet demand. Imports have long been an integral part of the country's timber market, and the country has been a net importer of logs and sawnwood since 1977. Shortages of domestic raw wood were reported by millers even at the height of Thailand's own logging activities. A more appropriate indicator of the sufficiency of Thailand's wood supply would therefore be the country's apparent wood consumption—defined as the officially recorded level of domestic wood production and imports, less exports. Apparent wood consumption in 1979 and 1989 was roughly 4 million cubic meters; in between these two years, consumption dipped below 2.5 million cubic meters. These dramatic changes in apparent consumption, however, were accompanied by slow, but steady growth in wood-related sectors (see figure 2.1).

These figures suggest two things. First, because the measure reflects only legally procured timber, large quantities of illegal wood must also have been processed. A lower bound on the illegal log supply can be roughly and very conservatively estimated by assuming that actual consumption remained constant after 1979 and that no illegal wood was consumed before 1980. Between 1980 and 1988, the illegal log supply must then have totalled over 14 million cubic meters, roughly equivalent to the legally reported production during that time. A second point, which follows from the first, is that both illegal logging and economically acceptable imports have proven capable of insulating Thailand's downstream wood users from significant fluctuations in the legitimate domestic supply.

It is difficult to generalize about the price effects of the logging ban. The price of wood ranges widely according to species, grade, location and level of processing. The effects of the ban are therefore difficult to isolate from normal price fluctuations. Estimates suggest a jump of roughly 20–50 percent in log and sawnwood prices immediately following announcement of the ban (RFD 1991). Within the year, however, sawnwood prices appeared to settle roughly 15 percent above 1988 levels. Dramatic growth in the Thai economy, particularly in the construction sector, should also be expected to raise prices, further obscuring the relationship between the logging ban and sustained timber price increases. The effect of the logging ban on timber

Figure 2.1 Apparent wood consumption in Thailand, 1976–90



Note: Apparent wood consumption is the officially recorded level of domestic wood production and imports, less exports. Wood-related sectors include processed wood products, wooden furniture, pulp and paper, and construction.
Source: RFD and NESDB, various years.

prices, if any, is also difficult to detect through forward linkages.

Income growth in the wood-based industries (paper and paper products, furniture, and processed wood products) has not been significantly affected by restrictions on the domestic log supply.[12] Since the 1970s Thailand has encouraged the production of processed wood products. As a consequence, the total income earned by wood-based industries exceeded that of forestry in 1977, and by 1990 it was nearly five times as high. Wood-based industries have continued to grow since the ban. The construction sector, which accounts for the use of roughly 90 percent of domestic logs and 65 percent of imported logs, has been one of the strongest performers in the economy, showing uninterrupted, extraordinary growth following the 1989 ban (RFD 1991).

Thailand's forestry sector exports have declined since the 1989 logging ban. But again, the wood-based manufactures appear unaffected by the downward trend in forestry production. The export performance of wood-based products has been remarkably strong, driven largely by parawood furniture exports, which now account for some 80 percent of all furniture exports. The cutting of parawood, which is the sawnwood of cultivated rubber plantation trees, remains unaffected by the national forest logging ban.

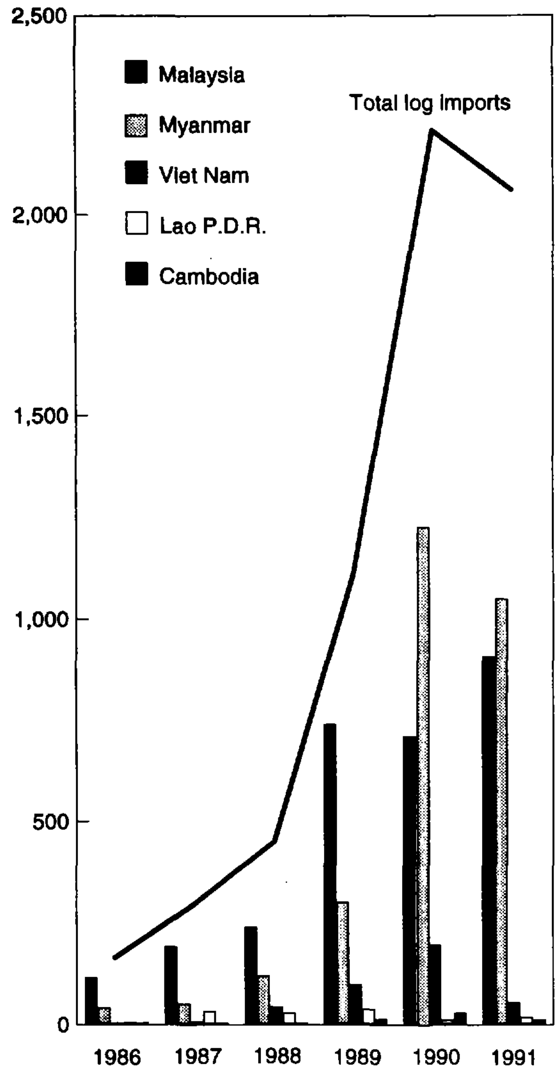
ASIA REGIONAL ISSUES. In order to insulate Thailand's wood-related industries from the adverse effects of a restricted domestic log supply, policies to facilitate regional timber imports were adopted in concert with the logging ban. Certification requirements were lifted, customs procedures were expedited, and duties fell to negligible levels. These related measures must be considered both in terms of their effect on Thailand's supply of imported logs and their effect on the logging policies of the exporting nations.

Thailand's log imports grew more than fourfold in the first two years following the ban and are seen to be causing a sizable spillover effect of deforestation and environmental damage in the region. It has become increasingly apparent that while Thailand's forests may be spared by the logging ban, Thai import demand has contributed to widespread and relatively uncontrolled logging in the forests of its trading partners. The isolated national ban is simply shifting deforestation across borders. In response, however, the Southeast Asian nations have begun to tighten regulations and control the flood of logs into Thailand. The future of Thailand's log import supply is therefore uncertain (see figure 2.2).

Myanmar is the fastest growing source of Thailand's log imports. A long-standing ethnic rebellion along the Thai-Myanmar border, an area covered largely in virgin forest, created a situation in Myanmar that was reminiscent of Thailand during the 1970s when communist rebels operated under cover of the dense Thai forests. Adopting a strategy similar to Thailand's, General Saw Maung agreed to grant logging concessions in the rebel held areas. The concessionaires were expected to build access roads through rebel territory, lessen ethnic control over the lucrative illegal log trade, and generate badly needed foreign currency for Myanmar, one of Asia's poorest countries. Logging concessions in Myanmar became increasingly more complex and less profitable. Heavy fees paid both to Yangon and to the rebels continued to climb. The government has now declared that its borders will be closed to foreign logging interests.

Log imports from Cambodia have been expedited since 1989 by opening new customs checkpoints along the Thai-Cambodian border and dropping the Thai government requirements for certification of overland imports. Because the Thai government had not recognized the Vietnamese-backed government of Hun Sen, Thai imports of Khmer logs that originated in Phnom Penh before 1993 never required origin certification, although certificates of origin had been required for logs removed from resistance held areas along the countries' common border.

Figure 2.2 Thailand's log imports and major sources, 1986–91



Source: RFD, various years.

Logging in Cambodia increased dramatically leading up to the 1993 elections, as the country's four warring factions[13] logged and granted concessions in the areas under their control. In response, the Supreme National Council[14] declared a moratorium on log exports that has been upheld by the newly elected government.

Lao People's Democratic Republic (Lao P.D.R.), like Cambodia, was targeted for imports shortly after the logging ban was established. Requirements for certification of origin were waived for logs entering over the Thai-Laotian border, and the Thai Forest Industries Organization began negotiating for felling rights by early February 1989.

In August, 1991, Lao P.D.R. tightened controls both on domestic logging and on foreign forestry investment in the country. Prime Minister Khamtai Siphandon, then newly appointed, issued the 1991 decree to slow timber exploitation while a nationwide forest survey and other protective measures were to be implemented. The Lao system of forest management and regulation is being reviewed and restructured. While it is unclear to what extent the eventual restructuring will affect Thailand's imports, it can be expected to decrease supply and/or significantly raise costs.

In Viet Nam rapid deforestation since the mid-1970s is believed to have directly contributed to the increased severity and frequency of flooding over the past decade. In response to the ever-increasing rate of forest loss, the government of Prime Minister Vo Van Kiet banned timber exports in March 1992. The new ban disallows exports of timber and sawnwood and calls for the revocation of export permits. It remains unclear whether the export ban can be circumvented by sufficient levels of wood processing.

Clandestine timber trade is believed to continue with all of these countries. The trend, however, is to stem the flow of cheap log imports to Thailand.

Natural resource accounting and Thailand's logging ban

Applying the user cost method

Following the user cost approach, a capital consumption charge was calculated to reflect the portion of revenues necessary to maintain the productivity of Thailand's forests. This value, or user cost, was then subtracted from the standard measure of real income generated by the forestry sector.[15] User cost was calculated as:

$$\text{User Cost} = \sum_{r} (ND_r) \times (CR_r) \qquad r = 1,\ldots,4 \tag{4}$$

where,
ND_r = net deforestation by region
CR_r = cost of reforestation by region.

The calculation of this charge requires specification of the timing, definition of "forest area," and costs and extent of reforestation.

TIMING. The timing of forest replacement will affect both the total area replanted and the cost per unit area reforested. Reforestation is calculated here as the net area cleared of forests at the end of each accounting period. Yet, a considerable decline in the density of forested areas has occurred as well. Charging the costs of reforestation only when an area is fully cleared postpones the penalty to an accounting period in which most, though not all, of the forest loss occurs.

Before an area is cleared, however, it still retains great natural regenerative capacity. Because it is the loss of this productive capacity that is measured by user cost, it would be inappropriate to apply the penalty to an area in which natural rehabilitation was not significantly compromised. Even if a practicable definition could be found to identify the point at which forests no longer can effectively renew themselves, the lack of forest volume data in Thailand makes it impossible to distinguish declining forest density until the forests crown disappears from LANDSAT images and the area is recorded as nonforest.

Furthermore, past experience in replanting forests as they are thinned, rather than after they are cleared, suggests that this method of reforestation would be prohibitively expensive and complex in Thailand. Unsuccessful replanting of selectively logged forests led to calls for forest clearcutting in the mid-1980s—a practice that was then officially agreed to on an experimental basis but that had always been the *de facto* system of logging. The only technically acceptable criterion for reforestation in Thailand would therefore appear to be total replanting of cleared forest areas.

UNITS OF FOREST MEASUREMENT. Another issue that must be clarified to define user cost is whether forests should be maintained in terms of *land area* or *wood volume*. In this study land area was chosen. If a wood volume approach were adopted, larger tracts of natural forest cover could be replaced with smaller, higher-density, monoculture plantations. Wood, however, is only one of many forest products. Many nonmarket forest functions would in fact be hampered by high-volume monoculture plantations. Plantations of this type crowd out undergrowth, limiting the diversity of flora and fauna supportable in the secondary forests. Widespread public protests have occurred regarding the harmful effects of commercial plantations, particularly eucalyptus, which has been found to significantly draw down the water table of surrounding agricultural lands.

Furthermore, there is a clearly articulated social preference in Thailand to maintain significant and specific areas of forest cover. Each of Thailand's seven National Economic and Social Development Plans (1961–96) have called for a target of at least 37 percent forest cover in the country, although in nearly all periods actual forest area has fallen well below the target level. These repeated calls for ecological balance suggest that conservation of forest area in itself is a priority for Thai society.

Deforestation was therefore defined as the net forest area cleared each year. Forest losses by region over the period were calculated by interpolation of periodic aerial photography and LANDSAT survey data published by the RFD.

COST OF REFORESTATION. The cost of reforestation is calculated here as the sum of the present discounted costs of establishing a forest plantation and maintaining it until a harvestable age. This would be the amount necessary to set aside in the year deforestation occurred in order to allow complete forest renewal. Costs, as discussed above, are based on the replanting of deforested areas, which is the generally accepted approach to reforestation in Thailand.

Reforestation is by nature a labor-intensive operation, particularly if its purpose is to preserve the integrity of the surrounding natural forest to the greatest extent possible. The cost of reforestation is thus driven by the cost of labor. Calculations of reforestation costs over time were therefore derived primarily from labor requirements[16] and regional wages.[17]

Costs over the ten-year cycle were discounted back to the year deforestation occurred in order to arrive at the present value of reforestation per rai (about one-fifth of a hectare or half an acre) by region in each year.

$$PVL_r^t = \sum_i \frac{(W_r^{t+i} \times L^{t+i})}{(1+d)^{t+i}} \qquad i = 1,\ldots,10 \tag{5}$$

where,
PVL_r^t = the present value of regional labor costs for reforestation, in time t
W = regional legal minimum wage, in time $t+i$
L = man-days of labor required, in time $t+i$
d = rate of discount (5 percent)
i = years in the plantation cycle.

The series of present value regional labor costs (PVL_r) was then weighted by the proportion of terrestrial deforestation, and hence required reforestation, in each region during the relevant period.

$$PVL_w^t = \sum_r (PVL_r^t) \times \left(\frac{ND_r^t}{ND_{total}^t}\right) \qquad r = 1,\ldots,4 \tag{6}$$

where,
PVL_w^t = the present value of regionally weighted, total labor costs for reforestation, in time t
ND_r = net deforestation, by region
ND_{total} = net deforestation, country total.

The PVL_w^t series represents the total discounted labor costs for the full reforestation cycle, calculated per rai in each year. To this, capital costs were added. Capital requirements, which account for roughly 10 percent of total costs, are relatively small and unchanging. Capital inputs were therefore assumed to be a constant 10 percent of labor cost in each period. The time series of reforestation costs calculated under these assumptions fell well within the range of published cost estimates for plantations of various types.

Finally, total costs were deflated[18] to create a time series of total, real reforestation costs per rai.

$$CR^t = (PVL_w^t + K) \times \left(\frac{100}{GDP_{def}}\right) \tag{7}$$

where,
CR^t = total real cost of reforestation in time t
K = capital inputs
GDP_{def} = GDP deflator.

The resulting series (CR^t) was multiplied by net deforestation in each period to arrive at the real user cost penalty for that period. This forest depletion penalty was then subtracted from forestry sector income to determine the user cost–adjusted forestry income in each period.

User cost–adjusted forestry sector income between 1971 and 1982 was found to be negative. Rapidly increasing rates of deforestation, accompanied by slow growth in formal timber sales, produced net losses in the forestry sector. The annual cost of maintaining Thailand's forest assets, at its peak in the late 1970s, would have been 16.6 percent of standard, real agricultural GDP and 3.7 percent of the country's total real GDP.

The forestry sector user cost adjustments called for an average annual downward adjustment of 1.5 percent of total real GDP between 1970 and 1990 but a slight increase in the growth rate of GDP from a trend rate of 7.3 percent to 7.4 percent. Slowing deforestation after the 1970s led to relatively lower forest depletion penalties and hence an upward adjustment of the GDP growth trend. If forest depletion, thus calculated, were subtracted from fixed capital formation, those figures would require average annual adjustments of 6.4 percent below their standard measures over the 1970 to 1990 period.

After establishment of the nationwide ban on logging in 1989, user cost–adjusted forestry sector income was positive and higher than it would have been if the ban had not been established. The user cost adjustments therefore recommended continuation of the logging ban as a forest policy that was both economically and ecologically beneficial.

Applying the depreciation method

The depreciation of Thailand's forest stock is defined here as the value of the net change in forest stock.[19] Estimates were first made of changes in forest volume, by type and region, over time. The stumpage value of the annual change was then calculated as the depreciation or appreciation of the forest stock, as follows:

$$D_{nr} = \sum_{r} (dVol_r) \times (SV_r) \qquad r = 1,\ldots,4 \tag{8}$$

where,
D_{nr} = the value of natural resource depreciation
$dVol$ = the change in commercial forest volume by region
SV = the stumpage value of wood by region.

The volume of the forest stock will depend on both forest area and density. Forest areas and densities were calculated for four forest types—tropical evergreen, mixed deciduous, dry dipterocarp, and pine—and four regions—the northern, northeastern, central, and southern.[20]

No current or time series forest density data exist for Thailand. The First and Second National Forest Density Inventories, taken in 1969–73 and 1975–79, are still considered the best available density measures. A considerable decrease in density, approximately 6 percent annually, was seen between the two surveys, suggesting that forests were being thinned as well as cleared over time. A straight application of the densities recorded in the late-1970s would thus almost certainly overstate actual forest volume by failing to account for such thinning. On the other hand, a projection assuming a continuation of the rate of decline in density seen between the two inventory periods might well understate actual densities, because the period in which the measurements were made was a time at which forest clearing was at its peak.

The relationship between the rate of change in forest area and the rate of change in forest density was found to be statistically significant at the 95 percent confidence level for each of the forest categories over the period between the two national inventory surveys. A simple model was therefore constructed using deforestation rates as a proxy for pressure on the forests to estimate the change in forest densities by type and region.

$$\mathrm{d}\,Density_r^{ft} = f(\,\mathrm{d}Area_r^{ft}\,, c\,) \tag{9}$$

where,
$\mathrm{d}Density$ = change in forest density
$\mathrm{d}Area$ = change in forest area
r = region
ft = forest type
c = constant.

This derived density function was used to project changes in density from a base-year measurement of the second national forest inventory in 1977. The density model permitted both increasing and decreasing forest densities, capturing natural regeneration in previously thinned forest areas where decreased pressure on the forest allowed for net growth. Where this relationship projected an increase in forest density that exceeded the forest type's natural growth rate, the natural growth rate was used to project density changes.[21]

The estimated density series[22] fell markedly over time, as expected, but did so at a declining rate after the late-1970s. The reliability of the function can be tested by comparison to a later, partial inventory carried out by the RFD. In 1988–91, density surveys were made of twenty-two working forest areas in the north and northeast, under the supervision of the RFD.[23] The average densities derived in this paper are roughly 60 percent higher than those found in the RFD sample working forest areas for the corresponding forest types, regions, and periods.[24] Although the areas measured were not forest logging concessions, they were relatively accessible, and their densities are likely to be lower than average as a consequence. If, in fact, the densities estimated here are high, then wood loss will be understated and the depletion penalties will be conservative.

The total volume of the forest stock over time was calculated by applying forest densities by type and region to the corresponding forest areas. These calculations, like those performed in the user cost analysis, capture only the wood loss resulting from total forest clearing; declining densities in remaining forest areas are not reflected by these measurements.

Changes in the physical volume of the forest stock must be quantified in monetary terms if they are to be incorporated into a national income accounting framework. The market price of wood products, however, is not an appropriate value to attach to the wood inherent in a standing forest. A stumpage value—the value of wood still on the stump—must therefore be calculated.

Stumpage values are calculated from market prices by subtracting the costs and profits associated with the production of wood-based goods. These costs generally include extraction, transport and milling. World average export (f.o.b.) log prices were used as a starting point for the calculation here, as they reflect the economy's opportunity cost of wood. Thailand's export prices could not be used because forest log exports have been banned for over a decade. Calculations based on log rather than sawnwood prices do not require data for milling costs, hence decreasing the scope for errors. A profit margin of 6 percent was assumed for extraction and transport activities.[25]

Regional stumpage values were applied to that portion of wood volume loss that could reasonably have been expected to arrive at market. Wood that either lacks commercial value or is effectively irretrievable has no opportunity cost. Volume was therefore adjusted to include only commercial species in each region. Percentages of commercial species by region were taken from Thamminchia (1982) and were assumed to remain constant. Adjustments were also made to allow for the volume of timber normally damaged in the logging process, an amount that would be reflected in net forest loss but that could not be expected to reach market. A ratio of 1.71[26] was used to reflect the total volume of wood felled or damaged for every cubic meter marketed.

The depreciation of forest assets would then be subtracted from standard measures of income to arrive at forest depletion-adjusted NDP. For purposes of comparison, however, depreciation adjustments here were made relative to GDP.

Depreciation-adjusted forestry sector income, calculated as standard forestry sector GDP less forest asset depreciation, was found to be negative between 1970 and 1982. The maximum annual depletion adjustments were estimated at 6 percent of the country's total real GDP, more than three times the standard, recorded forestry sector income.

During 1970–90, an average annual downward adjustment in total real GDP of 2.2 percent was recommended by the depreciation adjustments; modifications in GDP *growth* over the same period suggested an increase of 0.3 percent. Again, this upward adjustment in GDP growth reflects the falling rates of deforestation after the 1970s. Fixed capital formation, according to the depreciation-adjusted figures, was overstated by an average of 9.5 percent.

Following Thailand's 1989 logging ban, depreciation-adjusted incomes fell below zero, though user cost-adjusted incomes were positive. Depreciation-adjusted income analyses found that the ban, while ecologically desirable, was not economically beneficial.

Results of the case study

Resource depletion adjustments indicate that the failure to account for the cost of deforestation in standard measures of GDP has led to consistently overstated levels of national income in Thailand. Following the user cost approach, GDP adjustments for forest loss between 1970 and 1990 yielded an average annual income 1.5 percent lower than the figures derived by standard calculations. The depreciation approach called for an average downward adjustment of 2.2 percent.

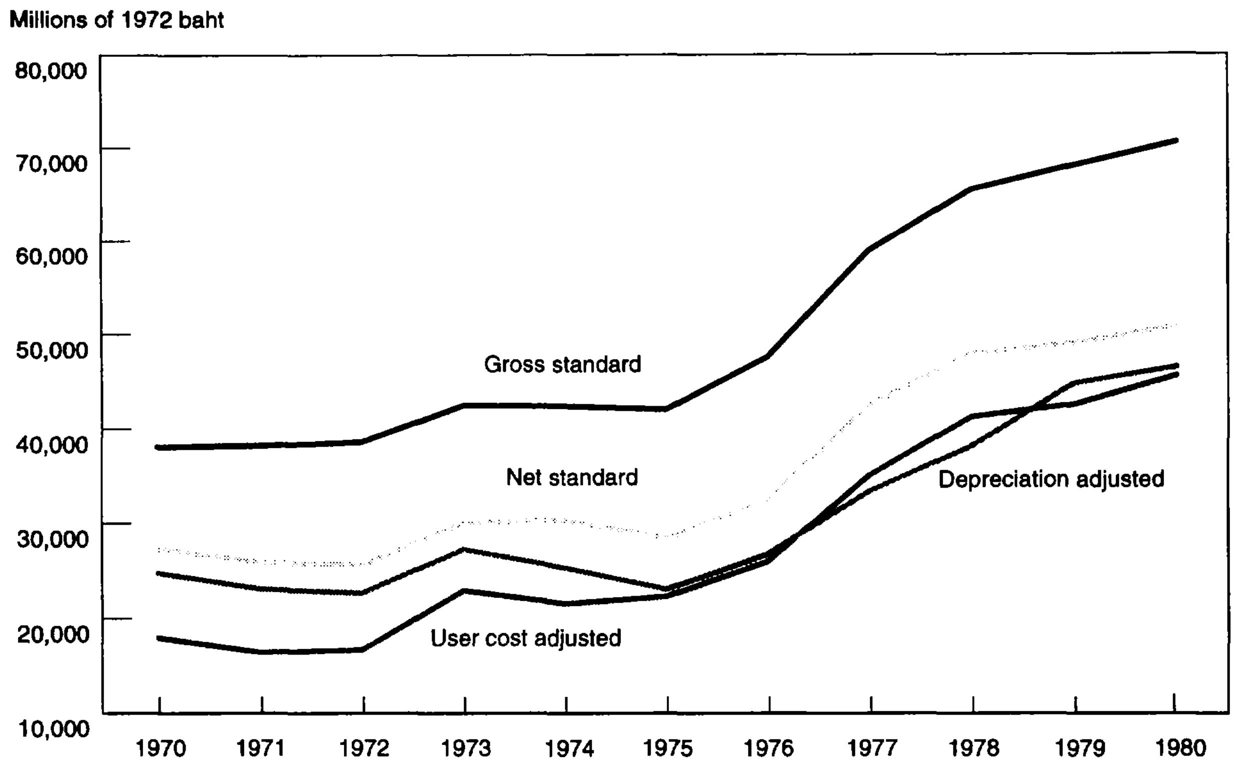
At the same time, the adjustments indicate that the rate of Thailand's GDP growth is actually understated. Standard GDP calculations found 7.3 percent real average annual growth between 1970 and 1990. Over the same period the user cost-adjusted incomes grew at a rate of 7.4 percent, while depreciation adjustments resulted in a real growth rate of 7.7 percent. The upward adjustment in income growth is a result of the declining rate of deforestation and hence the declining amount of resource depletion adjustments since the 1970s.

The depletion of natural resources will also affect a country's productive capital stock. If the decline in forest assets were charged against fixed-capital formation for the period 1970–90, the user cost and depreciation penalties would require annual downward adjustments averaging 6.4 and 9.5 percent, respectively. These penalties represent an additional 21 and 31 percent of the total manmade capital consumption currently recorded as depreciation in the standard GDP calculations. Natural asset depletion, calculated here for forests alone, appears to be a substantial cost of Thailand's economic development—a cost policymakers should be made aware of (see figure 2.3).

DEPLETION-ADJUSTED INCOMES. Following both the user cost and depreciation methodologies, depletion-adjusted forestry sector income between 1971 and 1982 was actually negative.[27] In other words, Thailand's forests not only failed to generate income but were a drain on the economy. When deforestation rates peaked in the late 1970s, the maximum annual depletion adjustments were estimated at 3.7 and 6.0 percent of the country's total real GDP, following user cost and depreciation adjustments, respectively. This is more than three times the total forestry sector GDP, the value that is reportedly extracted from the forests.

A reversal in the sign of adjusted forestry income (that is, the shift from positive to negative incomes) results from the fact that climbing rates of deforestation in the 1970s were not matched by corresponding increases in the sale of timber. Standard measures of forestry GDP over the period remained quite steady while depletion penalties rose, leading to negative depletion-adjusted incomes. A further implication is that deforestation in the period was not effectively driven by commercial logging operations but was more the result of agricultural expansion and forest encroachment. It is therefore interesting to note the effect of forest depletion adjustments on the overall level of GDP earned in agriculture. Agricultural income grew steadily over the period but did not show the dramatic, sustained gains that might be expected to follow the accelerated deforestation and crop land expansion of the 1970s. This suggests that much of the cleared timber stock may sim-

Figure 2.3 Domestic capital formation, 1970–80



Note: Forest depletion adjustments appear to reflect a significant erosion of the capital stock.
Source: NESDB, various years; Sadoff 1992b.

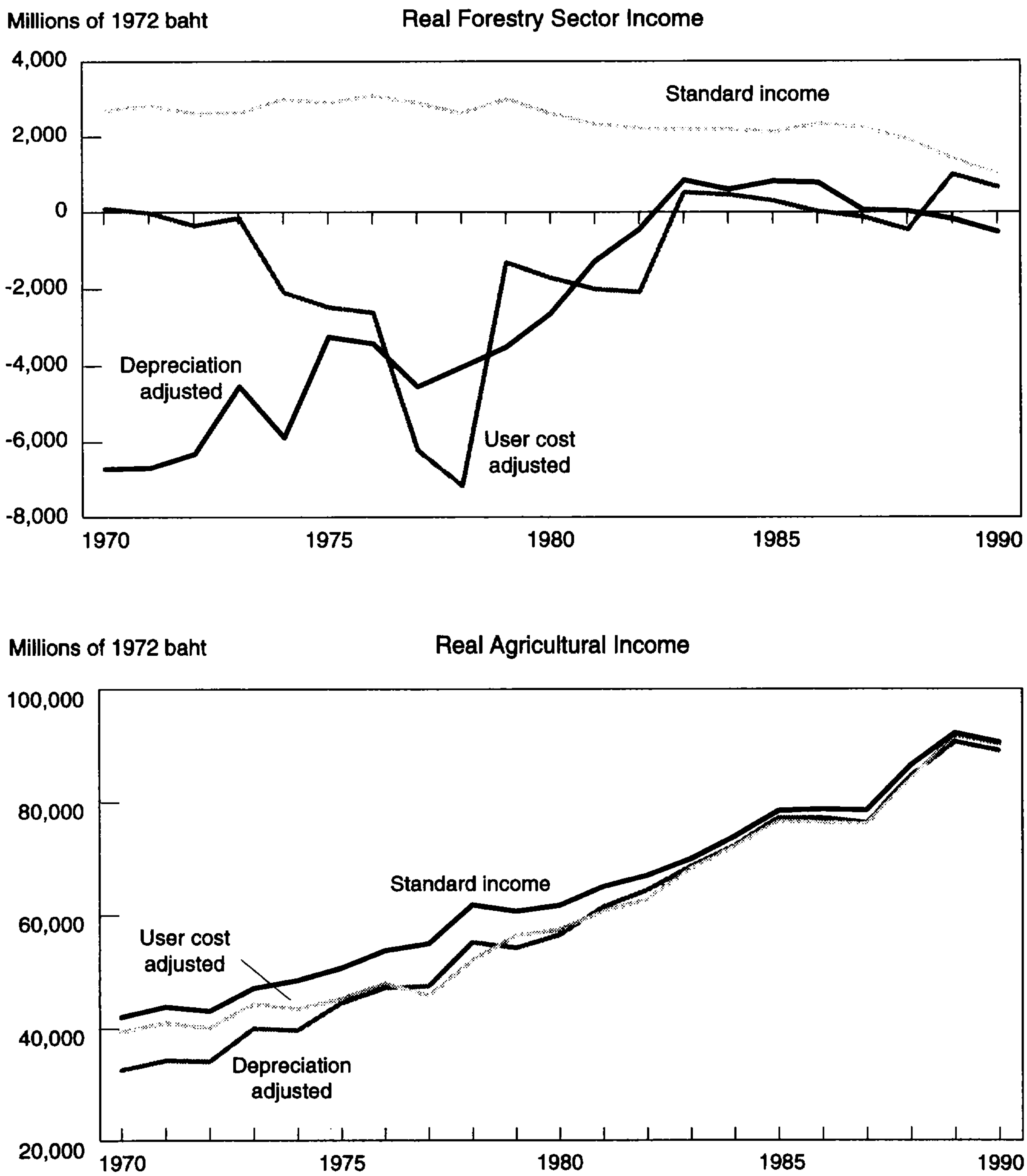
ply have been squandered for fleeting agricultural gains (see figure 2.4).

THE LOGGING BAN. To examine the economic effects of the logging ban, two scenarios were projected to the year 1995: (a) assuming continuation of the current ban and (b) assuming that the ban had never been imposed. Comparison of the scenarios provides insights as to whether the logging ban has proven beneficial.

The forest depletion-adjusted income projections indicated that if enforcement were tightened the logging ban actually would lead to economic benefits rather than sacrifices and, at the same time, would further the original goal of preserving the environment. The two accounting approaches applied in this study, however, differed in their implicit evaluation of the logging ban. While the user cost adjustments showed the ban to yield net economic gains, the depreciation approach captured changes in wood volume and demonstrated that stricter control of wood removals is required to economically balance forestry income that is forgone under a logging ban (see figures 2.5 and 2.6). Changes in wood volume (which drive the depreciation methodology in this study) appeared to be more revealing than forest area losses (the basis of the user cost adjustments) because forest densities declined markedly over the period examined and were not reflected in measurements of forest area.

Results of the user cost adjustments to forestry income recommend continuation of the current logging ban. The ban has led to considerable decreases in forest area loss and, therefore, decreases in user cost deple-

Figure 2.4 Real forestry and agricultural income, standard and forest-depletion adjusted, 1970–90



Note: These graphs report income for Thailand's forestry and agricultural sectors, calculated by three methods: the standard national accounting measure, the user cost-adjusted income, and the depreciation-adjusted income. The first graph suggests that when resource depletion costs are incorporated, the forestry sector has often had significant income loss. The second graph shows a steady increase but not the jump in agricultural income that would be expected had the land cleared during the rapid deforestation of the 1970s been converted for productive cultivation.
Source: NESDB, various years; Sadoff 1992b.

tion penalties. The value of this forest area savings outweighed losses in recorded forestry GDP, making a continued logging ban the highest income scenario. An enforcement level of 80 percent, in forest area terms, was required to achieve net economic gains following the user cost approach.[28] The current ban has decreased forest area losses by 86 percent, hence its recommendation by the user cost analysis.

The depreciation-adjusted income projections, however, recommend a different policy ranking. While the ban has produced environmental gains, enforcement must be tightened in order to yield economic benefits as well. An enforcement level of 50 percent, measured by commercial wood volume losses, was required to balance forgone forestry income and produce positive depreciation-adjusted incomes. The current ban, however, has achieved only a 26 percent decline in commercial wood volume removals, thus creating net economic losses when depreciation adjustments are made.

Thailand's logging ban has slowed deforestation, but depreciation adjustments show that forest savings have not been sufficient to achieve the net economic gains that could also be realized by the ban. This result should not necessarily be interpreted as a recommendation to repeal the logging ban. Given a societal goal of forest conservation, this analysis illustrates the fact that economic gains could be achieved at the same time if forest protection were more effective.

Both methodologies revealed that positive depletion-adjusted forestry incomes are attainable in Thailand. Between 1970 and 1990 an average of just 43 percent of the potentially salable commercial wood removed from the forest was sold in formal markets and hence contributed to recorded forestry sector income. By tightening enforcement of the pre-ban forest protection statutes to control losses of unmarketed wood, it should therefore be possible to maintain pre-ban levels of forestry sector income, while at the same time reducing wood volume losses by nearly 60 percent.

Comparison of methodologies

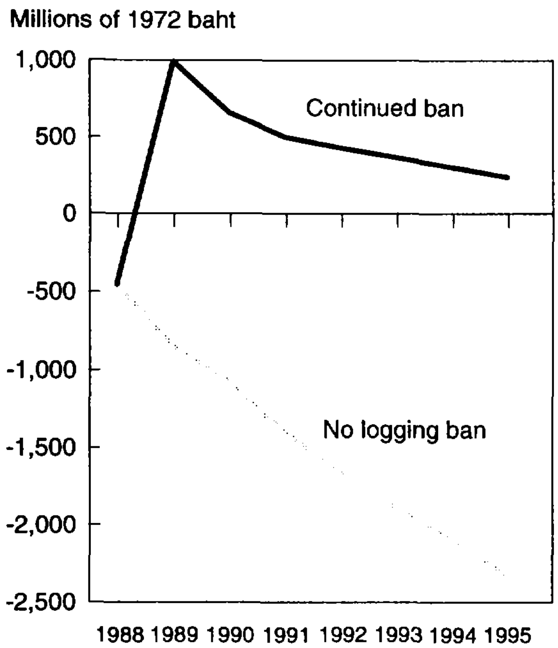
The two valuation methodologies produced forest depletion adjustments of the same order of magnitude, following roughly the same trends. Divergences occurred, however, both in the size of the penalties and in the policy implications of the adjusted income series (see figure 2.7).

CONTRASTING RESULTS. In the early 1970s forest depletion penalties calculated using the depreciation methodology were much higher than user cost–depletion penalties. As a result depreciation-adjusted forestry income was significantly lower than user cost–adjusted income. After the early 1980s, however, user cost–calculated penalties exceeded depreciation penalties (see figure 2.7).

Perhaps the most obvious divergence in the results of the two methodologies is that they differed in their implicit assessment of Thailand's logging ban. Following the 1989 ban, user cost–adjusted forestry sector income was positive. Projections showed that forestry income earnings under a continued ban would exceed those estimated assuming the ban had never been imposed (see figure 2.5). Depreciation adjustments yielded the opposite conclusion. Depreciation-adjusted forestry sector incomes were negative and projected to be lower with a logging ban than without (see figure 2.6).

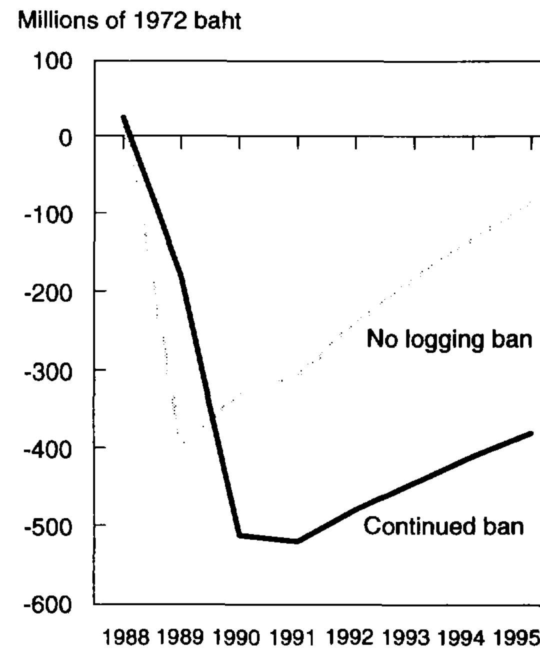
SOURCES OF DIVERGENCE. The major differences in the results of the two methodologies arise from the fact that the user cost calculations performed in this particular application are based on forest losses measured in *area*, while the depreciation approach specifically measures the *volume* of commercial wood lost. The density, or wood volume per unit area, of Thailand's forests has declined nearly continuously since the 1970s. Thus, in the earlier years, changes in forest area led to proportionately larger changes in wood volume. Furthermore, densities in this study were

Figure 2.5 Comparison of user cost-adjusted forestry income with and without logging ban, 1988–95



Note: The projected user cost-adjusted forestry income suggests that the logging ban has been economically beneficial.
Source: Sadoff 1992b.

Figure 2.6 Comparison of depreciation-adjusted forestry income with and without logging ban, 1988–95



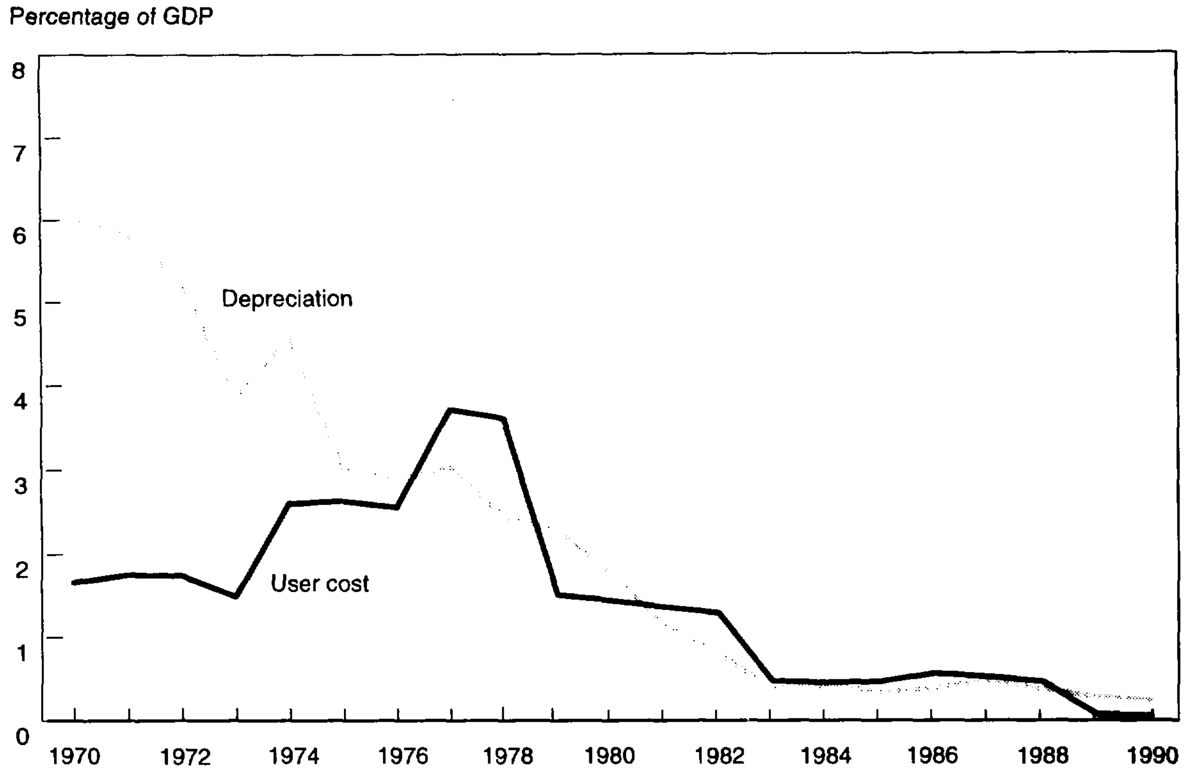
Note: The projected depreciation-adjusted forestry income suggests that no logging ban would be more beneficial economically.
Source: Sadoff 1992b.

modelled to be directly related to forest area losses. The rapid rates of deforestation in the 1970s therefore led to more rapidly declining forest density estimates, and both served to increase calculated volume losses and hence depreciation penalties (see figure 2.8).

The difference in penalties in the early 1970s is intuitively appealing because the depreciation approach charges the value of the forest product against income, while the user cost approach subtracts the cost of forest replacement. The gap in penalties therefore shows the difference between the value and the cost of forest wood. The difference in part represents the opportunity cost of capital over the forests' maturation period. Reforestation costs for the full growing cycle are discounted to the period in which deforestation and initial replanting occur, reflecting the portion of that period's income that would be required to renew the forests. Depreciation costs, on the other hand, are measured when mature forests are harvested.

In the early 1980s, however, user cost penalties grew larger than depreciation penalties. Depreciation penalties declined because the forest areas cleared in the 1980s supported far less commercial wood volume. User cost penalties remained tied to the costs of replanting deforested areas, regardless of how sparsely forested they had been. User cost penalties were thus unaffected by falling forest densities and continuously affected by ever-rising labor costs.

Figure 2.7 Forest resource depletion penalties, 1970–90



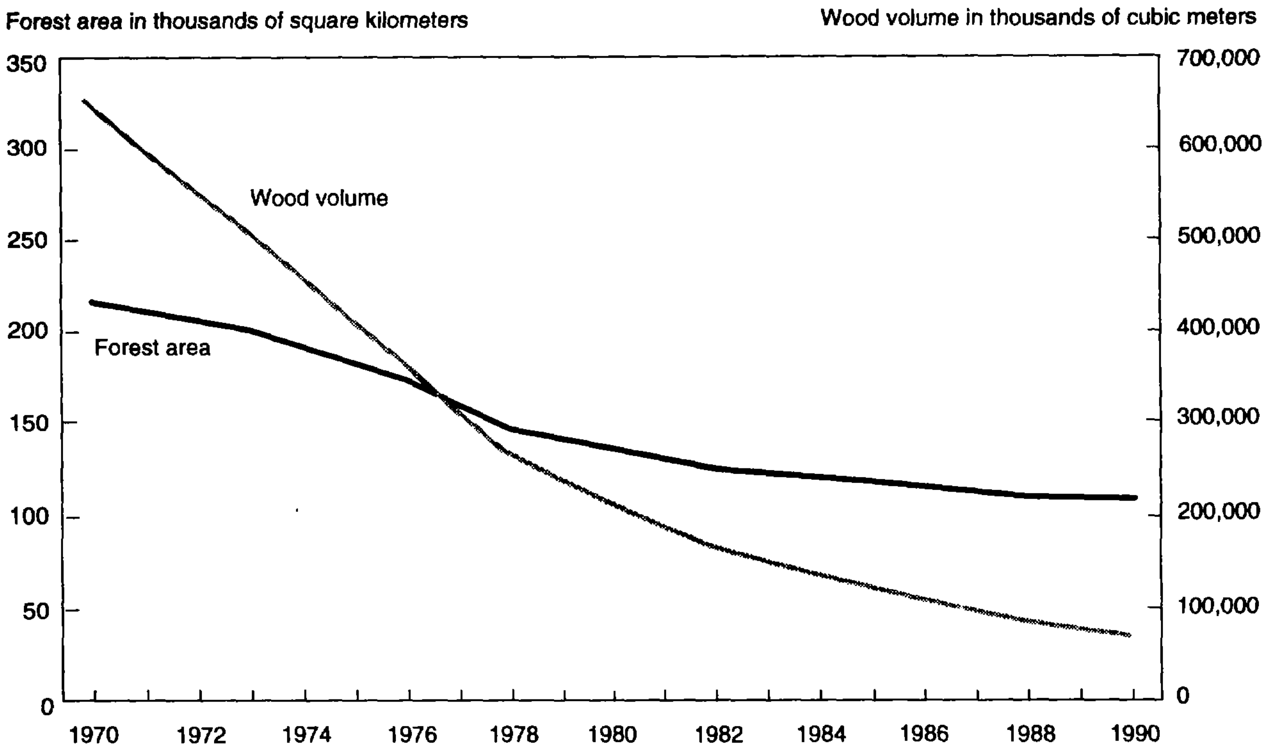
Note: The penalties are charged against standard measures of forestry income to calculate resource depletion-adjusted incomes. In the early 1970s, depreciation penalties were considerably larger than user cost penalties because the forests' commercial wood volume per hectare—from which the depreciation penalties are calculated—was much higher.
Source: NESDB, various years; Sadoff 1992b.

POLICY IMPLICATIONS. In the context of Thailand's logging ban, the user cost and depreciation methodologies produced different policy recommendations. This divergence, again, follows from the area/volume distinction. The user cost approach, here calculated on the basis of forest area savings, showed the ban to produce economic as well as ecological gains. The depreciation approach, calculated on the basis of wood volume losses, suggested the ban was not economically beneficial. While the logging ban has been 86-percent effective in curtailing the loss of forest area in Thailand, it has been able to save only 26 percent of commercial wood volume loss (see figure 2.9).

The ban severely restricts recorded forestry income, regardless of its effectiveness in forest protection. Depletion penalties, however, are calculated in proportion to actual forest savings. User cost calculations showed forest area savings to be of greater value than forgone forestry income, hence the positive user cost–adjusted incomes. Forest savings in terms of commercial wood volume were considerably lower and did not outweigh forgone income. Depreciation-adjusted incomes were therefore negative. If, however, the logging ban were more strictly enforced and achieved at least a 50-percent decrease in commercial wood volume losses, it would produce depreciation-adjusted net economic gains.

The explicit accounting of volume changes in the depreciation methodology called attention to important facts about the

Figure 2.8 Forest area and wood volume, 1970–90



Note: Wood volume is measured in hoppus terms; only the commercially marketable portion of standing wood is recorded.
Source: RFD, various years; Sadoff 1992b.

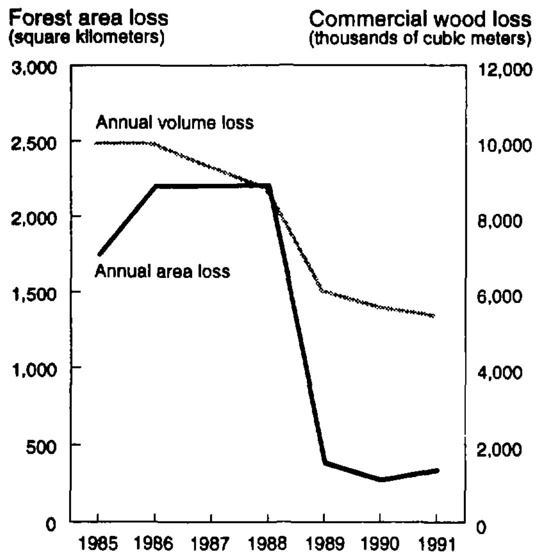
logging ban's enforcement that were not reflected in the user cost analysis.[29] Effective forest protection in Thailand clearly has been extended only to those areas in which logging is least profitable. Continued illegal logging in Thailand's most dense, commercially valuable forests has led to unintended and unnecessary economic and ecological damages.

Conclusions and recommendations

Parallel applications of the user cost and depreciation methodologies were used to compare the practical strengths and weaknesses of the two techniques and to assess the effects of Thailand's forest management. Both methodologies suggested that standard GDP calculations overstated Thailand's national income by failing to account for forest depletion. The user cost methodology suggested that real GDP was overstated by an average of 1.5 percent annually, while the depreciation adjustments found GDP inflated an average of 2.2 percent. Gross capital formation was found to be inflated by 6.4 percent according to the user cost method and by 9.5 percent with the depreciation method.

The user cost analysis found the ban to be both ecologically and economically beneficial, while depreciation adjustments suggested that forest protection was not sufficient to reap net economic gains. This divergence, however, is not so much a result of differences in the theories themselves but rather of data choices in their application.

Figure 2.9 Annual forest loss, 1985–91



Note: Wood volume is measured in hoppus terms and is adjusted to account for commercial species only.
Source: RFD, various years; Sadoff 1992b.

The depreciation penalties are based on losses in commercial wood volume, losses that have slowed only 26 percent since the logging ban. The basis of the user cost penalties is forest area, and the ban has successfully slowed those losses by 86 percent. If the ban were more strictly enforced, and commercial wood volume losses were curtailed by 50 percent, the depreciation adjustments would also show both significant economic gains and forest preservation.

To protect the country's remaining forests, and at the same time provide economic benefits, Thailand's logging ban must be significantly tightened. If enforcement were stricter, however, Thailand's demand for imported timber would rise. Increased demand for timber imports would contribute both to further increases in logging elsewhere, most likely overwhelming any regionwide ecological gains, and to rising log prices, which would erode the economic benefits of the ban in Thailand. Funds and energies might be better spent on the design and implementation of truly sustainable forest logging policies in combination with more effective protection programs.

The Thailand case study highlighted the difference between the two resource accounting techniques. The depreciation approach, by examining wood volume, revealed information that was crucial for a thorough policy evaluation and that was not captured by the area data used here in the user cost analysis. The divergence in the rates of forest area and wood volume decline that is highlighted by the choice of area data in the user cost analysis and volume data in the depreciation analysis, in turn, leads to the differences in the policy rankings of the two techniques.

Predictably, the more-specific data provided more-complete information. The apparent discriminatory superiority of the depreciation approach in this case might simply be interpreted as a recommendation for calculating market proxy values as specifically as possible. The limited availability of data will always pose difficulties, at least until clearly established methodologies provide incentives to gather and standardize such information.

On a theoretical level, the user cost approach appears the more defensible. The modification of national income accounts following a user cost approach would bring the system more closely in line with proper economic definitions of income and capital consumption. It would separate the cost of environmental disinvestment from value added and income. The depreciation methodology would not.

The best approach might therefore be to construct user cost penalties on a wood volume basis—to charge against current income the cost of replanting the *volume* of wood lost in each accounting period rather than the area of forest lost. Presumably this would capture the same trends in forest density that are reflected by the depreciation penalties in this study. The species and spacing specifications for reforestation could be made in accordance with social preference.

Natural resource depletion adjustments show that resource-related incomes in the national accounts are relatively inflated and most probably unsustainable. Perhaps the clearest and most compelling lesson from this study, however, is the importance of standardizing the principles of valuation in natural resource accounting. If the costs and benefits of resource use policies can be prescribed by the choice of valuation technique, then natural resource accounting without a standardized valuation methodology cannot provide a consistent analytical framework for the economic evaluation of resource management.

Notes

1. Generally, the conversion of forest land to agricultural cultivation is believed to produce net income gains. In Thailand, however, deforestation has been so severe that marginal land conversion has been associated with net losses in agricultural sector income.

2. The costs of natural resource extraction may in part be captured by diminished land values. These costs, however, would not be charged against the revenues of the exploitive activities, whose incomes would therefore remain inflated.

3. Adam Smith wrote in his classic *Wealth of Nations* (1776), "The gross revenue of all the inhabitants of a great country, comprehends the whole annual produce of their land and labor; the neat revenue, what remains free to them after deducting the expense of maintaining; first, their fixed; and, secondly, their circulating capital; or what, without encroaching upon their capital, they can place in their stock reserved for immediate consumption, or spend upon their subsistence, conveniences, and amusements. Their real wealth too is in proportion, not to their gross, but to their neat revenue."

4. David Ricardo (1772–1823) and Thomas Malthus (1766–1834) were British economists who were concerned and wrote about issues of population growth, trade, and economic growth.

5. This was the era of the Corn Laws, when sliding duties prevented cheap imported grains from entering the English market. The effects of the duties were compounded by poor crop yields and the Napoleonic Wars to drive up commodity prices.

6. "Although the System is designed essentially for market economies in which prices are determined and resources allocated mainly by the interplay of market forces, it is otherwise intended to be theoretically neutral. It is not geared to any particular school of economic thought—Keynesian, neoclassical, monetarist, etc.... Economic theory does not always provide very clear criteria or guidelines, however, for implementation within the System. For example, the concept of income is not precisely defined in economic theory (UN 1990)."

7. Whether reinvestment actually occurs is irrelevant. The methodology is designed to isolate the portion of revenues which could be consumed without decreasing future income. Limiting consumption to this level is therefore a necessary, though not sufficient, step toward insuring nondeclining income.

8. The user cost approach argues that only a portion of the value of extracted resources needs to be deducted from the GDP to compensate for forgone future income, allowing Hicksian income to be recorded in the GDP.

9. In practice, non-commercial felling is generally ignored rather than prohibited.

10. The legal status of forest dwellers in Thailand is complicated by the fact that many farmed their land before legislation prohibited such activities. Various efforts are being made to grant land titles to forest dwellers.

11. In the absence of logging ban, the rate of deforestation is projected to decline. The effect of the ban therefore must be considered the actual decline in deforestation, less the decline expected in the absence of a ban. For details of the forest area and volume calculations reported here, see Sadoff 1992b.

12. The Thai pulp and paper industry is also insulated by its reliance on waste paper and nonwood pulp for fiber inputs.

13. The Khmer Rouge, the royalist Funcinpec party, and the noncommunist Buddhist Liberal Democratic party had challenged the ruling Cambodia People's Party since a Vietnamese invasion brought them into power in 1979.

14. The Supreme National Council (SNC) was the interim governing body established by the

Paris Peace Accord in 1991. Elections sponsored by the United Nations in May 1993 replaced the SNC with a constitutional monarchy.

15. It could be argued that this penalty be charged against agricultural income, as the majority of forest land is converted for agricultural purposes.

16. Labor requirements for reforestation were drawn from a detailed study of the employment effects of forest plantations by Tingsabadh (1989) and based on a ten-year profile for the establishment and maintenance of a mixed-forest plantation. A mixed plantation standard was used on the assumption that, though monoculture plantations have somewhat lower maintenance costs, mixed forests are closer ecological approximations of natural forests. In this study a mixed dipterocarp plantation was used as a model, though the choice of species actually planted would not be limited by this assumption. The ten-year cycle of planting and maintenance could be applied to most indigenous forest species in Thailand.

17. A conservative estimate of the cost of labor was calculated at the prevailing legal minimum wage, which varied by region until 1981. The minimum wage series was built on unpublished data provided by the Department of Labor and linear extrapolations where data were unavailable. Bangkok metropolitan wages, which are significantly higher than wages elsewhere in the country, were excluded because they do not apply to the labor pool from which reforestation projects would likely be staffed. The wages commonly paid to workers are often below the legal minimum, in which case actual labor costs might be inflated. The assumption of legal minimum wage for labor involved in replanting, however, could also be expected to understate total labor costs by not explicitly differentiating supervisory from labor wage rates, excluding any labor contracting costs which are common to the region, and ignoring any upward pressure in localized wages which might be created by such massive replanting schemes.

18. The deflator was taken from the National Economic and Social Development Board (NESDB), National Income of Thailand, various years.

19. For a mathematical proof of this assumption see Tropical Science Center and World Resources Institute 1991.

20. Forest area estimates were derived from published and secondary RFD data sources and were broken down by type using RFD surveys that delineate the four regional forest types. Proportions of the forest types for each region were interpolated between the two survey years and elsewhere assumed constant. The constructed forest area time series reflects the net changes in each period, by forest type and region.

21. Growth rates were assumed to be 2.5 percent for evergreen, 2.0 percent for mixed deciduous, 1.5 percent for dry dipterocarp, and 2.5 percent for pine forests.

22. Density measures were given in hoppus volume cubic meters per hectare. Hoppus volume is a measure of useable wood, roughly 79 percent of total log volume and 50-70 percent of total stem volume. Only those trees over 100 centimeters in girth at breast height were included in the volume inventories.

23. Unpublished data from the Forest Inventory Division, Royal Forest Department, 1991.

24. An exception to these comparisons is the case of pine forests. The estimated pine density, though it dropped by half since the second national inventory, was over three times higher than the RFD measurement for pine densities. Total pine area, however, accounts for no more than 1.5 percent of total forest area in any given year, and an overestimation of pine forest density will lead to a more conservative final adjustment of income by understating forest loss.

25. Extraction costs were estimated from benchmark year reports on the cost of forest log felling and removal. Transport costs were calculated in two parts. Estimates were first made for the cost of transporting logs from their roadside felling sites to sawmills. The rates charged for these transfers were higher than the standard transport rates because they travelled more remote and less well-kept road networks. Average distances between felling sites and sawmills were used for each region. The second component of transportation cost was the transfer of logs from sawmills to Bangkok. Stumpage values calculated from f.o.b. prices must include all of the costs required to deliver logs to the location at which import prices would apply, in this case Bangkok. Regional distances were determined by weighting the distance from provincial capitals to Bangkok, by each

province's sawmill capacity. Cost rates for standard highway trucking were then applied to find the cost of transfer from mills to Bangkok. Average costs and distances were taken from Hoamuangkaew and Intrachandra 1991.

26. This ratio was taken from *Accounts overdue: Natural resource depreciation in Costa Rica* (Tropical Science Center and WRI 1991) and has been corroborated by informal estimates of logging damage in Thailand.

27. For purposes of comparison, the depreciation penalty is subtracted from GDP rather that NDP in this section.

28. Simulations were performed to find the threshold level of enforcement at which net economics gain could be achieved under a logging ban. Scenarios were constructed assuming varying levels of ban enforcement, where the level of effective enforcement was judged to be the percent decline in deforestation below its expected trend.

29. It should be noted, however, that in this instance the difference in illustrative power of the two methodologies is largely a result of the variables chosen in their application rather than a consequence of the theoretical underpinnings of the two techniques.

Bibliography

Ahmad, Yusuf J., Salah El Serafy, and Ernst Lutz, eds. 1989. *Environmental Accounting for sustainable development*. Washington, D.C.: World Bank.

Bartelmus, Peter, Carsten Stahmer, and Jan van Tongeren. 1989. "Integrating environmental and economic accounts." Paper presented at the Twenty-First General Conference of the International Association for Research in Income and Wealth. Germany, 20–25 August.

El Serafy, Salah. 1990. "Natural resources accounting: An overview." Paper presented to conference of the Overseas Development Institute, London, England, 27–28 March.

———. 1989. "The proper calculation of income from depletable natural resources." In Jusuf J. Ahmad, Salah El Serafy, and Ernst Lutz, eds., *Environmental Accounting for sustainable development*. Washington, D.C.: World Bank.

El Serafy, Salah, and Ernst Lutz. "Toward improved accounting for natural resources and the environment." *Revista de Analisis Economico* 5(November): 33–44.

Forest Industries Organization (FIO). Various years. *FIO annual report* (in Thai). Bangkok: FIO.

Hicks, J.R. (1939). *Value and capital: An inquiry into some fundamental principles of economic theory*. Oxford: Clarendon Press (second edition 1946).

Hoamuangkaew, Wuthipol, and Prakong Intrachandra. 1991. "The structure of sawmilling industry and sawnwood markets in Thailand." Paper presented at the Thai Forestry Sector Master Plan Seminar, "Demand for industrial forest products and roundwood in Thailand up to year 2015," Bangkok, 25 November.

Inter-Secretariat Working Group on National Accounts. 1990. "System of National Accounts (SNA) review issues." Paper presented at the 1990 Regional Commission Meeting on SNA, United Nations Statistical Office, New York, February.

Lutz, Ernst, and Salah El Serafy. 1988. *Environmental and resource accounting: An overview*. Environment Department Working Paper 6. Washington, D.C.: World Bank.

MIDAS Agronomics Company, Limited. 1991. *Study of conservation forest area demarcation, protection, and occupancy in Thailand*. Bangkok: MIDAS Agronomics Company, Limited.

National Economic and Social Development Board (NESDB). 1991. *Summary: The seventh national economic and social development plan (1991–1996)*. Bangkok: NESDB.

Onchan, Tongroj, ed. 1990. *A land policy study*. Bangkok: Thailand Development Research Institute.

Panayotou, Theodore, and Chartchai Parasuk. 1990. *Land and forest: Projecting demand and managing encroachment*. Bangkok: Thailand Development Research Institute.

Repetto, Robert. 1990. "Integrating natural resources and environmental accounting into the national income accounts." Paper presented at the Workshop on the Economics of Sustainable Development. Washington, D.C., 23–26 January.

Richards, John, and Richard Tucker, eds. 1990. *World deforestation in the twentieth century*. Durham, North Carolina: Duke University Press.

Royal Forest Department (RFD). various years. *Forestry statistics of Thailand*. Bangkok: Forest Statistics Subdivision, Planning Division, RFD.

Sadoff, Claudia W. 1992a. "The importance of accounting for natural resource accounting approach." TDRI *Quarterly Review* 7(June):18–24.

———. 1992b. "Natural resource accounting: A case study of Thailand's forest management." Doctoral dissertation submitted to the University of California at Berkeley.

———. 1991. "The value of Thailand's forest." TDRI *Quarterly Review* 6(December): 19–24.

Smith, Adam. (1776). *An inquiry into the nature and causes of the wealth of nations*. New York: Random House (reprint edition 1937).

Thai Forestry Sector Master Plan. 1992. "Forest plantation development." Working draft 3. Bangkok: RFD.

———. 1991. "Markets for industrial forest products and roundwood in Thailand." Paper presented at Thai Forestry Sector Master Plan Seminar, "Demand for industrial forest products and roundwood in Thailand up to year 2015," Bangkok, 25 November.

———. 1991. "Forest inventory team working document," Bangkok.

Thammincha, Songkram. 1982. *Thailand's forest resources data*. Bangkok: Food and Agriculture Organization.

Tingsabadh, Charit. 1989. *Employment effects of reforestation programs*. Bangkok: Thailand Development Research Institute.

Tropical Science Center and the World Resources Institute (WRI). 1991. *Accounts overdue: Natural resource depreciation in Costa Rica*. Washington, D.C.: WRI.

Tuammali, Thaveep, and Wuthipol Hoamuangkaew. 1987. "Economic of *Casuarina junhuhniana* plantation in Changwat Chachoensao." *Thai Journal of Forestry* 6(2): 134–145.

United Nations (UN) Secretariat. 1991. *Revised system of national accounts: Draft chapters and annexes*. Provisional ST/ESA/STAT/SER.F/Rev.4. New York: UN.

United Nations Economic and Social Commission for Asia and the Pacific (ESCAP). 1990. *State of the Environment in Asia and the Pacific*. Bangkok: ESCAP.

Ward, Michael. 1982. *Accounting for the depletion of natural resources in the national accounts of developing economics*. Paris: Organization for Economic Cooperation and Development.

World Resources Institute (WRI). 1988. *World resources 1988*. Washington, D.C.: WRI.

3

Forestry Policies in India

Arnoldo Contreras-Hermosilla

Introduction

Government policy has intense and lasting impact on forest resources management and conservation. Taxes, subsidies, technical assistance, terms of forest concessions, administered prices, controlled transportation of forest goods, limits to private ownership of land, tariff and non-tariff barriers to international trade, all affect economic motivations and the management and conservation of forest resources. Unfortunately, available evidence in various countries suggests that in many cases—and despite good intentions—government policies have generated unintended negative effects on forest management and conservation.

The policies in Indonesian, for instance, that were intended to promote industrialization by banning the export of logs proved instead to be economically very costly and have not necessarily promoted better forest management and conservation (Repetto and Gillis 1988). The policies for developing agriculture in the Brazilian Amazon have clearly been one of the main causes of deforestation and degradation in that region (Mahar 1989). The logging ban in Thailand appears to have had limited effect on reducing the rate of deforestation—and instead may have caused illegal fellings and illegal trade to increase (see chapter 2). In Costa Rica, incentives to encourage reforestation and forest management have been not only very expensive but also unnecessary and have resulted in negative equity. And by increasing the financial profitability of plantations, they often accelerate conversion of the biodiversity-rich natural forest. Costa Rican policies on livestock, agriculture and trade have compounded these problems by generating biases against forestry investments and thus inducing conversion of forest land to economically and environmentally inferior uses (World Bank 1993). In most of these cases, the results were totally opposite the original intent of the policies, and the pervasiveness of such negative effects justifies giving greater attention to the policymaking process itself.

In India, forests are mainly the property of the state and are directly managed by the government or are given in usufruct to communities under a variety of arrangements. Trees are grown under private ownership only on farms or community lands. This chapter analyzes selected aspects of government policy and its effect on the management of private lands and on the private management of public lands. It focusses on policies directly related to the forestry sector, although policies designed primarily to influence other sectors such as industry, livestock, and infrastructure also have an important impact on the management of forest resources. After identifying the main policy failures and their plausible causes, the chapter proposes various options to guide future development.

Overview of problems

Indian forest resources are under immense pressure from a large population of 850 million people. While 90 percent of forests are owned by the government, local populations make intensive use of all forests, public and private, for everyday needs for building materials, agricultural implements and fuelwood. Forests are also extensively used for grazing. They are of particular importance for the subsistence of the poor living in or around them and for tribals, who are about 8 percent of the Indian population.

These various and intense demands have resulted in heavy degradation. Only about half of the forest area has a crown density of 40 percent or more, and in many places the forest cover has completely disappeared. There are only 8 hectares of forest per 100 people in India, as compared with 90 hectares in Indonesia and 120 hectares in the United States. Unless effective action is taken in the next few decades to change this negative situation and these trends, further environmental degradation will result, leading to losses in agricultural productivity and deprivation for the poor.

Because pressure on forest resources in India is very high, it is impossible to conserve and manage forests without the active participation of the local people. Thus, government policies that affect farmers and local communities—including taxation, subsidy systems, and incentives—are of paramount importance.

The impact of government policies

Policies for promoting farm forestry

The main efforts of the Indian government toward promoting private tree planting have related to the Social Forestry Program. Although these policies were originally designed to increase tree planting on underproductive non-forest government and community lands, greater importance was soon accorded to "farm forestry," whereby farmers were encouraged to plant trees on their own land.

Incentives have included subsidized seedlings, extension services, and outright monetary rewards for the survival of plants in private plantations. These incentives were aimed mainly at increasing profits and reducing uncertainty, cash flow difficulties, and problems caused by inadequate knowledge. Table 3.1 lists some of the most common of the incentives targeted to problems in the farm forestry.

Policies for the promotion of farm forestry emphasized different issues from state

Table 3.1 Main incentives in farm forestry

	Primary target			
Incentive	*Knowledge*	*Profits*	*Cash flow*	*Uncertainty*
Research and analysis	x			
Extension and education	x			x
Subsidized seedlings		x	x	
Land tenure security			x	x
Subsidized credit		x	x	
Marketing infrastructure	x	x		
Crop insurance		x	x	x
Simple laws regarding harvesting and transport of forestry products		x	x	x
General forest protection		x		x
Infrastructure		x		
Consolidation of landholdings		x	x	x

Source: World Bank data.

to state. Monetary incentives related to the survival of plants were provided in Bihar and Orissa but not in the states supported by World Bank or USAID projects. Extension workers were appointed in Andhra Pradesh, Tamil Nadu, West Bengal, Madhya Pradesh, Bihar, and Orissa but not in the northwestern states. To support the farm forestry program, a separate Directorate of Social Forestry was created in Maharashtra, but in other states the program was supervised by the existing Forest Department. In some states (Uttar Pradesh, for example), private nurseries were granted a certain amount of money (about Rs 0.40) for each seedling raised, and private producers were free to sell them in the open market. In many other states where the government was distributing free seedlings and no private market existed, a buy-back arrangement with private nurseries was promoted whereby the Forest Department would buy seedlings and plant them on public lands or distribute them to farmers. It was assumed that farmers would react to these various incentives by planting trees on homesteads or farm boundaries primarily to meet their immediate requirements for fuelwood and other rural uses of wood and would thus reduce pressure on public forest lands.

The initial success of the farm forestry program in some states—notably, Gujarat, Uttar Pradesh, Haryana and the Punjab—generated great enthusiasm and the belief that government policies had been highly effective in promoting tree planting. However, this optimism was short-lived. With some exceptions, the farm forestry program was confined to the more prosperous and technologically advanced regions and made little impact on the vast subsistence areas of India. Even in some regions where the program had been successful in the early 1980s, it could not be sustained beyond 1986–87. Except in a few areas, government policies were generally not successful in promoting sustainable farm forestry.

In areas where the program did succeed, however, the initial response was spectacular and exceeded the most optimistic expectations. In one year alone, farmers in Gujarat planted as many as four times the total planted before the program started. In Uttar Pradesh, the supply of seedlings grew from the originally planned 8 million to 350 million during 1979–84. According to internal World Bank data, in Haryana, the area under trees grew at an incredible 53 percent per year between 1975 and 1984. In these areas farm forestry was celebrated as an unqualified success and as an example of effective government action.

However, after this spectacular initial boom, farmers' interest declined sharply. The search for explanations of the success and eventual decline of the program suggests that tree planting was to a great extent coincidental with, more than the result of, government incentive policies. The prevailing market conditions in different regions—not government policies, despite their visibility—seem to have been the key factor in stimulating tree planting and in determining its subsequent decline. An examination of some of the common incentives shows how this could happen.

One of the main incentives the government has provided is the *seedling subsidy*. To foster private tree planting, seedlings were distributed by the government either free or at a very low price. The government effort in this respect was not insignificant: during 1985–89 the total number of seedlings distributed under the farm forestry program in India was on the order of 1.4–2.0 billion a year (enough to plant 560–800 thousand hectares) at an annual cost of about Rs 700–1,000 million (US$50–65 million) (Chambers, Saxena, and Shah 1989). However, the incentive does not appear to have operated for more than a short period of time. For example, in Uttar Pradesh when brisk demand caused a shortage of government seedlings in 1981–86, private nurseries sprung up to cope with the demand and sold seedlings at up to ten times the official—subsidized—price. And after 1986, when farmers' enthusiasm for planting eucalyptus in the northwestern states declined and the Uttar Pradesh state government started distributing free seedlings, planting did not resume.

The government also sought to stimulate planting by increasing the *number of nurseries* and thus make seedlings available locally to all farmers. During the first phase of the program (1982–86), the number of government nurseries expanded substantially through an ambitious "decentralized nurseries scheme." However, soon many nurseries had to be closed down for lack of demand. Those that survived did so only because they supplied the seedlings to government plantations and thus had a captive market. It therefore appears that increasing the local availability of seedlings did not encourage private planting either.

Another instrument—*extension services*—also seems to have had a limited impact on farmers' decisions to invest in tree planting. For example, government extension expenditures and infrastructure in the northwestern states was almost nonexistent, but farmers enthusiastically planted trees, nevertheless. By contrast, in states such as Bihar and Orissa where a large number of "motivators" were appointed and where ecological conditions were more favorable to trees than in the semi-arid western and northern India, the tree planting program was a comparative failure.

These examples show that other factors—not government incentives—probably played a more determining role in decisions on private forest investments. And the degree of success likely depended on the very different economic conditions of farmers from commercial and subsistence regions. Also, success depended on the effect of various restrictive policies—as opposed to incentive policies—that dominate the Indian forestry scene.

POLICY IMPACTS IN COMMERCIAL REGIONS. The tree planting program in India initially achieved a high level of success in the regions characterized by commercial agriculture—in the northern states of Punjab, Haryana and Western Uttar Pradesh and the southern and western states of Gujarat, Maharashtra, Andhra Pradesh and Tamil Nadu. In these states, financial profit appears to have been a major motivation for farmers to participate in farm forestry plantings. Thus, in contrast to the official expectation that trees would be planted to satisfy household needs for fuelwood, farmers instead planted trees for the market and for profit.

That financial profitability was paramount in farmers' minds is illustrated by a survey in Gujarat in which 51 percent of the farmers said they planted eucalyptus because it was more profitable than annual crops; 35 percent said they planted trees because agriculture was becoming uneconomical and risky; and another 10 percent preferred to plant trees because of labor shortages (Saxena 1991). Thus, a full 96 percent of the trees were planted for reasons related to the market or profitability.

In fact, profitability during the first years of the farm forestry program was generally high. According to ten case studies in Andhra Pradesh, Maharashtra, Tamil Nadu, and West Bengal, profitability for farm forestry investments ranged from 14 to 55 percent (see table 3.2). The profitability levels tended to be highest in areas of high productivity and an intensely commercial orientation. In such areas most investments in farm forestry took place only when agricultural prices were depressed and when the rapid expansion associated with the "green revolution" had led to high wages and low unemployment. Under these circumstances, forestry investments were comparatively attractive financially. The seedling subsidy appears not to have had an important effect on profitability rates, and it therefore probably had little to do with planting decisions.

Strengthening this argument is the fact the although initial studies showed the seedling subsidy to cause an increase in total profitability by 2–7 percentage points (as shown in table 3.2), they assumed comparable quality in the subsidized seedlings and the seedlings from commercial nurseries—when in reality the seedlings were

Table 3.2 Levels of profitability and the impact of seedling subsidies in ten case studies

Model	*Financial rate of return (%)*	*Financial rate of return with subsidy (%)*	*Seedling cost as a percentage of total cost during first year*
West Bengal, farm forestry, rainfed areas	21	28	36
South West Bengal, multi-tier reforestation, degraded lands	21	23	20
Maharashtra, bamboo plantations on bunds, irrigated lands	38	42	37
Maharashtra, eucalyptus plantations, rainfed areas	25	28	23
Maharashtra, multi-species plantations, rainfed areas (up to 45% slope)	16	18	24
Maharashtra, plantations, degraded lands	14	18	23
Andhra Pradesh, group farm forestry	14	17	40
Andhra Pradesh, fruit gardens	55	62	32
Andhra Pradesh, rehabilitation of degraded forests	15	17	31
Andhra Pradesh, viable rootstocks and gap planting	20	21	22

Note: These rates of return assume that the quality of the subsidized seedlings is comparable to that of seedlings from private nurseries.
Source: World Bank data 1993.

quite different. The subsidized seedlings were *notably inferior* to those produced in private nurseries, and it must be assumed that the respective yields of plantations would be different. The net effect on financial profitability of using subsidized seedlings—considering both lower prices but also lower final yields—would probably be negative in most cases.[1]

The subsidized seedling policy alone, therefore, provided little or no incentive to plant trees. However, statistics show that farmers did use subsidized seedlings in many cases, and in view of the analysis above, the question is, why? A plausible reason may be simply that many of the farmers could not raise the needed cash to purchase superior seedlings from private nurseries. In fact, as seen in table 3.2, the cost of seedlings generally was a substantial proportion of planting costs in the first year.

Another feature of highly productive, commercial areas was that the new agricultural varieties associated with the green revolution required intensive management and close supervision of farming activities. Land in these areas also became more valuable and therefore the risk of illegal occupation grew. Many absentee landowners planted trees to discourage encroachers. Planting trees was merely a good way to keep squatters out at a relatively low cost, requiring only modest management inputs and sporadic presence by the landowner.

POLICY IMPACTS IN SUBSISTENCE REGIONS. In contrast with their record in commercial regions, farm forestry programs were successful in only a few subsistence areas of Karnataka and West Bengal. Success in the case of West Bengal *patta* holders seems to have been influenced by the fact that they were able to harvest and sell their trees without government restrictions rather than by government incentives. But in all other subsistence regions, the program did not succeed, compared to commercial regions, despite the greater government investments in subsidies, extension and staff.

The agrarian structure of subsistence regions in eastern India and tribal areas is characterized by heavy dependence on grain production, smaller holdings, low overall incomes, low marketable surplus, imperfect credit markets, more dependence on village merchants, interlocked credit and output markets, less monetization, less diversity of rural incomes, greater debt bondage, a less-developed infrastructure for supplying agricultural inputs, greater insecurity of land tenure, and, on the whole, scarce technical and managerial expertise. These conditions lead at best to low-intensity tree growing for home consumption and are not conducive to market-oriented strategies.

Furthermore, although the technical failures certainly were not exclusive to subsistence regions, their effect was more dramatic on the poor living in those areas than on the relatively affluent farmers living elsewhere. The low quality of seedlings supplied by the government has already been mentioned. But other technical failures were also manifested. For instance, in the tribal areas of Andhra Pradesh and central India, the favorite tree of farmers was the *mahua*, but the Forest Department did not have the technology for large-scale propagation and regeneration of the species. Much of peninsular India is semi-arid and characterized by intense competition for moisture between crops and trees, but—with the exception *khejri* (*Prosopis cineraria*) in Rajasthan's arid zone—species of complementary crops and trees still need to be identified. While farmers in subsistence regions have identified several traditional agroforestry practices in which tree growing is complementing to agricultural production, the farm forestry program emphasized technologies involving short-rotation trees that tend to compete with annual crops. In the hills of Uttar Pradesh where trees play a very important ecological and subsistence role, there was no emphasis on agroforestry in the government's program; it concentrated instead on departmental plantations on public lands. Often, interagency rivalry also contributed to the lack of success. Agroforestry has been ignored in the past by both the Agriculture and Forest Departments of the government because of competition for land. Monocropping, to the exclusion of intercropping, is preferred by both departments.

In addition, promoters of tree planting have often failed to fully understand the socioeconomic features and cultural patterns prevalent in subsistence areas. Villages in semi-arid regions are often spread over a large area and fields may be far away, making tree protection more problematic. The young trees planted under government programs need to be protected from cattle, but village livestock nonetheless are let loose to browse on agricultural residues and stubble. Despite ecological necessity and the easy availability of marginal and degraded lands, protecting young seedlings is more difficult in monocropped areas as compared to irrigated villages. Unlike a farmer's decision to plant annual crops, which can be made autonomously, the decision to plant trees has to take into account all of these variables—the herding practices of the village, availability of irrigation for double cropping, distance of the fields from his hut, and the cropping pattern of other farmers. Conditions outside the farm thus become as important as the simple costs and benefits of the preferred land use options. These considerations have not generally been understood by the planners of social forestry programs.

Furthermore, most of India's forests are located in areas of subsistence agriculture. In these areas, there are trees on forest and other public lands that are accessible to villagers. This open access to public lands substantially reduces the cost of obtaining tree goods for a gatherer, and is a powerful disincentive to grow trees.

SUMMARY OF IMPACTS OF PROMOTIONAL POLICY. In short, farmers, in both subsistence and commercial regions, have been motivated to invest in planting trees by a number of economic factors, and in most cases government incentives appear to have been only marginally important. The incentives policies seem to have been more coincidental with favorable market conditions than a truly determinant factor in inducing the farmers' response. In commercial areas planting took place when there was a relatively depressed agricultural market; it was undertaken mostly by relatively rich—often absentee—landowners who had a more-aggressive attitude toward risk and enough cash——or at least better access to institutional credit—to sustain longer periods without financial returns. Where poor farmers in subsistence areas were concerned, the inability to wait until trees matured, the relative difficulty in obtaining credit, the lack of dynamic markets, and the modest levels of financial profitability did not encourage planting in the same measure. As subsidies appear to have had a rather limited role is shaping total profitability of forestry investments, it is not surprising that they were not effective in determining the pace of farm forestry in India. As soon as market conditions deteriorated, the rhythm of planting slowed down irrespective of the intensity of government efforts.

Policies that create disincentives in farm forestry

In India, land and tree ownership can become very uncertain once trees are planted. According to an internal Bank report, "there is a widespread impression in the villages that if trees are planted on private lands, not only will the trees belong to the government, but land on which such plantation takes place may also revert to the government. . . .the fear is not baseless as the Bihar Private Forest Act and similar enactments did precisely this in the past by 'nationalizing' private trees." These provisions have also had very negative environmental effects because private individuals have indiscriminately harvested all trees that may be affected just before the acts became effective. In Maharashtra, for example, there was widespread and indiscriminate harvesting of trees on private lands just before the Private Forest Acquisition Act of 1975 was approved. This is a clear example of government policies having the opposite effect (excessive harvesting) to the intended objective (less harvesting).

Another frequent undesirable outcome is that when products from forest lands are marketed at subsidized prices through the state machinery, farmers find it difficult to compete with the state and make an profit. In Orissa, the growing of Eucalyptus on forest lands by the Forest Department was one of the reasons farmers were not motivated to grow commercial trees on their plots.

In most states of India, private individuals can cut trees on their land only after going through a cumbersome process to obtain government permits. In some cases even trees grown on private lands cannot be cut or sold without government authorization. Once trees are harvested, usually the farmer must get further authorization to transport products. The problem is often compounded by cumbersome bureaucratic procedures: in Tamil Nadu, for example, it often takes three months to get a transportation permit. Small farmers are most affected because they lack direct contacts with the market and thus must rely on traders who collect output from several producers often at exploitative prices. Since these traders are used to dealing with the police, they can handle the bribes and other "costs" of transporting the output to markets. Chambers, Saxena and Shah (1989) report that "transporters carrying fuelwood to Delhi have to pay Rs 500 per truck as 'on road considerations,' a euphemistic phrase for bribes."

In certain cases—such as in Himachal Pradesh—the farmer is compelled to sell forestry output only to the government, and this "privilege" can be exercised only once in ten years. The Himachal Pradesh Forest Corporation takes years to pay the agreed price. In Bihar, private wood must be sold to the state trading arm of the Forest Department.

Obviously, these restrictions discourage investing in tree planting trees and negatively affect total national forestry output and preclude the environmental benefits associated with planting trees. Furthermore, these regulations encourage corruption and discriminate against poor farmers who are less able to obtain the necessary permits on time and to deal with government officials (thus having a negative equity effect).

Policies that affect how rural people use public forest lands

Apart from attempting to foster farm forestry, the Indian government has also tried to regulate how rural populations use public forest lands. The poor in general, and tribals in particular, are highly dependent on products—fuelwood, construction materials, medicinal products, and food—obtained from public forest lands. Local people also use the lands for grazing their livestock. In many cases public forest lands provide the only form of subsistence, and in Andhra Pradesh, Bihar, Madhya Pradesh and Orissa, they are the main provider of household incomes (Khare, Rao, and Panda 1987). In Maharashtra, edible forest products such as leaves and vegetables, tubers, fruits, bamboo shoots, small animals and honey provide as much as one-third of villagers' diets and help bridge seasonal food shortages as their maximum availability coincides with the monsoon when the supply of grains begins decrease.

The interaction between the government and people in the utilization of public forest lands has been affected by numerous policy changes. Past government policy was predominantly oriented to generating forest raw materials for industry. Consequently, monoculture forests were favored over mixed-species forests. This policy deprived people of the livelihood goods that they used to get from mixed-species forests and exacerbated population pressure on the more-scarce products, hindering the regeneration of the forests. Also, the growing scarcity and higher prices caused more illegal harvesting. Thus, industrial support led in fact to negative equity and environmental consequences. In addition, because industrial supplies were sold to industries at below-market prices, the policy also resulted in misallocation of scarce natural resources and to opportunities for administrative malpractices in allocating government timber supply contracts. In Maharashtra, the state government supplied plywood logs at $131 per cubic meter while the market price was $442. Until recently, the same state government was selling bamboo to paper mills at Rs 115 per ton, while prevailing market rates were Rs 700–800, thereby subsidizing the industry by several million dollars yearly—an unnecessary subsidy as the industry was internationally competitive.

Another policy affecting the use of public forest lands by rural people has been the "nationalization" of the collection, processing, and marketing activities in schemes that are supposed to favor local rural populations. These nationalization schemes have been developed for tassar silk growing, pine resin tapping, and turpentine production in the Himalayan region; the collection and processing of *bidi* leaves in Madhya Pradesh, Orissa, Andhra Pradesh and Maharashtra; the harvesting of bamboo for the paper industry; and the collection of *sal* seed for fatty oils. The Forest Department in Maharashtra has handled the trade of *tandu* leaves since 1969, and the Gujarat State Forest Development Corporation has been directly involved in the collection of non-timber products since 1977. In Bihar, the Forest Department has traded in *tandu* leaves since 1973, and the State Forest Development Corporation has had a monopoly on the trade of oilseeds of tree origin (for example, *sal*, *mahuwa* and *kusum*). The Bihar State Cooperative Lac Marketing Federation organizes the processing and marketing of *lac*, and the State Cooperative Development Corporation handles the procurement and marketing of beans, *tassar* cocoons, and other products. In Orissa, *tandu* leaves are directly collected by the Forestry Department and marketed by the Orissa Forest Corporation.

However, despite these and numerous other attempts at organizing and rationalizing the collection, processing, and marketing of non-timber forest products from public lands, evidence shows that while these efforts have led to greater income for gatherers in some cases, the government often has benefitted even more. In other cases, while government revenues have increased over the years, income to collectors has remained low and often below subsistence levels (Gupta and Guliera 1982). Chambers, Saxena and Shah (1990) describe cases in Madhya Pradesh where tribals collected *sal* seeds for the state monopoly but received less than one-fifth of the total income generated—about one-half the revenues accruing to the government (45 percent) and contractors (36 percent). The nationalization policy has reduced the number of legal buyers and inhibited the free flow of goods, and because of the protracted bureaucratic procedures, has led to delayed payment to the gatherers. Often it has resulted in illegal sales and in increased corruption. Expanded government control, justified by conservation and equity objectives, also has had the unintended result of reducing local incentives for local management and conservation. Furthermore, bureaucratic procedures called for under the National Forestry Policy, such as the establishment of depots to supply the needs of local populations, encourage illegal harvesting and hinder proper conservation and management measures.

Access to forest lands has been restricted in other ways, with generally negative consequences not only for the poor but also for the sustainable management of forests. For example, on the recommendation of the National Commission on Agriculture, many states have transferred productive forest areas to Forest Development Corporations, which implement plantation programs and harvest forest produce mainly to supply industry. The access of local people to forest lands has thus been restricted, reducing their interest in preserving and managing the public forest resources. Although some programs for sharing in the forestry produce are in place, many have been tainted by corruption.

Other government policies create additional uncertainty. Joint management experiments between the forestry administration and local communities in the past have been unclear about the proportions to be shared, legal status of the local bodies, and length of the agreements. For example, sharing percentages are usually arbitrarily determined, and there is no way for the forestry administrators to tell whether or not they are sufficient for encouraging private action or whether they are excessive.

Reasons for policy failures

It is apparent that policy measures have failed in many cases. The measures intended to encourage private farmers to plant and manage trees have had limited effect. Policies intended to protect forest lands have instead tended to generate incentives for mismanagement of forest resources. But what is behind these negative outcomes? There are several plausible explanations.

First, policies generate a number of complex reactions that need to be analyzed in detail to understand their impact and avoid undesirable results. However, expertise for analyzing policy is scarce in the Indian government. In most cases observed, not even a preliminary assessment of the total impact of policies was carried out. The policymaking process has instead tended to focus on partial objectives without examining the trade-offs involved. Thus, policies with, for example, an environmental objective have been formulated without exploring their economic efficiency or equity impacts. Table 3.3 illustrates the diversified impact of various of the most-important policies implemented in India and the conflicts and trade-offs involved. Had a more-careful analysis of policy impacts been carried out, some of the undesirable results could probably have been avoided. This applies to policies developed for the forestry sector and, perhaps even more importantly, to policies in other sectors, many of which have a considerable impact on forest management, deforestation, and degradation.

Second, even if the necessary analytical capacity were in place, in many cases there is a host of unintended consequences that can seldom be accurately predicted at the time of policy design. Policies often interact in subtle ways. There is, for example, considerable skepticism about the real effects of restrictions on tree harvesting. These restrictions are likely to push the price of wood even higher and increase the incentives for illegal felling. The net effect may not be what was initially expected. The well-publicized case of diversion to non-fuelwood uses of the outputs of social forestry projects that had as a main aim the increase in the supply of fuelwood is a clear case of such hard-to-predict results.

Third, an effective policy framework can work only if there is adequate institutional structure and capacity for implementing it. This institutional capacity should include a system of incentives for forestry officials, particularly for field staff, to promote initiative, increase morale and reduce corruption. These conditions are mostly absent in the state forestry administration. For example, agency performance tends to be evaluated in terms of the achievement of physical targets rather than of actual development. Unrealistically ambitious planting targets forced Forest Departments to adopt strategies for high-density plantations, rather than to popularize low-input tree cropping models that would be complementary to agriculture. Seedlings that could be raised in short periods of time were given priority over easier-to-integrate multipurpose trees requiring longer periods at the nursery. Also, the pressure to produce large numbers of seedlings unquestionably led to poor quality. There currently is no institutional incentive to effectively involve rural people in forestry programs. Forestry Department officials have not been sufficiently trained in, or sensitized to the need for, adequately integrating peoples' concerns, values and constraints in planning forestry-related activities. Thus, while farmers in subsistence regions have developed several traditional agroforestry practices in which tree growing complements agricultural production, the farm forestry program has emphasized technologies involving short-rotation trees that tend to compete with annual crops.

The division of responsibilities between government agencies is not conducive to the effective implementation of multidimensional, integrated programs. Critical land issues have not been tackled by forestry policies that tend to provide prescriptions for forestry actions unrelated to a structured and comprehensive frame of reference for governing complex land use demands. Forestry policies have tended to be formulated in isolation from the broader land use issues. It is significant that when the public administration has been able to take action unconstrained by interagency boundaries, it has had success.[2]

Fourth, success in the programs has been hindered by technological and planning deficiencies. Less-than-adequate yields can be attributed to a great extent to low-quality seeds and poor nursery, planting and silviculture techniques. At other times, poor planning is clearly the problem. For instance, eucalyptus was introduced by the government in Rajasthan where there were

Table 3.3 Policy distortions affecting afforestation and forest management

Policy/Practice	*Economic impact*	*Equity impact*	*Environmental impact*
Supply of industrial raw materials from natural forests at subsidized, lower-than-market rates (contradicting the National Forest Policy, 1988).	Considerable loss of government income. Waste in industrial processing. Reduction of incentives for industrial reforestation and for proper forest management.	Large enterprises benefit the most. Non-industrial activities do not benefit at all. Government loses income. Farmers are deprived of profitable investment opportunities.	Excessive levels of cutting. Inadequate incentive for reforestation and consequent decrease in forest cover.
No natural forest is made available to industries even for the purpose of undertaking plantations (National Forest Policy, 1988).	Particularly, if poor natural forest had been replaced by highly productive plantations, policy reduces economic output. Increases in imports. Increased costs of industrial supplies due to dispersed nature of supplies.	Policy affects all industries, but mainly medium and large ones. It would benefit the poor if combined with policy to give local management rights to communities.	Policy has a generally positive impact.
Introduction of exotic species prohibited unless there is scientific evidence of no negative impact on native vegetation and environment (National Forest Policy, 1988).	Negative economic impact if exotics are more productive than native species.	Ambiguous impact depending on relative dependency of different income groups on exotics. However small farmers are unlikely to experiment with exotic species.	Ambiguous because no exotic species has exclusively negative or exclusively positive environmental impacts.
Limits to private ownership of land.	Difficulty in obtaining supplies for industrial processing in large quantities from block plantations. Loss of economies of scale.	Policy tends to avoid excessive land concentration and therefore discourages polarization of land ownership.	Due to small size of plots excessive fragmentation though inheritance is possible leading to intense land uses that may deplete land resources.
All forests property of the state.	An effective disincentive to investments in afforestation of private lands.	Policy affects land owners who may have otherwise engaged in rehabilitation of degraded private lands.	Policy promotes deforestation and generates disincentives to afforestation. Loss of forest cover.
Clear-felling restriction (National Forest Policy, 1988).	Loss of immediate and future economic output in cases where clear-felling may be the right silvicultural treatment. Loss of government revenue. Reduction of industrial supplies.	Negative effect on large industrial concerns dependent on large supplies from public forests. It may benefit private landowners if industries turn to them for supplies.	In some cases, positive environmental effect. In others, particularly when there is low forest cover that could have been replaced by richer natural or manmade regeneration, impact will be negative.

no markets for eucalyptus wood—no paper mill or other large buyer of eucalyptus—and where poles are generally imported from Haryana. Small farmers therefore found no buyers for their trees.

Fifth, an intractable problem seriously affecting the performance of government institutions is widespread bureaucratic corruption. To quote the National Development Council,

> . . .a considerable amount of public resources is already being spent on a variety of rural development and anti-poverty programs. But their impact and effectiveness are seriously compromised by the fragmentation of programs; contradictions and overlap among them;. . . .*the use of these programs as instruments of political patronage; their pre-emption by entrenched elites; and the pervasive leakages* [emphasis added]. These trends have to be reversed and distortions corrected (GOI 1990).

Conclusions

Managing the huge area of forest lands in India is obviously a major undertaking and policies aimed at solving problems are extremely complex. Policies will probably not be effective, therefore, unless they are applied in the right operational framework.

Given the complexity of the forestry situation in India, it makes sense to concentrate government action on those areas that are characterized by large discrepancies between private and societal costs and benefits or areas in which the government has a comparative advantage in organizing efficient action. Thus the government should give preferential attention to lands where environmental values are extremely important and where the market is not likely to generate actions leading to conservation. At the other extreme are lands that are well integrated with modern markets, where environmental values are not of major importance, and where the best land use is obviously a commercial-based activity. In these lands the government should strive for creating an environment conducive to private investment, letting market forces operate on the basis of economic merit and comparative advantage of activities.

Another important component of this framework is the provision of adequate technical packages for promoting profitable forestry production. A distinction should be made between forestry policies aimed at commercial production and those aimed at production for local consumption and for local markets. In the latter, innovative technical packages should focus on production of multiple outputs useful to rural people, rather than exclusively on wood. Grasses, leaves, legumes, wild fruits, nuts and other non-timber forest products should be an integral element in forestry incentive policies. For low-income communities, benefits from forestry programs start flowing as soon as possible. These technical packages should also allow, through increased diversification, for greater adaptation in situations involving risk.

There is also a need to integrate forestry incentive policies with agricultural and rural development policies. This need arises from the close linkages between forestry activities and other agricultural and rural development schemes, for example, in forestry, fodder production, livestock raising, and other agricultural activities. A proper design of incentive policies thus depends on systematic planning in light of these links with other sectors. It would appear that most states lack the necessary technical expertise to develop such integrated plans and therefore action should concentrate on providing the necessary technical assistance. International assistance projects should include provision for systematic policy analysis.

Forestry policies will not succeed without the participation of local people. This entails a clear understanding of people's objectives and constraints. Incentives designed in terms of paternalistic beneficiary-oriented schemes must be replaced in most cases by schemes that rely on participatory principles. Despite official rhetoric, effective participation has not been achieved except in a limited number of cases. Participation requires intensive retraining of forestry staff, a multidisciplinary approach to forestry actions and appropriate institutional incentives. NGOs can in some cases provide an effective input, and closer links with other agencies such as those in charge of tribal development would widen the scope of forestry projects and contribute to a better understanding of factors influencing participation and self-reliance.

There is an acute need to abolish restrictive regulations on property rights and on the harvesting, transport, and selling of trees to eliminate disincentives to planting those very species that are most valuable. A fear is often expressed that giving complete relaxation, especially in heavily forested states like Madhya Pradesh or Andhya Pradesh, might increase theft from government forests, but there are ways of tackling this risk and at the same time avoid the inducements to corruption that are associated with restrictive norms. For instance, species like eucalyptus that are popular with farmers would not be grown on public forest lands, thus helping to reduce competition between farmers and the government, provide a better price to producers, and avoid glutting the market. Another way to phase in the change would be to relax restrictions in areas that are remote from government forests.

The adequate implementation of forest policies will also depend on an adequate public forestry administration. There is a need to strengthen the institutional capabilities to generate multidisciplinary programs; to effectively liaise with other government agencies, with NGOs and private sector organizations; and to design models for the effective participation of local people in forestry development programs. Research programs must be redirected to generate incentive programs for local people. Furthermore, training of forestry professionals must be adapted to the new demands of multidisciplinary work and more-intense rural participation.

A related point is that bureaucratic corruption should be minimized. Corruption generates disincentives to the creation, proper management, and conservation of forest resources. The reform of the public forest administration should include measures to increase transparency of operations. A better monitoring and evaluation system that is open to public scrutiny would help, and NGOs can play an effective role in this respect. Also, as discussed earlier, unnecessary regulations that are bound to increase the propensity for corruption should be eliminated. Furthermore, the public forest administration should also consider divesting itself of all those tasks for which it has no particular competitive advantage and that could be more effectively performed by the private sector.

Notes

1. In Andhra Pradesh, high-quality seedlings cost over ten times more than subsidized seedlings. However, calculations indicate that better seedlings would yield a 38–40 percent financial rate of return.

2. The Forestry Department in Rajasthan, for example, in conjunction with other agencies very successfully popularized the grafted *bar* (*Ziziphus mauritania*), a fruit variety that has high levels of profitability and provides income after only the second year.

References

Binswanger, H. 1989. Brazilian policies that encourage deforestation in the Amazon. World Bank, Environment Department Working Paper No. 16. Washington, D.C.

Chambers, R, N.C. Saxena, and T. Shah. 1989. To the hands of the poor: Water and trees. New Delhi: Oxford and IBH Publishing Co.

Government of India (GOI). 1990. Toward social transformation: Approach to the eighth five-year plan, 1990–95. Planning Commission (May).

Gupta, T., and A. Guleria. 1982. Non-wood forest products in India. New Delhi: Oxford and IBH Publishing Co.

Khare, A., A.V. Ramakrishna Rao, and N.K. Panda. 1987. Linkages between forestry and other sectors of the economy with particular reference to afforestation of wastelands in India. Expert Consultation on Inter-Sectoral Linkages in Forestry Planning (15–18 December). Bangkok: Food and Agriculture Organization of the United Nations (FAO).
Mahar, D. 1989. Government policies and deforestation in Brazil's Amazon Region. Washington, D.C.: World Bank.
Poffenberger, M., K. Bhatia, and B. McGean, eds. 1990. Forest management partnerships: Regenerating India's forests. Executive Summary of the Workshop on Sustainable Forestry (10-12 September, New Delhi). New Delhi: Ford Foundation.
Repetto, R., and M. Gillis, eds. 1988. Public policies and the misuse of forest resources. Cambridge: Cambridge University Press.
World Bank. 1993. Costa Rica: Forest sector review. Washington D.C.

4

Institutional and Environmental Issues for Forest and Wasteland Development in India

Augusta Molnar, Malcolm Jansen, and J. Gabriel Campbell

The forests in India, as in the rest of the world, provide varied and important economic and environmental services—such as timber, fruits and nuts and helping to maintain the balance of atmospheric carbon. But the forests in India are under severe pressure, and the threat of their degradation is among the most serious in the world.

The outlook for these forests is indeed bleak, but—although it is scant—there is some good news. For instance, proper incentives and development strategies should make it possible to retain the current area under forest cover as well as to improve the quality of the more degraded sites. One promising strategy for this sustained forest development is joint management whereby local communities enter into partnerships with the state to develop a wide variety of resources. Another effective strategy is to maintain a viable protected areas (PAs) network that emphasizes biodiversity more in the multiple-use forests and PAs and that integrates people into the overall PA management plans.

If these goals and strategies are to be met, however, there are major gaps in the information needed about forests and related issues that will have to be filled. For instance, very basic information is needed on the potential to sustain and expand enterprises using non-timber forest products (NTFP) in different forest types. Information or management models are needed on multiple-use plantations and forests particularly in areas of heavy grazing demand and shifting cultivation. Information is needed for identifying which non-forest wastelands[1] have the greatest potential for development and should be targeted by investment programs. And as work progresses on these issues, more information needs will probably arise.

This chapter analyzes the current status of forests and wastelands and outlines the potential for their future development. Key issues that underlie development alternatives are discussed, and various promising institutional arrangements for forest and wasteland development are analyzed. The chapter concludes with a brief overview of the major issues in conserving biodiversity while developing forests and wastelands and proposes a strategy for meeting them.

The economic importance and status of India's forests

India's forests and non-agricultural lands provide a diverse and life-sustaining net of environmental and economic services. Forest products valued by urban and rural populations for meeting consumption needs, supporting agriculture and animal husbandry, and generating cash income include fuelwood, fodder, timber, and a variety of roots, tubers, herbs, leaves, fruits, fibers, resins, and nuts. In regions where the ratio of cultivated to noncultivated land is low, resources from forests and pastures are essential to agriculture and, in addition, may provide most of the local income (for example, in the migratory cattle and livestock areas of Rajasthan and Gujarat, the highlands of the Himalayan range, the Western Ghats, and the heavily forested areas of central India). Forestry activities provide a significant source of employment for a large proportion of the rural population. In upland catchments and fragile ecosystems, non-agricultural lands (including forests) provide important environmental services in checking wind and water erosion, preserving and enriching soil nutrients, and mitigating the vagaries of climate, especially the periodic floods and droughts. Private and public forest lands contain a wealth of biological diversity of both known and unknown economic, social, and ecological values. India is one of the twelve "megadiversity" countries that together contain 60–70 percent of the world's biodiversity, and most of India's diversity is found in its forests.

Patterns of dependency on forest and tree products

India's population size and the per capita consumption of forest products are both on the increase, with a much larger share of forest products being channeled to commercial, urban, and industrial use. Although there is some fuel substitution in urban areas, a large number of industries and urban households continue to depend on fuelwood for a large proportion of their cooking and heating needs. Agricultural productivity has not increased commensurate with population growth, and a growing amount of cultivated land is being taken out of production by environmental degradation, placing increasing pressure on the cultivated land that remains productive. Employment opportunities that are not based on land use are still limited relative to the size and employment needs of the population. Many of India's rural poor depend heavily on marginal income generated from the collection and sale of a variety of forest products or the grazing of scrub animals in forests and on common property resources (CPRs).

The pattern of forest product use in the different geographic and ecological zones of India is very diverse. In the higher altitudes, where forests are relatively accessible and the population consumes greater quantities of fuel for cooking and heating, fuelwood and fodder consumption is highest. Studies in Nepal indicate that Himalayan farming systems require about 1.4 hectares of forest land per hectare of arable land to sustain agriculture (Environmental Resources Limited 1988). Fuelwood, fodder and NTFP consumption is high in the central forest belt as well, and fuelwood sale is an important source of income for the rural poor and tribals, particularly as NTFP availability is on the decline. In the irrigated tracts (30 percent of India's gross cropped area) where agricultural land is more fertile, such as in the Punjab, the population primarily uses cow dung and agricultural residues as fuel. This is not a completely new pattern, but it has been intensified by the increase in irrigated land (projected to reach 43 percent of gross cropped area in the future) and the higher-yielding crop varieties that generate more residues on private lands.

In the semi-arid regions, there are large tracts of uncultivated lands within private holdings. These are fallows or government-owned lands designated as pasture, scrub forest, or areas for future village expansion. Where significant blocks of non-forest, public lands still exist, they function as de facto CPRs. The area under CPRs even in rainfed areas has been steadily decreasing as more land is diverted to marginal agriculture, homesteads, urbanization, or other uses because of population pressures, land settlement procedures, development activities, and unequal land distribution.[2]

Current condition of forests and wasteland areas

Present government policy states that one-third of the country's geographic area should be under forest cover for balanced economic and environmental land use. The current extent of forest resources is significantly less than this figure, and as the next section will show, it is unlikely that forest resources will increase to any significant extent. The total forest area as identified by LANDSAT satellite imagery (AC1) is barely 20 percent. Even accounting for the limitations in LANDSAT imagery, which cannot capture forest areas smaller than 50 hectares, the total area under forest is unlikely to be more than 20–22 percent. Government forest land (90 percent of the country's forests) covers 67 million hectares of which only 30–35 million hectares has 40 percent or more forest cover. While there has been extensive planting under the social forestry programs, conservative estimates are that 5 million hectares, at most, have been planted (AC1). Traditional tree groves and privately grown freestanding trees cover a possible 5 million hectares more (see table 4.1). Areas protected for biodiversity conservation cover 12 million hectares, of which 8 million hectares at most are forested. The current situation is therefore that about 74 million hectares are forested, of which 30–35 million hectares in the forest estate are known to be severely degraded.

Forests are not spread evenly in India but are concentrated in the northeast, the Himalayan and Siwalik ranges, the central belt, strips along the Western Ghats and other hill areas, and in patches of coastal mangroves. Exclusive of mangrove areas, there are four main forest types: (a) moist, tropical forest (including the high-value Sal forests); (b) dry, tropical forests in the semi-arid regions (where teak is a valued species); (c) Himalayan and Siwalik forests; and (d) Western Ghat–style forests. More than 50 percent of the forest land is located in the five states of Madhya Pradesh, Arunachal Pradesh, Andhra Pradesh, Orissa, and Maharashtra. Thirty percent of Madhya Pradesh and Orissa is forest, 82 percent of Arunachal Pradesh, and 15 percent of Andhra Pradesh and Maharashtra. This contrasts to the situation in other large states; for instance Gujarat, a primarily semi-arid and arid state, has barely 6 percent land under forest, and Rajasthan and Punjab, each have less than 4 percent.

Degradation and deforestation

Forests and other nonagricultural land resources are under extreme pressure. Unofficially, it is estimated that 1.3 million hectares of forest are lost annually through deforestation or continued degradation of already degraded forest area. This is almost 2 percent of the current forest area. Although degradation is on the increase, the trends for actual forest conversion appear to have slowed down in recent decades. Dramatic conversion of forest areas occurred in the past to support the expansion of infrastructure during the colonial period and post-independence for large development and energy projects, refugee resettlement, agricultural expansion, and forest clearing by private owners in response to policies for government acquisition of all land under forest. The large expansion of cultivatable wastelands is a dramatic trend outside the government forest estate. Wastelands in government terminology include permanent fallows, degraded pasture and forest, eroded and drought-prone lands, gullies and ravines, extremely saline and alkaline soils, and waterlogged areas. The National Wasteland Development Board (NWDB) states that 175 million hectares of India's 329 million hectares is wasteland and includes in this estimate those margin-

Table 4.1 Current and projected area of selected land categories in India
(in million hectares)

Land category	*Total area*	*Area in forest*	*Projected area in 2010*	*Available for forestry use*
Forest (+40% cover)	34	34	25	25
Forest (–40% cover)	33	33	30	30
Revenue uncultivated	22	—	12	4
Private under trees	6	6	n.a.	6
Private fallows	27	—	21	6
Private marginal sown	142	—	n.a.	3
Urban/Nonagricultural	20	—	n.a.	0
Rock, barren	20	—	20	0
Total	304	73	n.a.	74
Total protected areas	12	8	12	n.a.

— Data not available.
n.a. Not applicable.
Note: Records are available for 304 million hectares.
Source: Based on Chambers, Saxena and Shah 1989; Contreras 1989; Agarwal and Narain 1989.

ally sown croplands that support very low yields.

There have been a number of studies on how much area is actually wasteland in India, including forest land, and how much of this area can be economically and realistically treated. Estimation is made difficult for a number of reasons. Wastelands fall under a variety of tenure categories and are counted differently in various land classification statistics and records. Since departments disagree on jurisdictions, wastelands can be omitted or double-counted in particular surveys. A given piece of land may also have different tenure classification from the perspective of different users or agencies. What appears unutilized to the revenue department may be marginal pasture to the users. Marginal croplands in semi-arid and arid regions that are productive only in years of good rainfall may be counted as uncultivable wasteland even though the owner would be unwilling to divert such land to an alternative use. The area under CPRs declines rapidly when irrigation is introduced, but even in semi-arid regions, a number of forces have led to the privatization of public lands. Post-independence settlement policies have contributed to CPR privatization in a number of states, since lands that were under poorly recorded or complex, customary systems of communal use were often made available for private acquisition.

Table 4.2 summarizes the various estimates that have been made by specialists. Saxena (1988) made the most careful estimate of the wasteland available for development—84 million hectares of land in all ownership categories (see table 4.3).

Development potential of India's forests and wastelands

What is a realistic goal for reversing deforestation and forest and other land degradation over the next decades? Built on the information available in Contreras' overview (see chapter 3) and the 1989 report on Common Property Resource Management prepared for the Bank, a realistic estimate of the area that could potentially be developed or retained as a productive forest or silvipastoral resource is about 74 million hectares. This area is equivalent to that presently estimated to be under some type of forest but is much smaller than the 33 percent (or 100 million hectares) that the government of India (GOI) would like to retain in forest cover.

Table 4.2 Estimates of extent of degraded land in India

Estimated by	*Area considered degraded (million hectares)*	*Comments*
National Commission on Agriculture (GOI 1976)	175	This figure includes 85 million hectares of agricultural land, which is considered degraded by the NCA; has been questioned by Bhumbla and Khare (1984).
Gadgil and others (1982)	88	These authors' breakdown is: pasture 12 million hectares, degraded forests 36 million hectares, culturable waste 17 million hectares, and fallows 23 million hectares. They assumed that the entire area of culturable waste, fallows and pasture lands was degraded. Cultivated degraded lands were not considered in the estimate.
Bentley (1984)	115	This includes 15 million hectares of marginal agricultural lands and recently deforested forest lands.
Bhumbla and Khare (1984)	93	They considered only non-forest wastelands. Adding 36 million hectares of degraded forest area brings the total to 129 million hectares. The NWDB accepts this figure of 129 million hectares (1986b).
Vohra (1985)	103	The breakdown here is forest land 30 million hectares, uncultivated land 33 million hectares, and cropland 40 million hectares.
Khan (1987)	80	According to Khan, a forester working in the NWDB, this consists mostly of degraded forests and private marginal land.
World Bank (1988)	115–130	This includes 32–40 million hectares of degraded agriculture land. The rest of the breakdown is similar to that given above by Gadgil and others.

Source: Chambers, Saxena and Shah 1989.

The estimate is made up of the categories summarized in table 4.1. The area currently under good-quality forest is 34 million hectares. The degraded forest area under the control of the Forestry Department is 33 million hectares. Assuming that some further conversion of forest to other uses is inevitable, given present trends an estimated 2 million hectares of each category may be irretrievably lost for forest use and another 5 million hectares may be uneconomic to treat. This leaves 30 million hectares of good forest and 23 million hectares of degraded forest for treatment and improved management. Aside from government forest land, an estimated additional 12 million hectares can realistically be treated. Chambers, Saxena, and Shah (1989) argue that 12 million hectares of public uncultivated land, 13 million hectares of private marginal cropland, and 21 million hectares of private permanent fallows are available for cultivation. Based on past experience in motivating farmers and communities to treat wastelands, a conservative but quite believable estimate of the area of these lands that

Table 4.3 Current classification of degraded land available for tree growing
(million hectares)

Category of land	*Total area*	*Trees*	*Private department*	*Forest*	*Revenue/Other*
Cultivated	142	13	13	—	—
Forest	67	36	—	36	—
Uncultivated/non-forest	55	33	21	—	12
Strips	n.a.	2	1	—	1
Total	264	84	35	36	13

— Data not available.
n.a. Not applicable because already included in the previous categories.

could be treated is 3.5 million hectares (25 percent) of public uncultivated land, 2.5 million hectares (20 percent) of private marginal land, and 5 million hectares (25 percent) of private permanent fallows.[3] Adding the already existing 5–8 million hectares of tree groves and freestanding trees, the total would be about 74 million hectares.

By this calculation, the area under forest would not increase but would be sustained and a large area presently degraded could be improved.

Government forest strategies

There has been a major shift in government policies and strategies in recognition of the acute resource problems facing the nation. The government re-examined the implications of its development strategies for forestry in the 1988 Policy Statement and tried to reverse earlier policies that favored the clearing of land for agriculture or industrial development and to shift emphasis in forest management away from commercial values of the forest and toward subsistence and environmental values. Recent policy and strategy changes pertinent to forest and wasteland development have included a reallocation of resources to non-irrigated agricultural systems, tenure reforms for public lands that increasingly devolve responsibility for resource development and management to local people, clearer environmental guidelines and procedures for designing and approving development projects and for allocating resources, channeling of resources to afforestation and forest and pasture rehabilitation through state and national programs (drought-prone area development, social forestry schemes, employment guarantee schemes, and NWDB funds), and attempts to revitalize the role of local institutions in natural resource allocation and management.

Policies in the sector have begun to reflect a more participatory view of development. Governments are encouraged to promote a wider range of institutional arrangements for local initiatives. In states where decentralization is being promoted, local governments are encouraged to target development funds for afforestation. Attempts are being made to improve the dissemination of information through more extension efforts by the government, multimedia information campaigns, environmental education, and a shift of financial resources and implementation responsibility to districts, villages, and nongovernmental organizations (NGOs). Public debate on the principles of sustainable development has grown, with arguments and counterarguments about the relative merits of promoting modern, resource-demanding western lifestyles versus modern but resource-intensive Indian lifestyles. There is a proliferation of NGOs dedicated to tackling and raising awareness about environmental issues and mobilizing very diverse levels of financial and human resources.

There is a more open climate for channeling government resources to the local, private and voluntary sectors.

Constraints on implementing new policies

The problems with implementing more environmentally sound policies and strategies for forest and wasteland development are numerous and complex. Government agencies are still staffed in old patterns with outdated or inefficient administrative structures and procedures. Agricultural policies continue to promote dramatic increases in food and cash crop production rather than sustainable land-use, partially contradicting the objectives of forest policy. Urban and industrial development strategies conflict with the strong forest conservation strategy outlined in the 1988 Forest Policy. Responsibilities for less-traditional aspects of forest and wasteland development such as the introduction of technical forestry models geared to multiple uses and services, pasture development, or the development of more sustainable rainfed agriculture packages are not clearly allocated to any agency or institution. Energy conservation and wood substitution goals are not linked to substantial amounts of funding or large-scale programs in any government or private sector program. While the overall size of the Indian forest staff is large (93,000 forestry staff throughout India, state forest departments are poorly staffed and are structured for specialized tasks, including managing the network of protected parks and sanctuaries. There are a number of changes needed in the existing legal framework that underlies the incentive structures or tenurial arrangements, and better procedures are needed for implementing the improved legal provisions that will support land rehabilitation or forest development.

Key issues in developing forests and wastelands

The three main practices affecting the development of forests and wastelands are the use of fuelwood as the major source of energy (46 percent of the national consumption); dependence on forests and other non-cropped lands for fodder and grazing; and unsustainable methods of shifting cultivation. The following sections explore how each of these practices can be changed to allow forests and wasteland development to succeed.

Energy

Fuelwood continues to be the major source of energy for cooking and heating in India (46 percent of the total energy consumed in the country). National fuelwood consumption is estimated at 230 million tons per year, about ten times the amount of recorded extraction. For example, West Bengal estimates its consumption of fuelwood at 13.80 million metric tons against the recorded supply of 0.13 million metric tons.

The alarming gap portrayed by these macro-level statistics was the analytic driving force behind the large-scale forestry programs supported by the World Bank in the late 1970s and 1980s. The undoubted dependence of the rural and urban poor on fuelwood for cooking—and the severe implications for the labor and reduced productivity of the women having to gather the wood—provided a very convincing argument for the afforestation programs aimed at reducing this gap. Surprisingly, a very small proportion of the hundreds of millions of trees grown through this effort were planted or used primarily for fuelwood by the participating farm households and communities.

It is now time to reassess the prevailing macro-level analyses of the role of fuelwood and tree production in the energy economy of India. First, it is evident that current demand-supply analyses are severely distorted. If similar analyses had been carried out forty years ago, they would have projected that all trees in India would be gone by now. The currently recorded supply of wood classified as fuelwood is probably a small fraction of the mostly legal supply of burnable biomass. Not only are large amounts of twigs, branches, brushwood, and leaves removed annually from government forest lands, but an even greater supply of biomass is provided from private and village sources. It is also likely that the percentage of cooking energy derived from livestock dung, agricultural residue, and manufacturing residue is considerably higher than estimated. Furthermore, studies of energy consumption in areas of high population density and no forests nearby have shown that households are able to meet their annual domestic energy needs with less than 150 kilograms per capita fuelwood consumption. Given the opportunity to grow a tree, the people inevitably grow it for sale to the pole market to obtain cash—a far-higher perceived need. The problem of illegal fuelwood removals from government forest lands are generally traceable to the same need for income for poor headloaders.

Second, it is increasingly evident that the use of forestry resources for fuelwood is economically and environmentally unsound in the long run, although it will continue to be necessary in the immediate future. For instance, much of the wood supplied for fuelwood by the government could go to alternative end uses that have much higher economic returns given the high prices for wood in India. The environmental effects are far-reaching. The burning of fuelwood in open hearths or unimproved furnaces is a major contributor to atmospheric and indoor pollution. The sweeping of the forest floor for leaves and the removal of ground cover has led to much higher levels of soil erosion in forests and plantations than is generally recognized.

In the long run, national policies must promote the substitution of fuelwood for almost all household energy use. In the immediate future, this is not possible or desirable for the poor half of India's population that currently collects available biomass at very low marginal costs to households. However, approximately 40 percent of the fuelwood used is purchased by urban (or peri-urban) households and small-scale industries. The prices paid are rarely less than equivalent costs of energy from electricity, kerosene, coal or bottled gas. The principal constraint to the substitution of these alternatives is the lack of a reliable supply through the regulated government agencies and the lack of policies that would promote their use over fuelwood through the commercial market. Even in the short run, it should be possible to provide economic substitutes for this commercial market to divert better-quality wood to more-profitable end uses and to make more existing burnable material available to poor collectors.

Current efforts toward reducing consumption have focused on improving end user efficiency through the introduction of improved cookstoves. In addition to the small components in social forestry projects, a large-scale program for improved cookstoves and biogas plants has been launched by the government through the Department of Non-Conventional Energy. While a large number of stoves and biogas plants have been distributed, the adoption rates have been low, and the likely impact on fuelwood consumption is almost negligible.

Worldwide research has demonstrated that improved woodfuel stoves have the potential to provide substantial benefits for health and fuelwood consumption. That many of these benefits have not yet been captured reflects the technical and social difficulty of developing site-specific technologies that are responsive to the varied requirements—size, energy needs, cooking styles, and fuelwood mix—of different user households. Subsidized government programs and the use of socially unresponsive technologies have prevented the guided development of market solutions. A comprehensive new initiative is needed to examine the present strategy and programs and determine how best to streamline and expand programs to have a maximum impact. The potential interface between integrated health schemes and cookstove programs could provide the additional access to women and female extension workers that current programs tend to lack. Perhaps even more promising would be systematic examination of alternative methods of reducing consumption through changes in food preparation patterns (presoaking lentils), fuel preparation (drying or using briquettes), and promotion of commercially available precooked foods ("minute-dal" or "minute-rice"). Already, the availability of noodles that cook in only three minutes is changing food habits in India.

Making public fuelwood more available to the women of poor households who will have to depend on this resource for the immediate future also needs increased attention. Fuel collection and cooking tasks place a disproportionate burden on poor women and children and have increasing negative impacts on productivity, nutrition, health, and children's education. Households that have to move down the biomass chain to less-calorie-intensive burning materials (leaves, twigs, and so forth) bear the brunt of these negative effects. The complex distribution issues associated with various social forestry programs can function to either improve or worsen this situation. A study in West Bengal has shown, for example, that eucalyptus leaves from farm forestry on marginal private lands are a significant benefit to middle-income households, generating important time-savings for other purposes. More understanding is needed of the supply chain of various kinds of tree planting and forest management at the micro-level, so that technologies and institutional arrangements promoting regular, increased supplies of less-valuable fuelwood to poor women collectors can be encouraged.

Fodder and livestock

Dependence on forest and other non-cropped lands for fodder and grazing has a long history in India. Recently, government forest management plans have included the regulation of grazing and fodder extraction through user fees and permit systems.

There are two main types of livestock pressures on forests and wastelands: one is from sedentary village livestock, cattle and small ruminants, and the other is from migratory animals belonging to a variety of traditional, ethnic grazers. Historically, the size of the nomadic population and the movement of herds have fluctuated with the changing patterns of land use and periodic drought cycles. In recent decades, there has been a reduction in the number of nomadic households in response to competing demands on land. There has also been a change in the composition of livestock—generally, more cattle and small ruminants and fewer buffalo that require high-quality and reliable sources of fodder. Among sedentary agriculturalists, owning livestock has always been an important subsistence strategy of the rural poor, providing an important source of cash and a cushion against lean periods of employment.

Pressures are heavy on the forest estate. According to a survey of 174 of the nation's protected areas, 67 percent of the national parks and 83 percent of the sanctuaries reported grazing incidence. In twenty-four PAs, cattle density was higher than the Indian average of 0.75 per hectare; in twenty-two PAs, goat density was higher than the national average of 0.24 per hectare; and in thirty-two, the sheep density was higher than the average of 0.13 per hectare).

There is a large gap between policies and programs to tackle the issue of dependence on forests and wastelands for fodder. There is inadequate attention to the problem among government agencies, and no clear division of labor among concerned agencies. Although stall-feeding of productive livestock and producing fodder in high-yielding agricultural areas is recommended, the economics of raising fodder in drier areas or of the relative merits of stall-feeding compared to regulated grazing is not well understood. High-yielding cattle breeds cannot be supported by rural poor through stall-feeding in most areas of India and even less so in dry regions. Yet programs promoting livestock raising continue as though there were no conflict with wasteland and forest rehabilitation programs. Managed rotational grazing is likely the only system economically viable for the majority of residents in the semi-arid tracts and near forest lands, but the institutional arrangements for this and the technical prescriptions are still poorly developed. Creative strategies clearly need to be explored. Foresters in the Himalayan region have advocated that transhumant animals be trucked between the summer and winter pasturage to reduce pressure on the resources along traditional routes. Rotational grazing has been recommended for public uncultivated lands and silvipastoral forest lands, but there have been no focussed extension efforts to help grazers develop viable systems and institutional frameworks.

Shifting cultivation

An estimated 10 million hectares in India is used for some form of shifting cultivation, of which only a small proportion is cultivated under a sustainable fallow cycle. Efforts to influence the methods used are complicated by the diversity of people practicing shifting cultivation. A minority of traditional cultivators still practice relatively sound farming systems, but an increasing number have been pushed out of their traditional agricultural and forest areas and have been forced onto smaller and more-marginal lands. The rural and urban poor who have been forced by acute poverty to move into forest areas and take up shifting cultivation generally use poor agronomic practices and inadequate fallow cycles.

A number of initiatives have been undertaken to improve shifting cultivation, but the results have been varied. In some cases, balanced development programs introduced in areas where traditional groups still have relatively long fallow cycles (ten years or more) could allow continuance of shifting cultivation without negative environmental impacts. Studies by a number of researchers indicate this is a sound strategy for parts of the northeast (see Ramakrishnan and Singha 1991, for example). In other cases, combinations of agroforestry and sustainable rainfed farming need to be introduced, but the appropriate technical packages do not exist. Nor are the micro-level planning strategies in place that provide for employment or income generation during the transition period to more sustainable land use systems.

The government has been reluctant to experiment with policies that improve land tenure for shifting cultivators for fear of encouraging more encroachment by the non-traditional groups. This has hindered experimentation with commercial tree crop alternatives that require long-term tenure security as an incentive. A better policy framework is needed that takes a comprehensive view. This might entail titling, where appropriate, of traditional areas of shifting cultivation; establishment of clear systems of participatory forest management for forest lands under government ownership to check further encroachment by outsiders; development programs for reducing the influx of underemployed into forest areas; and development of agroforestry, NTFP-focussed, or mixed-cropping systems that are attractive and support a transition period.

Institutional arrangements for development of forests and wastelands

Government forest lands

Current institutional arrangements for managing forest lands under the Forest Department's nominal control derive from the legal designation of the forestry estate through survey, demarcation and notification. Legally, forests classified as protected (national parks and sanctuaries) and reserves place the greatest restrictions on use by local people and contain the highest-quality forests. At the other end of the scale are unclassed or undemarcated forests where local usage is the least controlled. Demarcated but unprotected forests fall in between. In addition to the general national and state restrictions applying to these forest categories, each particular forest area provides for specific local rights and concessions that are enshrined in the original settlement and are renewed or modified in the ensuing working plans governing the forest's management.

The complex mosaic of legal and administrative arrangements for the use of government forests by local populations is further complicated by the lag time typically involved in revising and maintaining up-to-date working plans and by the frequent disregard of the written arrangements—by the surrounding population and, at times, the Forest Department itself. This gap between the theoretical arrangements for forest management and the actual practice is largely responsible for the degradation that is occurring, as well as the current dearth of accurate statistics on the forest estate. Although the working plans and forest settlement reports show that an extensive attempt has been made to provide some of the needs of local users, the lack of direct involvement or incentive for these local users to participate in achieving management objectives has resulted in continuing theft and overuse in much of the forests. The proliferation of forest guards has doubtless stemmed the amount of destruction, but it has also introduced large overhead costs for personnel who not infrequently profit from illegal removals themselves.

If the continuing gradual degradation of the nation's forestry estate is to be reversed, it is imperative that more effective institutional arrangements between the forest departments and the local people be established.

JOINT MANAGEMENT. Efforts to develop joint arrangements for sharing forest management and benefits have received sporadic and isolated attention in Indian forestry. The Van Panchayats of the Uttar Pradesh Himalaya and the Forest Cooperatives of Himachal Pradesh are two examples initiated prior to independence. While these experiments showed both promise and problems, they were generally undermined by more traditional concerns for timber production and government control.

More recently, since the preparation of the West Bengal and Maharashtra Forest Sector projects, there have been encouraging new developments in the area of joint forest management. Fourteen states have passed legislation or government orders supporting joint management experiments. The GOI has also issued a government order supporting widespread experimentation with joint management of government forest lands in all parts of India. In West Bengal more than 200,000 hectares are now being managed by more than 2,000 forest protection committees, and in Haryana more than forty communities have started catchment protection through forest protection committees and village leasing of grass harvesting rights along the Sukhumajari model. The earlier efforts have been expanded and revitalized: the forest committees have been revitalized and now cover 180,000 hectares of forest land in Orissa, Van Panchayats have been given new life in Uttar Pradesh, experiments have been started in Jammu and Kashmir, and village forest protection efforts have mushroomed in a tribal-dominated district in Gujarat (Surat). In addition, new efforts to establish joint management are now being tried in a wide variety of ecozones, in some cases with support from NGOs.[4]

The initial results from these efforts have shown an overall increase in the level of forest protection with a consequent increase in overall productivity, although results are not consistent for each site. Where equitable benefit sharing has been instituted, such as in West Bengal and Haryana, a net increase in benefits to both the local users and the Forest Departments has resulted. While these arrangements have generally shown such overall increases, the effectiveness of joint management in specific forests and villages is variable. It has been most promising in areas with homogeneous village populations (predominantly tribal), areas requiring low forestry investment to generate regular and quick returns, and areas where there was a history of local resource management traditions.[5] These results indicate that while joint management is not a panacea for institutional effectiveness everywhere, it does result in a net improvement over current arrangements and shows promise for reversing degradation trends.

Capitalizing on this potential for joint management on a large scale will require significant shifts in investment and strategy. Forest areas suitable for joint management need to be identified. Of the estimated 23 million hectares of degraded forest land, an estimated 10 million hectares have good-quality root stock that would could be regenerated through protection and cultural operations with levels of investment at less than 10 percent of the cost of new plantations. An estimated 8 million hectares could be rehabilitated thorough a combination of protection and enrichment planting, at approximately 30–50 percent of corresponding plantation costs. The remaining 5 million hectares would require full plantation-level investments, although technological packages that emulate the regular flow of intermediate products found in natural forests are likely to improve the success rate of joint management ventures.

Appropriate forms of joint management also need to be extended to the suitable higher-quality forests that are under pressure from surrounding populations. As yet, experiments with joint management have been mostly limited to low-value forest lands where degradation is severe or soil fertility and climatic and growing conditions are relatively poor. Although there are no legal impediments in the 1980 Forest Conservation Act to designating good-quality forests for joint management, forest departments and governments are reluctant to do so even though the incentives and returns are likely to be considerably higher for both parties where pressures are acute and social conditions amenable. Constraints to changing this policy include the fear of encouraging further encroachment, the lack of institutional capacity for supporting and monitoring implementation of joint management schemes, a historical distrust of local populations, and a national forest policy that is still conservative. It is estimated that at least 50 percent or 15 million hectares of forests are in imminent danger of degradation unless improved institutional arrangements are instituted through joint management.

The legal and organizational framework for joint management remains controversial. Some legal experts question the use of forest user committees without legal standing and advocate the use of legal bodies such as the panchayat. Other analysts praise the informal nature of arrangements between communities and forest departments because it allows communities to be selected according to appropriately sized user groups and to manage their resources relatively free from the power struggles common to village panchayats—and because it allows forest departments to help shield committees from such interference. There has also been controversy over the definition of users in relation to a given forest. In both West Bengal and Haryana, there have been conflicts related to the status of secondary users (those living in hamlets more distant from the forest who have traditionally harvested products). Resolving this issue is one objective of concentrated extension efforts by the forest departments of both of these states. Methods for providing legal protection and the tenurial security it affords while maintaining the advantages of small, informal, nonpolitical groups will need to be the subject of continuing applied research and monitoring in the context of state-specific programs.

There is growing availability of information about the characteristics of successful joint management or benefit-sharing arrangements gained from ongoing experiments. Much still needs to be learned, however, to know whether the emerging patterns are generally applicable. Where the character of the forest products allows a large part of the benefits to be reaped in the short term (for instance, they can be gathered right away), there is a broad distribution of benefits across income groups with substantial benefits accruing to poor and marginal households. Where the products are less diverse but there are materials such as grasses or bamboo that are valued by the poorer segment of households, these poorer households may take on a disproportionate share of the protection and maintenance duties to obtain these products. Where the majority of forest products accrue to the user group only over the long term, such as through sharing in the rotational timber harvests, the distribution systems may entail creating a user group fund for development activities rather than distributing shares. In this case the benefits to poorer segments of the group vary considerably. In the first FPCs established in West Bengal, the Forest Department increased incentives and ensured the more equitable distribution of benefits by setting up a system whereby each household would receive a cash share of the timber harvest. This model has not yet been replicated elsewhere.

Widespread adoption of joint management arrangements will also require substantial re-orientation of forestry staff, working plan procedures, and monitoring capability. Although NGOs can provide valuable assistance in the process (see below), a substantial commitment to a long-term approach will be necessary to achieve substantive impacts. Unfortunately, the alternative is the continuing steady erosion of remaining government forests.

ROLE OF NONGOVERNMENTAL SECTOR. The 1988 Forest Policy proposes a much greater involvement of NGOs, local government, and the private sector. The mechanisms to implement this approach are not well defined, and recent efforts in this direction by the National Wastelands Development Board have been disappointing. Constraints to effective NGO involvement stem from a misunderstanding of NGO strengths and weaknesses, contractual and funding hurdles, mutual distrust, and the lack of managerial and technical skills among many NGOs.

Efforts made by the NWDB to provide centrally channeled grants to NGOs for afforestation programs attempted to ignore state constraints—at the cost of local coordination and state level control. Without legal access to land and adequate technical knowledge, many NGOs performed poorly. It is estimated that only 2 percent of new tree planting or wasteland reclamation has been carried out so far through all NGO efforts. This experience demonstrated that (a) NGOs generally should not be used in afforestation programs as a substitute for the forest departments; (b) both state and local level arrangements are necessary; and (c) NGO input should be defined as a complement to government activities, with concomitant NGO-strengthening programs.

The involvement of nonprofit NGOs in environmental education, the organization of forest committees, the facilitation of joint management schemes in both public and private lands, the training of forestry personnel and local leaders, market and processing support (particularly for women), and multi-disciplinary applied research has shown considerably more promise than in afforestation programs. Intermediary NGOs such as the Society for the Promotion of Wasteland Development (SPWD) and PRADHAN are increasingly providing critical technical assistance and training to local NGOs. Some states have developed creative mechanisms such as jointly-formed societies to overcome problems with procurement and contracting.

Constructive involvement of the nonindustrial "for-profit" private sector remains more problematic. Current policies do not encourage the formation and use of private consultants or small-scale enterprises in furthering forest policies and programs. This severely constrains forest departments from obtaining the specialized expertise they lack in management, marketing, processing, information systems, group formation, communications, and so forth. In addition, it discourages the development of small-scale enterprises that could increase the returns in forest product processing and marketing to local people and could increase system efficiency.

Public lands outside the forest estate

SOCIAL FORESTRY AND WASTELAND DEVELOPMENT. Social forestry programs and other government schemes have implemented a variety of strategies for the rehabilitation and afforestation of degraded public lands outside the forest estate. All of these lands fall within the overall jurisdiction of the Revenue Department and are therefore referred to in the Indian context as "revenue lands." Revenue lands may include lands under the jurisdiction of the village panchayat authority, common lands under customary systems of group tenure (such as shamlat lineage lands in the northwest), lands managed by roads and railways department acquired when this infrastructure was constructed, and undesignated lands loosely administered by the district collector.

The actual tenure arrangements for revenue lands are often complex and may be differently understood by various users. As discussed earlier, land settlement procedures seldom took the complexity of nonprivate land use and tenure into consideration. Consequently, lands that local people still perceive as having a specific group tenure use may be classified as panchayat or unspecified revenue lands. Most function as de facto CPRs unless otherwise allocated by local or district authorities. In the Deccan, CPRs have been much more loosely managed at the local level, because the tenure system codified there under British rule (*ryotwari*) did not provide communities with strong usufruct rights in nonagricultural lands. In parts of North India where the *zamindari* system was in effect, landlords were given jurisdiction over nonagricultural lands and in turn passed on these rights to their tenants.

Social forestry programs evolved a number of strategies for developing revenue lands. Some were transferred to panchayat bodies for afforestation, the smallest legal entity that could be entrusted with public land jurisdiction, and others were parcelled out in various tree tenure schemes, emulating some principles of the West Bengal group farm forestry scheme.[6] The panchayat woodlots proved very problematic. Many of the more productive lands were already privatized or allocated to another use. Many of the woodlot sites are of very poor quality and require considerable investment and gestation time to generate returns. The panchayat proved a too impersonal and elitist body to become an effective broad-based forum for sustained resource management. Individuals within the panchayat were too unsure of returns to protect areas, panchayat leaders were reluctant to assume responsibility for the government schemes, and forest departments were too overstretched to manage the afforested areas. Since plantations were modelled on commercial Forest Department models, the range of products produced is the same as for farm forestry and government forest plantations. This has meant that woodlots compete with other plantations for the same markets and do not generate the range of products needed by the marginal villagers most enthusiastic about CPRs.

TREE TENURE SCHEMES. These schemes have been fraught with problems: political favoritism, lack of financial or extension support to the rural poor, inability of the rural poor to wait for returns, and the difficulties of protection. Since states have not been willing to privatize lands under tree tenure, as was the case in group farm forestry experiments in West Bengal, the incentives to participants have been poor. As in farm forestry, seedling quality has also been poor, and this has greatly constrained both woodlot and tree tenure schemes. Environmentalists have also criticized tree tenure schemes for privatizing resources that rightly support a much wider set of users than can be allotted individual plots.

NEW TRENDS IN REVENUE LAND DEVELOPMENT. Recognizing the problems in earlier implementation, the states have introduced a number of changes in their programs. Technologies have broadened to include pasture development, silvipasture, more planting of multipurpose species, and multitier canopy models. Much more work is needed in this area, but technologies are changing. The NWDB has involved a variety of NGOs in planting schemes, but as mentioned above the NGOs and their clients have seldom been given adequate tenure rights. Experiments have allowed smaller groups than the panchayat to manage plantations, but extension to such groups and tenure security have still been weak.

Indian experts are divided about the potential for developing revenue lands. There is no argument that the least productive lands are unlikely to be successfully developed. Nor is there argument that without careful attention to tenurial, institutional and technical arrangements, such development is unlikely to be economical or sustainable. Where opinions differ is whether with proper extension, inputs, and training, local communities will sustainably develop and manage CPRs or whether most villages in India are too "modern" to revive the CPR systems.

One major problem is the failure to target resources to sites and village institutions having more chance of success. Government and NWDB strategies still channel financial resources for wasteland development in equal amounts regardless of the site quality. Another problem is the continued lack of a coherent policy for allocating public wastelands to interested user groups.

The estimate made earlier in this paper that 2.5 million hectares of public wasteland can successfully be developed with proper attention assumes that the major initiative will come from NGOs and local communities themselves. The NWDB should continue to promote development of such lands, but extension efforts by the Forestry Department should be much more focussed on technical packages for promising sites and on supplying the short- and long-term benefits that sustain the interest of groups managing the resource. Since it is impossible for the government to target revenue lands with the greatest potential through general state programs, it is important for forestry departments to give the responsibility for site selection and afforestation to local groups interested in such initiatives. Grant programs should promote creative institutional arrangements that involve smaller user groups endorsed by the panchayat (but not necessarily dependent on the panchayat for its management), channelling funds through [the NWDB and other locally organizations. NGOs should play a major role in providing technical assistance for institution building, group formation, and training.

Private wasteland development

There is much more scope for developing private wastelands than public uncultivated lands, largely because tenure security is greater and institutional arrangements are more simple. Issues surrounding incentives in farm forestry remain problematic in most states, but with proper policy reform and technical support, development of a portion of private, uncultivated lands under trees or pasture can be economical. Analysis of the potential, however, is complicated by the many constraints now facing farmers: (a) the generally poor genetic quality of many of the trees planted; (b) the difficulty in obtaining the necessary permits for harvesting or transporting restricted species; and (c) the competition in the same markets with products from different lands (for instance, trees from fast-growing plantations on government lands compete with those from panchayat-established plantations on common lands and those grown by private farmers). Where genetic stock is poor, it may not be economical to retain trees for longer rotations, since they may not put on incremental growth within an economic time frame or yield poles straight enough to be attractive to traders. Where official permits are required, middlemen enter the market to assist farmers with permits, raking off a substantial portion of the profits.

One model being promoted to help private farmers develop wastelands is cooperatives. Tree growers cooperatives have been developed on a limited scale thus far. In Gujarat, tree growers cooperatives provide a lobby for information and services and may market collectively; in Gujarat and Karnataka, dairy cooperatives have also developed fodder reserves on communal or private wastelands. Effective mechanisms have not yet been developed for supporting the cooperative model on a large scale, however, since collective marketing depends on having both a tight organizational framework and savvy entrepreneurs within the organization. Extension support from social forestry staff has been poor, partly because of the limited coverage of extension workers (only 6 percent of ranger time in Andhra Pradesh, which is probably about the average in other states) and partly because of the limited marketing and entrepreneurial knowledge of the extension foresters.

Some NGOs have begun to concentrate efforts on privately owned wastelands rather than on revenue department lands, promoting and brokering informal agreements between marginal groups and landlords for development and protection of forest and pasture resources in exchange for usufruct rights and benefits. The Overseas Development Administration is funding experiments like this in Karnataka state through MYRADA and the Aga Khan foundation is financing similar experiments in the drought-prone districts of Gujarat through its Rural Support Program (AKRSP). These experiments are still relatively small, and data for assessing the minimum level of returns required to interest groups and landlords in such arrangements is lacking. The areas taken up so far, however, show promise.

Non-timber forest products

There is clear evidence that non-timber forest products are a significant source of subsistence products, employment, and household income to a large percentage of the Indian population. NTFP production and use is high in Madhya Pradesh, Maharashtra, Orissa, West Bengal, Andhra Pradesh, and the northeastern states. It is officially estimated that NTFPs generate US$700 million annually in Madhya Pradesh and about US$115 million annually in Maharashtra, compared to wood values of Rs 3,250 million in Madhya Pradesh and Rs 1,300 million in Maharashtra. Tribal populations depend very heavily on NTFPs for income and subsistence. The value of NTFP to tribal populations is very difficult to quantify because of the lack of data on consumption and collection rates or studies comparing the value of locally consumed NTFP with comparable commercial products. Maharashtra-based tribal groups living near forests derive about 30 percent of their diet from forest products, and West Bengali tribal groups in the rehabilitated forest areas of South Bengal collect thirty-nine plant food products and forty-seven medicines for human or animal use. Microstudies by IBRAD in West Bengal show that FPCs members earn on average Rs 2–9 per day from commercial NTFP.

The current and future potential for NTFP production, utilization, and income generation is very poorly understood. In areas under joint forest management in West Bengal, for example, studies on the current benefits from NTFP in the form of consumption products, medicines, saleable products, and NTFP-based processing industries have been carried out only for a few sites. The more productive forest committee members in those areas have earned about Rs 2,800 per year per family. Studies of Orissa tribal districts show that access to NTFP is affected by income strata and that elite tribals are capturing a larger share of NTFP by their control of lands close to the village. Not surprisingly, the income from NTFP was much higher for higher-income households in these districts, and poorer households were forced by to depend more heavily on illegal fuelwood headloading and sale.

Only limited research and knowledge is available about the techniques and potential for expanding production of NTFP and propagating the trees and shrubs that product them. Studies carried out on sisal, bamboo, and tassar silk during the preparation of a Bank-supported forestry project in Maharashtra showed a very mixed picture regarding the potential for these products. Studies on promoting the tassar silk industry in West Bengal demonstrated that supporting activities would be needed but that its promotion on a limited scale was economical. Processing technology is not yet efficient for these products, wage returns to labor are not high compared to other employment opportunities, and markets are not assured countrywide, particularly where a nonbiological substance can be substituted. Comparative studies for other states have equally undramatic results. Studies of NTFP enterprises in Karnataka that employ large numbers of women were commissioned by the Food and Agriculture Organization of the United Nations (FAO) through the Institute for Social Science Investigation in Bangalore. They show that in the *uppage* (a condiment) and *lac* industries women are being increasing marginalized as these products become commercialized and as markets for end-products change; that men are capturing higher-wage opportunities in the collection, processing, and marketing; and that sustainable systems for production of the raw material have not been put in place. These findings could apply to a host of other NTFP in India.

Government monopoly extraction, sale, and processing of NTFP in a number of states has apparently reduced exploitation of tribal collectors of NTFP, but has not led to substantially higher returns to labor, sustainable production systems, or participation of tribal collectors in higher-value management or entrepreneurial activities. The government is aware of the paternalistic nature of government monopoly extraction and trade in NTFP but has been unable to implement politically, economically, or institutionally viable solutions. The various cooperatives established in tribal areas have not developed strong tribal leadership, nor have these societies moved away from collection of raw materials to entrepreneurial marketing or processing roles. Through schemes for village ecodevelopment and joint forest management, the Maharashtra Forest Department intends to encourage the tribal Forest Laborer Cooperatives Societies to expand their plantation and timber harvesting activities to include contract afforestation and NTFP-related entrepreneurship. There is no clear evidence that the societies will be successful in expanding their present roles, however, particularly since the Forest Department did not find it appropriate to give them a free hand with plantation contracts when their harvesting activity was reduced in response to the 1988 Forest Policy.

A clear decline in the availability of NTFP because of deforestation and degradation has been documented (Fernandez, Menon, and Viega 1988). More work is needed on institutional arrangements, technical options, and market potentials before it is possible to make estimates about the future of NTFP as a source of revenue, employment, subsistence products, and income. Research is sorely needed in this area on the technical propagation and management options for different forest types and diverse institutional arrangements.

Biodiversity conservation

India includes ten broad biogeographic zones that incorporate a wide range of biodiversity in twenty-five distinct biotic provinces (secondary units or communities within a zone). Ten of these biotic provinces and eighteen biomes (an ecological unit within the biotic province) at risk today. Indian flora comprises around 15,000 flowering plant species, or 6 percent of the world total. An estimated 33 percent of these species are endemic, and as many as 3,000–4,000 are endangered. Areas rich in plant endemism are the northeast, the Western Ghats, and the northwestern and eastern Himalayas. The Andaman and Nicobar Islands contribute at least 220 species to the endemic flora. Diversity is also high among the faunal groups. Mammals comprise 341 species (23 endangered), with 63 percent of the land mammals found in the northeast, mainly in Assam. India's 1,178 bird species represent 14 percent of the world total; at least 70 of them are endangered. The reptile and amphibian fauna include 400 and 165 species respectively, with an unknown number under threat. Endemism among the faunal species varies substantially, from a low in mammals and birds (3.5 percent) to highs in reptiles (32 percent) and amphibians (62 percent). Important areas of endemism are the Western Ghats and the northeast. The World Conservation Monitoring Center has identified five locations in India in their list of World Centers of Plant Diversity.

The high human and livestock population density places considerable pressures on these resources. To conserve the high biological diversity, an extensive system of protected areas has been established in the country.

Policies and legislation

Protection of wildlife had a long tradition in Indian history. Directives to protect the environment and all forms of life were inscribed in ancient Hindu scripture. The concept of protected areas emerged during the fourth century B.C.E., with the establishment of *abhayaranyas* or forest sanctuaries. Sacred groves were much older, dating back several thousand years. Later, many rulers established hunting preserves, a number of which have been incorporated into current national parks and sanctuaries.

The first legal provision for the protection of wildlife to be enacted in India was the Elephant Preservation Act promulgated by the British in 1879. This single-species legislation was followed by the Bengal Rhinoceros Act of 1932. The first generalized law, the Wild Birds and Wild Animals (Protection) Act of 1912, was of limited use as it applied only to animals specified in the schedule and within the territory of British India. The Indian Forest Act (1865) that was later succeeded by the more comprehensive act of 1927 provided a considerable degree of protection to wildlife through the restriction of hunting to "reserved" or "protected" forests and the provision for sanctuaries.

Today in India, the legal protection of wildlife in India is based on the Wildlife (Protection) Act of 1972, which establishes protected areas and controls trade in wildlife products. The act also provides for wildlife advisory boards and preservation staff and for the notification of specified categories of protected areas: national parks, sanctuaries, game reserves, and areas closed by state governments. A major deficiency of the act is that it recognizes only animals and birds and not plants. It has been adopted by all states and union territories except Jammu and Kashmire, which has its own Wildlife (Protection) Act.

Under the Wildlife Protection Act of 1972, creating and maintaining national parks and sanctuaries and funding wildlife protection are the responsibilities of the state governments, although the central government has various schemes under which it can extend financial support. The central government has, however, overriding power on policy and legislative matters. The central government maintains a Wildlife Preservation Directorate within the Ministry of Environment and Forests to guide and help fund state wildlife programs.

At the state level, the wildlife sector is administered by the wildlife wings in the state forest departments. Although all state and union territories that have national parks and sanctuaries have wildlife units, not all them have control of all the parks and sanctuaries. On average, approximately 3 percent of the total Forest Department budgets are annually spent on the national parks and sanctuaries. The Wildlife Institute of India, the government agency responsible for wildlife research and training, increasingly contributes to policy and management concerns at the state and national level.

The most significant action toward wildlife conservation in India was the framing of the National Wildlife Action Plan in 1983. This plan guides the overall conservation of biodiversity in India through broad approaches: (a) establishment of a representative network of protected areas; (b) management of protected areas and habitat restoration; (c) protection of wildlife in multiple use areas; (d) rehabilitation of endangered and protected species; (e) captive breeding; (f) wildlife education and interpretation; (g) research and monitoring; (h) domestic legislation and international conventions; (i) national conservation strategy; and (j) collaboration with voluntary organizations and NGOs.

Special conservation projects aimed at preserving certain endangered species have been initiated by the central and state governments: the better-known ones are Project Tiger, Crocodile-Breeding Project, Gir Lion Sanctuary Project, and the Himalayan Musk Deer Project. While there is concern from environmentalists that these projects focus too much on a few "glamorous" species, they—particularly Project Tiger—have been very successful in protecting entire ecosystems that a disinterested public would otherwise have allowed to decline.

India is signatory to a number of international conventions and treaties, including the Convention on Wetlands of International Importance Especially as Wildfowl Habitat (Ramsar), the Convention on International Trade in Endangered Species (CITES), the Convention on the Conservation of Migratory Species of Wild Animals, and Convention between India and the Soviet Union for the protection of migratory birds.

Coverage of protected areas

India's rapid progress in expanding its network of protected areas, especially in the last thirty years, has been quite impressive. From a modest total of about 60 national parks and sanctuaries in 1960, the total today stands at more than 480 national parks and sanctuaries, covering nearly 4 percent of the country. Despite its wide coverage of biomes and species, the existing network poorly represents some biogeographic zones having critically endangered species, such as the Trans-Himalayan, Gangetic Plains, and the northeast. This probably is caused by the lack of uniform criteria for classifying protected areas as parks or sanctuaries, with the result that areas of great biological value are declared sanctuaries rather than parks or left out altogether while some parks and sanctuaries include areas of very low biological value. Seventeen mammal species in Schedule 1 of the Wildlife (Protection) Act have no viable populations in national parks and a further seven are dependent on the protection offered in a single park. Many of the sanctuaries are extremely small to be expected to maintain any viable populations, particularly of the larger mammals.

Furthermore, the existing national parks and sanctuaries are not well protected, for a range of problems: (a) legal procedures are incomplete for 60 percent of the national parks and 90 percent of the sanctuaries; (b) there are no management plans for 57 percent of the national parks and 29 percent of the sanctuaries; (c) the management of individual protected areas and their surrounding areas are not well integrated; (d) there is much destructive human activity within the protected areas such as collecting forest products and grazing animals; (e) there is no integrated protected area system (IPAS) to link the areas by forested corridors or complementary multiple use areas; and (f) the state wildlife units are typified by limited jurisdiction, understaffing, limited training, and inadequate budgets. The Wildlife Institute of India has proposed an expansion of the present network from 4.0 to 4.6 percent of India's geographic area in 148 parks and 508 sanctuaries, but the proposal has been drawn up entirely on biological considerations without taking into account the administrative, political and socio-economic problems that need attention if the this proposal is to be viable.

For most of this century, timber production has dominated forest management concerns in India. Although the exploitation of plantations within protected areas is prohibited by law, the reality is different. Many protected areas include plantation areas and logging in protected areas is therefore permitted in practice if it is not deemed detrimental to wildlife. Timber exploitation takes place in 78 percent of the sanctuaries and 16 percent of the national parks; however, there have been few studies on the impacts of these operations on wildlife.

There is also too few explicit guidelines for maximizing environmental benefits and biodiversity as well as marketable produce outside of the protected areas. The soundest strategy for preserving the full range of biodiversity lies in the establishment and stringent management of a comprehensive network of protected areas covering all biogeographic units, biomes and species. However, in a country like India where the human and livestock densities are high, pressures on protected areas are strong and their future cannot be guaranteed. Complementary strategies are needed for promoting biodiversity outside of protected areas as well as for seeking creative solutions to the management of protected areas under pressure.

Toward an improved strategy for biodiversity conservation

There are three interrelated components to an integrated protected area system (IPAS) for India: (a) extending and improving the protected area network; (b) increasing benefits to local populations in and around protected areas; and (c) managing multiple use forest lands for biodiversity conservation. India also needs an adequate information base on the various ecosystems for evaluating which ecosystems need most protection, what level of protection is required, and what minimum area coverage is needed for a particular ecosystem. To devise an adequate IPAS, better information is needed on (a) the appropriateness of the current proposal in light of social, political, and economic conditions; (b) the constraints on completing legal notification of protected areas and workable changes in procedures to address these constraints; (c) identification at a state level of the institutional changes needed to strengthen wildlife units and link these to state forest department planning cells; and (d) evaluation of the options for monitoring the environmental status of specific protected areas.

Given the extremely high human and livestock pressures on protected areas, strategies to conserve biodiversity must include people's needs as an integral part of management plans and must experiment with participatory approaches that involve surrounding populations in the management of protected parks and sanctuaries and the conservation of complementary areas outside them. Species and habitats within protected areas are certain to diminish dramatically unless local demand for forest products and services are met.

Three kinds of ecodevelopment strategies need to be pursued. First, parks and sanctuaries must be appropriately zoned to include core protection zones and areas that can provide food, fodder and forest products to the local people on a sustainable basis. Better management of non-forest lands under agroforestry, improved rainfed agriculture, and the promotion of non-farm income-generating enterprises can all relieve pressure on protected areas. Second, more forest lands outside the protected areas network can be managed under forest department jurisdiction or joint management to supply local needs or can be put under a multiple-use management system that conserves biodiversity while serving national and local interest. Third, joint management models can be expanded to protected areas to involve local communities as responsible partners in planning, implementation, and decisions on biodiversity conservation.

Given the lack of suitable models for ecodevelopment, pilot programs can test policies, institutional arrangements, and packages of interventions. To initiate such pilot activities, working committees need to be established at state levels, involving a variety of agencies, NGOs, and the private sector.

The isolation of individual protected areas as "islands" amid agricultural land and human settlements can result in a progressive erosion of genetic diversity within the protected areas themselves as a barrier is created to the normal mixing and outbreeding of populations. Multiple-use forests around protected areas, when managed with improved conservation ethics, can offer excellent opportunities for extending the range of biodiversity and can greatly enhance the conservation value of the protected areas themselves.

A number of states have working plans on paper that include forest zonation and silvicultural practices in multiple-use forests and plantations designed to encourage dispersal linkages between the core protection zones of protected areas and thereby enhance biodiversity conservation. These plans include the maintenance of natural forest strips along streams, other water courses, and migratory routes and the preservation of selective old-growth stands. Some silvicultural techniques for enhancing biodiversity include selective thinning to favor species characteristic of natural forests, staggered harvesting to suppress weed growth and favor maintenance of habitat diversity, and reductions in the size of coupe (the area of timber operations) and the rotational interval of harvesting.

Few states follow these measure in practice to any extent, however, and there is a need to monitor and revise measures to achieve the desired objectives. A national committee might be set up, perhaps including the Planning Commission, the Ministry of Environment and Forests, NGOs, and researchers to develop a strategy for experimentation in this regard. Simultaneously, planning units within state forest departments should include more ecological expertise to evaluate current working plans and make recommendations for adjusting those plans to meet biodiversity objectives.

Conclusions

With an improved policy and incentive framework and more targeted forest strategy, India could reverse the trend toward greater degradation and loss of forest and pasture resources. While it is highly unlikely that the total area under forest can be increased from the current 20 percent, it is possible to improve the quality of forest and pasture resources and to increase the extent of tree cover and flow of forest products from revenue department and private lands. And although it will be more difficult, it is also possible to improve the management and quality of protected areas, expanding these through the development of an integrated protected areas system. India's forest strategy must become more targeted—prioritizing forest development activities on lands with the greatest biophysical and socio-economic potential for development.

To achieve these objectives, it is imperative that local people become a more integral part of forest development and management and of protected areas management. Expansion of joint management should be a prime goal of government forest development. More attention is needed on restructuring the forest service at the state level to improve extension and provide necessary specialization of staff. The comparative advantages of NGOs to provide complementary extension support to government should also be explored and their participation promoted. More attention is needed to developing technical models that maximize returns (and thereby incentives) to local people for protecting and managing forests and pastures. In this regard, more research is needed on the technical models for increasing the production of non-timber forest products, and more support is needed for the promotion of value-added marketing and NTFP processing. More research is also needed on pasture development and strategies for controlled grazing in drier areas where stall feeding is not economical.

For those protected areas where human activities are extensive, the local population must be brought into management-planning and protection activities, experimenting with creative ways to share returns with local people. Greater attention must also be paid to development of corridors that link protected areas and to maximizing biodiversity outside of protected areas in multiple-use forests. The government should also develop a more comprehensive strategy for fuelwood substitution, particularly in urban centers, to reduce the pressure on forests and nonagricultural lands to supply fuel for cooking and small manufacturing.

Some forest lands will inevitably be put under a non-forest use—such as some of the areas currently under shifting cultivation or areas already heavily encroached by local populations on the forest fringes. For these areas a more sustainable land use should be promoted. Forest policy envisions returning all of these lands to forest department control, perhaps under a system of joint management.

Policy incentives are needed to encourage private planting in appropriate, presently underutilized fallow lands and marginal croplands. Research and focussed technology development are also preconditions for private wasteland development. These efforts, combined with more-targeted extension by forestry field staff to private farmers and promotional support from NGOs, are likely to increase the area under private forest and pasture.

While community approaches to wasteland development are still problematic, there is a clear need to continue to promote communal management of common property resources under revenue department jurisdiction to provide needed products and environmental services to local people, particularly the rural poor. The government does not have a comparative advantage in promoting community institutions for revenue land rehabilitation. Funds and extension support should be channelled through NGOs and local institutions, relieving the government of blanket afforestation targets on lands outside the forest estate that require an extensive government staff presence and divert government resources from other forestry programs.

There are a number of information gaps that need to be filled if the government and those responsible for state forest sector planning are to be able to devise practical strategies for future forest development in India. These include (a) information on appropriate institutional arrangement for the different private and revenue wastelands to be treated; (b) technical options for jointly managed forests, shifting cultivation lands, and pastures; (c) information on biodiversity dynamics and socio-economic conditions needed to redefine protect areas boundaries, improve management plans, and manage complementary forest areas for biodiversity conservation; and (d) information on the range of institutional arrangements that are appropriate for joint management, including the legal prerequisites for such institutional arrangements.

Notes:

1. The term "wasteland," as defined by the National Wasteland Development Board, means those lands that are currently used far below their productive potential.

2. A 1986 study in six states carried out by an ICRISAT researcher has documented that the poor derive the bulk of their fuel and fodder supplies and significant income from CPRs and that, in the aggregate, CPRs in twenty-four villages supplied

14–23 percent of average household income in all income strata (Jodha 1986).

3. To arrive at these figures, several assumptions have been made. Given the extreme ambiguity of tenure on public wastelands and their generally poor quality, it is unlikely that effective treatment could be carried out with sustained local management on more than 20 percent of the available area. While marginal crop lands would yield the highest productivity to farmers, many farmers with small holdings would likely be unwilling to convert even marginal crop land to trees and so we estimate that only one-quarter of this land would come under cover with proper extension. On private lands, farmers could devise ways to protect and have incentives to develop about a quarter of permanent fallows.

4. An update on these figures is provided by Shah (1994), who reports that more than 10,000 communities now protect some 2 million hectares of regenerating forests in eastern India, encompassing West Bengal, Bihar, and Orissa.

5. IBRAD, a research institute in West Bengal, studied forty-two Forest Protection Committees (FPCs) in Jamboni Range and found that: (a) 74 percent were functioning reasonably well; (b) there was considerable heterogeneity of ethnic composition, number of villages, and proportion of participating households among them; (c) the smaller the number of villages participating, the greater the effectiveness; (d) the greater the proportion of tribal composition in the FPC, the greater the effectiveness; and (e) the greater the proportion of households in each participating village included as FPC members, the better its management of the forest.

6. The farm forestry scheme of the West Bengal group was carried out in the semi-arid districts. As part of ongoing land reform, small farmers and landless households were given, with a 99-year lease (*patta*), land that was too degraded for agricultural crops. They planted the lands with eucalyptus seedlings, and formed groups with the farmers on contiguous lands to provide protection and group marketing capability. The program was extremely successful and led to the introduction of tree tenure schemes in other states. In contrast to West Bengal, the other states did not provide land *pattas*, but gave farmers rights over the trees being planted only for the life of the rotation.

Bibliography

Agricultural Finance Consultants. 1991. Study report on wastelands availability and production potential, Bombay.

Argawal, Anil, and Sunita Narain. 1989. *Towards green villages.* New Delhi: Centre for Science and Environment.

Asia Sustainable Forest Management Network. 1994. Proceedings of the policy dialogue, natural forest regeneration and community management workshop. Research Network Report no. 5, East-West Center, Honolulu, Hawaii.

Bentley, William R. 1984. The uncultivated half of India: Problems and possible solutions, DP no. 12 (mimeo), Ford Foundation, New Delhi.

Bhumbla, D.R., and Arvind Khare. 1984. Estimates of wastelands in India (mimeo), Society for Promotion of Wastelands Development, New Delhi.

Campbell, J. Gabriel. 1989. Whose land is this? Paper presented to CPRM conference, Durham, North Carolina, September.

Chambers, Robert, N.C Saxena, and Tushaar Shah. 1989. *To the hands of the poor: Water and trees.* New Delhi: Oxford & IBH Publishing Co.

Clark, Ann. 1991. *Marketing of forest produce in West Bengal.* Washington, D.C.: World Bank India Agriculture Section.

Contreras-Hermosilla, Arnoldo. 1992. *India: Forestry incentives.* Washington, D.C.: World Bank.

Environmental Resources Limited. 1988. Natural resource management for sustainable development: A study of feasible policies, institutions, and investment activities in Nepal with special emphasis on the hills. A study for the Overseas Development Administration and the World Bank.

Fernandes, Walter, Geeta Menon, and Philip Viegas. 1988. *Forests, environment and tribal economy.* New Delhi: Indian Social Institute.

Food and Agriculture Organization (FAO) of the United Nations. 1991. *Women's role in dynamic forest-based small-scale enterprises.* Rome: FAO.

Gadgil, Madhav. 1982. Forest management and forest policy in India: A critical review. In Walter Fernandes, ed., *Forests, environment and people*. New Delhi: India Social Institute.

Government of India (GOI). 1976. *Report of the national commission on agriculture, part IX: Forestry*. New Delhi: Ministry of Agriculture and Cooperation, GOI.

Jodha, N. S. 1986. Common property resources and rural poor in dry regions of India. *Economic and Political Weekly* 21(27): 1169–81.

Khan, Irshad. 1987. *Wastelands afforestation*. New Delhi: Oxford & IBH Publishing Co. Pvt. Ltd.

Kothari, A. 1989. Management of national parks and sanctuaries in India: A status report. New Delhi: Indian Institute of Public Administration.

Maharashtra Industrial and Technical Consultancy (MITCON). 1991. *Report on current situation and the potential for non-timber products: Bamboo*. New Delhi: Shivajinagar.

Poffenberger, Mark, Kirin Bhatia, and Betsey McGean, eds. 1990. *Forest management partnerships: Regenerating India's forests*. New Delhi: The Ford Foundation and the Indian Environmental Society.

Smith, Kirk R., and Jamuna Ramakrishna. 1991. Improved cookstove programs: Where are we now? East-West Centre, Energy Sector Management Assistance Programme, United Nations Development Programme Evaluation Report. Honolulu: Risk and Development Program, Environment and Policy Institute.

Vohra, B.B. 1985. The greening of India. In J. Bandyopadhyay, ed., *India's Environment, crises and responses*. New Delhi: Natraj, Dehradun.

World Bank. 1992. *Gender and poverty in India*. Country Study. Washington, D.C.

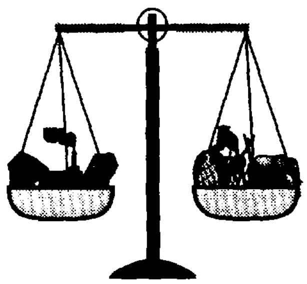
———. 1991. *Forest sector*. Policy paper. Washington, D.C.

———. 1990. *India: Industrial energy efficiency and modernization project*. Staff Appraisal Report. Washington, D.C.

——— 1988. *India: Wasteland development review*. Washington, D.C.

5

Economics of Tree Improvement in Development Projects in the Tropics



G. Sam Foster, Norman Jones, and Erik D. Kjaer

Introduction

People have reaped enormous benefits from domesticating annual plants such as wheat and rice and perennial plants such as apples, mangoes, tea and coffee. These species are fully domesticated and only the stock originating from selected genetic varieties is planted. A major benefit of domestication is the development of varieties with greater productivity and better resistance to disease and environmental stress and, ultimately, the production of a more-valuable crop. Another significant advantage is the ability to predict, with a high degree of accuracy, yields for given site conditions. The process of domesticating forest tree species is under way but much less advanced than that with agricultural species.

The success of artificial reforestation is determined by the physical and genetic quality of the planting stock. Ensuring physical quality requires careful handling of seed, appropriate conditions for germination, and proper nursery practices. The latter quality is influenced by genetic identification and manipulation—activities most commonly associated with tree improvement. For the purposes of this paper, the improvement of either aspect of quality is considered "tree improvement."

Tree improvement programs are an integral part of reforestation programs in many countries worldwide, especially where artificial regeneration is used, and have been active in some countries for forty years or more (Zobel and Talbert 1984; Zobel, van Wyk and Stahl 1987). Out of this experience has grown a good understanding of basic improvement procedures, such as the genetic control of economically important traits for many of the tree species of industrial interest.[1] Box 5.1 provides an overview of the basic concepts or steps in improvement programs.

The incremental cost of using high-quality planting stock is relatively insignificant compared to total plantation establishment costs, yet "cheap," low-quality seedlings or clonal propagules are frequently used and result in costly plantation failures. More often, the use of cheap seed simply produces poor-quality, underperforming plantations. Although these poor plantations may eventually yield wood, the yield is of low volume and value and the sites are underutilized. The indirect cost associated with the failure to use the full potential of the site is known as an opportunity cost. In the same way, poor nursery practices that result in poor plantation development or outright plantation failure have large opportunity costs associated with them.

Despite the importance and prevalence of these types of opportunity costs, little attention has been given to them in the literature

Box 5.1 Major steps in tree improvement programs

Most tree improvement programs can be divided into four major parts: selection, mobilization, orchard establishment, and genetic testing. *Selection* refers to the process of choosing a subset of the population that will be allowed to contribute toward either future reforestation or breeding toward that end. The old adage that local seed is best has been questioned (Namkoong 1969); therefore, identifying superior seed sources for a particular region or group of sites is often required. Where exotic species are concerned, determining superior sources is a mandatory first step, without which a potentially useful tree species may be rejected.

After superior seed sources have been identified, the next step (sometimes accomplished concurrently with seed source selection) is to select superior individual trees (phenotypes) for inclusion in the breeding and production populations. This is the *mobilization* phase, in which genetic material is selected and centralized at sites where it can be conveniently protected, manipulated and multiplied.

The *orchard* phase is marked by the establishment of a genetic archive (frequently called a clone bank) or a production seed orchard or cutting orchard. A seed orchard provides seed for seedlings and a cutting orchard provides cuttings for rooted cutting production. Two purposes are generally served in this part of the program: (a) collecting exact genetic copies of each select tree (via grafting, rooted cuttings, or tissue culture plantlets) at a single location for preservation and future breeding and (b) establishing a mechanism for producing adequate numbers of either genetically improved seeds (which become seedlings) or genetically improved vegetative propagules (usually rooted cuttings) for reforestation. These enhance forest productivity and hence increase financial returns.

The physical characteristics of each organism (phenotype) are the product of its genetic constitution (genotype), the environment in which it lives (environment), and the interaction between the genotype and its environment. *Genetic testing* refers to the methods whereby apparently superior trees are systematically tested to assess their true genetic value. Most, if not all, traits of economic interest in forest trees are controlled by many genes (polygenic inheritance), and to complicate the issue further, the true genetic value of an individual may be strongly masked by environmental effects. Therefore, genetic testing is an essential part of a tree improvement program. Genotypes with proven superiority, according to the genetic testing, can be selected either to enter the next generation of the program or to remain in a seed or cutting orchard after the proven inferior genotypes have been removed (rogued).

The benefits that arise from a well-designed tree improvement program are widely recognized, and fortunately a wealth of research has identified effective tree improvement measures that are relatively simple and inexpensive to undertake. This information is particularly important when experienced tree improvement workers or funding are in short supply. For example, all foresters are aware that seeds collected from superior phenotypes are likely to produce better trees than seeds from malformed trees. Further, empirical evidence indicates that rooted cuttings from rejuvenated superior phenotypes often perform better than seedlings from a general seed collection. This information can be used without further research. The observations mean that funds spent on selecting superior phenotypes and either collecting their seeds or cloning them will provide significant financial benefits.

on tree improvement or nursery practices. Perhaps because of this, many planters in public service departments and private business quibble over the minor amounts of money needed to provide improved planting stock. In response to these arguments, this chapter will

- Present an overview of the basic components of a tree improvement program

- Provide insight into the trade-offs that have to be made when a tree improvement program is being established or redesigned
- Examine the opportunity costs that arise when planting stock quality is compromised to save a small amount of money in nursery or seed procurement financing.

Choosing the appropriate intensity of a tree improvement program involves a careful comparison of the value of quick, medium results with the larger but delayed gains that can be achieved through a more-intensive and systematic program. For example, investment in either seed orchards or clonal production has to be weighed against the time it will take for improved material to become available in the quantities required for a planting program. This is not necessarily an either/or decision. There are some simple steps that can be taken to generate gains quickly, and these can be followed by a more-sophisticated, slower yet economically viable, improvement program. Finally, the delay of gains caused by not applying what is common knowledge must be entered into the economic analysis as a loss.

Objectives of a tree improvement program

When embarking on a genetic tree improvement program, or evaluating an existing one, it is crucial to identify the primary objectives of the program. In general, tree improvement activities are undertaken to improve the quality of the resulting plantations. However, it is rarely practical to improve several traits at once, because interactions between the genes confound the results and necessitate very extensive testing. Also, sometimes the improvement of one trait may lead to the regression of another. Therefore, improvement activities should be directed toward the specific traits that are considered most important for the particular species and reforestation program—often those strongly related to the economic value of a tree or plantation.

Deciding which traits to improve

The best traits to improve are those that are of high economic importance and are amenable to genetic improvement. Generally, the characteristics of high economic importance relate to productivity: volume production and wood quality in timber-producing species, dry matter production in pulpwood species, or fuel and fodder in many species used in agroforestry. Survival and health traits are always very important, and the need to target genotypes that are resistant to pests and disease becomes increasingly important as the level of domestication is increased. As discussed earlier, most traits of economic importance are controlled by complex interactions between several genes and are significantly influenced by environmental factors.

Knowledge of the relative and absolute economic value of the gains is important to determine the best breeding strategy. However, establishing the relative economic importance of various traits can be very difficult. For instance, the economic benefit of a 10-percent increase in timber volume production is relatively easy to assess, but the relative value of a 10-percent reduction in stem bends is much more difficult to appraise.

Moreover, not all attributes can be significantly improved. It is difficult to obtain genetic gains in traits that show little variability, and where a trait is uniform throughout the natural stands, improvement is not possible. Many traits also exhibit low heritability. Heritability is defined as the percentage of the total variation that is due to genetic differences. Low heritability indicates that the observable variation in a trait is caused mainly by environmental rather than genetic effects. Characteristics such as specific gravity, branch angles, or fodder value generally have higher heritability than volume growth does. Stem form often shows intermediate heritability depending on species and assessment age. In a tree improvement program, heritability can be increased when selection is based on the progeny of clonal trials instead of simple mass selection (according to the difference between selecting superior families rather than single trees as described in the appendix to this chapter).

The feasibility of improving several traits simultaneously depends on the correlation between the traits, but it is rarely possible to obtain substantial physical or economic gains if the breeding activities focus on more than a few traits. Table 5.1 shows how the expected gain per trait decreases when multiple uncorrelated traits are selected simultaneously. The selection intensity, which is the average superiority of the selected trees measured in terms of the trait's standard deviation (Falconer 1989), is also listed.

Techniques have been developed for calculating the optimal allocation of selection intensity for different traits according to their relative economic importance and mutual correlation (White and Hodges 1989). Such techniques require detailed information on the genetic behavior of the traits as well as their relative economic importance. Unfortunately, much of this information often is missing. However, the use of these optimal selection techniques does not change the basic fact that substantial gain can only be achieved if the tree improvement program is concentrated on the few most-important traits. Selecting which traits to improve is therefore one of the most important decisions in the design of a genetic improvement program, since it affects the gains and thus the economic return from the breeding activities.

Ranking by height, diameter, and volume

Wood volume production is probably the trait most widely included in tree improvement programs throughout the world. However, since volume is difficult to measure directly, tree height and diameter are usually assessed instead, and the gains are converted to estimated volume gains using volume tables or growth-and-yield equations in which height and diameter are independent variables. Volume is especially difficult to assess for multi-stem species. In these the total biomass is generally determined by weighing a sample of trees and correlating the weight of each individual to the number of stems and the diameter of the largest stem. The latter characteristics are then measured on all trees in the progeny trials (Steward and others 1992).

It is important to recognize that the growth rates of individual trees vary with age. The ranking of five-year-old trees by volume may be very different from the ranking of those same trees at an older age. Therefore, the best trees may not be selected

Table 5.1 Effects of number of traits selected on expected gain per trait

Expected number traits per selection	*Selected trees per 1,000*	*Selection intensity per trait* [a]	*Expected gain per trait (%)*
1	1/1,000	3.29	100
2	1/31.6	2.53	77
3	1/10	1.65	50
4	1/5.62	1.35	41
5	1/3.98	1.14	35

a. Selection intensity per trait assuming a selection of one tree out of one thousand, when different numbers of traits are included in the tree improvement activities. It is assumed that the traits are uncorrelated and have equal heritability.

Source: Modified from Wright 1976.

from progeny trials if selections are made on the basis of juvenile measurements. Empirical studies of a number of coniferous species in the temperate regions show that the importance of the changes in rank can be predicted roughly by a simple model suggested by Lambeth (1980). The model has proven fairly accurate in estimating the changes in rank for two tropical timber-producing species, *Tectona grandis* (teak) and *Gmelina arborea* (Kjaer and Lauridsen 1992).

Note that ranking the economic value associated with different levels of a specific trait can be more complicated than simply ranking trees on the basis of a physical characteristic; the gross economic gains are often greater than proportional to increases in volume. (Net gains are discussed later in this chapter.) On a per cubic meter basis, larger trees cost less to harvest and transport than smaller trees. Larger trees may also be used to produce products of higher value or grade. Finally, the use of improved stock may reduce rotation ages and contribute to economic value. On the other hand, improved trees may need lower stocking densities to obtain optimal growth, which influences production per unit area as well as establishment costs.

Improving wood characteristics and stem form

The improvement of traits related to quality may be attractive because they generally have high heritability and because improved quality can substantially increase wood value. Wood density and stem form are the most common quality traits recognized in tree improvement programs.

Wood density generally has high heritability but is time consuming to measure directly. However, indirect determination through use of the "pilodyn" has proven effective in several studies (Lauridsen, Wellendorf, and Keiding 1987, for *G. arborea;* Hoffmeyer 1979, for *Eucalyptus spp.;* or Cown 1978, for *Pinus radiata*).

Increased wood density raises the value of pulpwood, since pulp yields are higher per volume of raw material used. With the costs of pulping and related activities accounting for 20–30 percent of the cost of producing pulp, a 1-percent increase in wood density in effect lowers the total production cost by 0.2–0.3 percent. This may mean a 5–10 percent increase in the value of the wood. Breeding programs have developed progeny that provide significant savings in processing costs. In New Zealand, the progeny from one selected radiata pine require 25 percent less energy input for the same output of pulp (Poole 1991).

In addition, density is positively correlated with various strength properties that increase the value of dimension lumber produced from high-density trees. However, in several conifer species, fast growth is occasionally accompanied by decreasing wood density and strength. Therefore, breeding should strive to produce the optimum combination of growth rate and wood density to ensure the maximum economic net benefit.

Stem form is another important trait. Straight stems reduce transportation costs, increase the market value of veneer and timber production, and have higher fiber value since they contain less reaction wood. The price differential between high and low grades of lumber is usually at least several hundred percent and is often much greater in hardwoods. To the extent that poor stem form contributes to grade reductions or reduced lumber recovery, improved stem form can add significant value to wood.

Stem form has variable heritability. It can be difficult to quantify, but good results have been achieved in several investigations by using a scoring scale. Impressive improvement in stem form has been achieved in several instances following a single generation of tree improvement—for example, in *G. arborea* improved by Sabah Softwoods Sdn Bhd in Malaysia (Sim and Jones 1984).[2]

Color and other characteristics associated with the appearance of veneer are traits with high economic potential. Unfortunately, they are difficult to assess and little is known concerning their heritability.

Estimating fodder value and other multipurpose traits

Multipurpose species are frequently used in agroforestry and silvipastoral systems. The high production level and the nutrient content of the fruits and leaves are the major reasons that *Acacia* and *Prosopis* species are planted in dry tropical areas. These species also provide fuelwood and small timber. Studies of the fodder value and the nutrient content in leaves and pods have shown large variation between individual trees of the *Prosopis* and *Acacia* species (Graudal and Thomsen 1992), while several workshops have recognized the value of some Australian dry-zone *Acacia* species for human food (House and Harwood 1991). The major purpose for planting *Acacia senegal* (for example, in Sudan) is for the gum arabic extracted from this species (Bach 1992). Rubber trees are another well-known example of a multipurpose species; they can be harvested and used in the manufacture of wood products after latex production has declined. The improvement potential of all of these traits seems promising.

Tree improvement strategies

When a manager has selected which traits of a species to improve, the scale and design of the program has to be determined. The outcome depends in part on the optimal selection intensity, and it also concerns how closely seed sources are to be matched with the different growing conditions present in the forest estate.

Generally versus specifically adapted seed sources

Reforestation programs usually include large-scale plantings in different site conditions caused by variations in soil type, elevation, drainage, and humidity levels. Where variability is significant, an improvement program can be designed by (a) selecting seed sources for use over a wide range of growth conditions (*generally adapted*) or (b) identifying planting zones according to growth conditions and selecting or breeding seed sources that are *specifically adapted* to each planting zone (Namkoong and others 1988).

Breeding specifically adapted seed sources requires separate activities within each planting or breeding zone. Because costs increase with the number of zones identified, heterogeneous zones reduce potential economic gains. Genotypes that are fast growing on humid sites may be poorly suited to dry areas. These changes in rank are termed "genotype x environment (GxE) interactions" and their importance varies greatly with species and plantation site. GxE interactions are revealed by replicated field trials that cover a wide range of sites (Matheson and Raymond 1984). By analyzing such trials planners can estimate the expected reduction in yields and economic benefits of breeding from generally adapted seed sources. This kind of information will seldom be available in the initial phase of a tree improvement program. It is therefore advisable to divide an area that is very heterogeneous into two or more planting or breeding zones based on ecological parameters (such as elevation, precipitation or soil conditions).

A species can be grown for different purposes in different regions or even in different plantations within each region. In these cases it may be beneficial to produce seed sources suited to specific purposes (that is, develop multiple breeding populations), because of the difficulty (described earlier) of obtaining substantial gains in several traits simultaneously (table 2.1). These interactions are easier to predict than GxE interactions, and it is also easier to estimate the incremental economic costs and benefits in choosing the number of economic breeding zones to establish.

An intermediate solution is to breed in one general population (or gene pool) but to establish different seed orchards for sets of clones suited to different planting zones or end uses.

Selection intensity of an improvement program

There is an almost endless variety of tree improvement schemes, developed for different species, conditions, and available resources. Nine designs that represent most of the tree improvement programs currently used are described here (and are discussed in detail in the appendix):

- Option I: Seed source testing and collection of reforestation seed form the original locations.
- Option II: Seed source testing and collection of shoot cuttings for clonal reforestation from the best trees in either the best original locations or from the best trees in the seed source trial.
- Option III: Seed source testing, conversion of at least some of the trials to seedling seed orchards, and collection of seed from the orchards.
- Option IV: Seed source testing, followed by superior tree selection in the natural stands, progeny testing, and conversion of trials to seedling seed orchards.
- Option V: Seed source testing, followed by superior tree selection in the natural stands, progeny testing, and cloning (via grafting or rooting) the best trees in the progeny test into a seed orchard.
- Option VI: Combined seed source and half-sib family testing, with conversion of the trials into seedling seed orchards.
- Option VII: Combined seed source and half-sib family testing, with selection of the superior individuals in the tests and cloning the select trees into a seed orchard.
- Option VIII: Advanced generation tree improvement program in which superior selections from options IV, V, VI, or VII are intermated, progeny tested, superior selections made within the best full-sib families, and either the tests converted into seedling seed orchards of the superior trees cloned into a clonal seed orchard.
- Option IX: Clonal propagation of select trees and reforestation with the clones.

The most sophisticated program is not necessarily the best one for all circumstances. Each alternative meets a clearly defined purpose and the appropriate degree of selection intensity depends on the purpose of the program.

Several major themes can be detected as one reads descriptions of these alternatives. One theme is that tree improvement programs show diminishing returns. The first stage of improvement—seed source selection—tends to produce the largest gain, with subsequent stages providing lesser gains. Seed source selection can generate physical gains ranging from 10 to 30 percent. Seed source trials indicate which population to favor. They are followed by the selection of individuals initially identified solely by the female parent but eventually by both parents through controlled mating tests. Additional gains of 13–25 percent can be expected through choosing the best individual within a seed source, half-sib family, and the individual within a half-sib family (see option IV in the appendix). Further improvements of 15–25 percent arise when select trees are mated and selections are made within the resultant superior families.

A second broad theme is that increasing the selection intensity increases the time needed for obtaining usable results. For example, seed source identity trials give usable results in seven to twenty years, depending on the species. Testing individuals takes twelve to thirty-three years (option IV) while testing individuals of known parentage requires an additional twelve to twenty-six years (option VIII).

With virtually all of these alternatives, there will be some limitations related to the amount of seed available. Future seed requirements must be kept in mind when designing the seed orchard or seed production area. However, the use of vegetative propagation techniques allows for potential shortcuts in the production of seed and, for a number of species, of planting stock. Clonal production from selected phenotypes in the best populations will provide valuable interim productivity gains while waiting for further improvements from the breeding program.

To improve the supply of seed, clonal seed orchards can be established from either grafted plants or rooted cuttings from individuals selected in the most promising populations. In the first instance, clones are selected but untested. As the program progresses, progeny testing will verify individual superiority, and gains will be between 23 and 55 percent. When mature individuals are propagated (that is, grafted stock), early seed production can be expected; however, clonal stock from younger trees may take fifteen to thirty-six years to reach full seed production. If the chosen species coppice readily, as do some *Eucalyptus* spp., *Gmelina* sp., radiata pine, and a number of others, cutting orchards can be established alongside good, high-humidity propagation units. Planting stock can be raised by rooting cuttings, as has been practiced with poplar for centuries. Such populations will exhibit gains between 15 and 35 percent. If the parent stock is selected from the seed source trials, the cutting orchards will take from nine to twenty-two years to become fully established.

The clonal *Gmelina* sp., improved by Sabah Softwoods Sdn Bhd in Malaysia, was available for large-scale planting only three years after the best-suited source had been selected. A similar time scale has emerged in the World Bank–funded National Afforestation Project in China for some selected *Eucalyptus* spp.

Managers responsible for tree planting programs must review the alternatives and, taking into account the characteristics of the selected species (or related species), decide whether shortcuts are warranted. For a shortcut to be worthwhile, the benefits from immediate increased productivity must offset the period of time needed for the scientific evolution of truly domesticated planting material.

Economic assessment

The vast majority of studies on the performance of genetic tree improvement programs focus on temperate zone species, but the database on tropical species is increasing rapidly. The same analytical framework can be used to assess both programs, because the technologies used are all part of a process of species domestication.

Physical gains through genetic improvement

A sample of published rates of physical gain is presented in table 5.2. Only the rates of volume gain are shown, representing the most widely used measure of tree improvement success. These gains are attributed to changes in the genetic material alone or in both the genetic material and the improved nursery, planting and tending practices.

Most of the evidence in table 5.2 comes from work on loblolly pine (*Pinus taeda*), radiata pine and eucalypts. At the lower end of the spectrum, gains are on the order of 6–10 percent. However, a number of programs have shown considerably higher gains, with a few in the neighborhood of 40–50 percent. Overall, yield increases averaged 15–20 percent for loblolly pine, 20–30 percent for radiata pine, and 20–25 percent for eucalypts.

Volume increases from improvement programs focusing on other temperate softwood species have ranged from roughly 10 percent to a high of 80 percent, the latter reported by Brown (1987) from seed source selection of white spruce (*Picea glauca*). The greatest commercial impact is from Douglas fir (*Pseudotsuga menziesii*) in North America, where a simulation modelling exercise indi-

Table 5.2 Volume gains from tree improvement

Species	*Volume gain (%)*	*Situation*
Loblolly pine	10.7–13.0	Plus tree selection[a]
	32.5	Progeny test-save[a]
	17.0–25.1	Roguing/selection[b]
	10–20	First-generation SO[b]
	2.5–4	Minimum to support TI[c]
	8–15	Single cycle[d]
	6.4	Unrogued seed orchard (SO)[e]
	12.7	Rogued SO[e]
	15–20	Selection[f]
	23–25	Heavy roguing[f]
Radiata pine	19–23	Open pollinated (o/p)[g]
	27–32	Control pollinated (c/p)[g]
	15–18	First selection-o/p[h]
	25–32	Second selection-c/p[h]
	11–21	O/p orchards (1978)[h]
	45	C/p crosses (1978)[i]
	12–13	O/p (1979)[i]
	26	C/p (1979)[i]
	46	C/p crosses-best families (1968)[i]
	9–22	Seed orchard[j]
Eucalyptus	60	Improved seed[f]
	8.5	O/p progenies[e]
	7.8	Unpedigreed SO[e]
	7.8	Half-pedigreed SO[e]
	18.2	Rogued SO (forward selection)[e]
	17.4	Unpedigreed SO (initial selection)[e]
	22.6	CSO (backwards selection)[e]
	26–36	*E. grandis*-South Africa[g]
Caribbean pine	20–30	Provenance trials[h]
	10.4–14.7	SO-Queensland[i]
Maritime pine	15	CSO[j]
Pinus pinaster	30	Propagation-top families[j]
Jack pine	10[f]	
Red pine	10[f]	
Pine (var.)	5–15	South Africa[g]
Douglas fir	2.6–22.0	Simulation[k]
Norway spruce	10	Provenance test[l]
White spruce	80	Provenance selection[f]
	25	Improved seed[m]

Note: The percentage of volume gain is calculated from the additional volume of wood resulting from the genetic improvement and a base value. For example, an additional 1 cubic meter per hectare of wood under the tree improvement program as compared to a volume yield of 10 cubic meters per hectare from an unimproved source would be a 10-percent genetic gain. The basis for comparison can be either an unimproved seed source (or natural stand) or another improved seed source from, for example, an earlier generation.

Sources: a. Carlisle and Teich 1975. b. Porterfield 1974. c. Davis 1967. d. Hollowell and Porterfield 1986. e. Talbert 1982. f. Weir 1981. g. Arnold 1990. h. New Zealand Forest Products 1991. i. Shelbourne 1989. j. Wright and Eldridge 1985. k. Thomson and others 1989. l. Barnes 1986. m. Lester 1969.

cated gains of 2.6–22.0 percent. The tropical Caribbean pine (*Pinus caribaea*) holds promise of volume gains of up to 30 percent.

On the whole, the yield gains reported in table 5.2 are very impressive. The results shown demonstrate that greater gains tend to be achieved in more-southerly climes. The table also records the improvement practices followed in each study. In general, higher volume gains are the result of more-intensive genetic selection and more-sophisticated practices in seed orchards. These results provide a basis for considering larger investments in tree improvement programs.

While volume gain has been the major indicator of the biological effectiveness of tree improvement programs, there are other benefits that have been harder to quantify. These benefits include improved quality (straightness, fewer branches, higher specific gravity, and so forth), increased resistance to disease, increased survival, and reduced costs of weeding and seed collection. Many of these benefits help reduce processing costs or increase product revenue, which improves profitability in either case. A summary of these gains is provided in table 5.3.

As with volume yield, the most impressive gains are obtained using relatively sophisticated tree improvement technologies. The estimates described above are derived from rigorous trials with and without tree improvement technologies. Operational tree-growing practices are likely to be relatively poor in the absence of improvement technologies, particularly in developing countries. It could be argued that the use of genetic tree improvement technologies would lead to the adoption of more-rigorous physical procedures in nursery practices, planting operations, and forest management. The added expense of using these technological inputs could create an incentive to implement cultural practices more carefully. The aggregate benefits from tree improvement plus generally being more meticulous in cultural practices in the whole production process may lead to substantial financial benefits.

Economic and financial results

Estimating the financial benefits from tree improvement is not as straightforward an exercise as might be expected. It has already been noted that tree improvement work shows diminishing returns as the program intensifies. However, the two most important factors influencing the value of benefits are:

Table 5.3 Gains in traits
(other than volume)

Species	*Situation*	*Gain*
Loblolly pine	Improved seedlings	Process yield +5%[a]
	Improved seedlings	Process time –5%[a]
	Improved seedlings	Mill profits +15–41%[a]
	Improved seedlings	Straightness[b]
	Improved seedlings	Specific gravity[b]
	Improved seedlings	Disease resistance[b]
	Seed orchard—unrogued	18% value gain[c]
	Seed orchard—rogued	32% value gain[c]
Radiata pine	Open pollinated	+55% acceptable seedlings[d]
	Control pollinated	+78% acceptable seedlings[d]
	Improved seedlings	+50–80% acceptable trees for final crop[e]
	Improved seedlings	Improved straightness[e]
	Improved seedlings	Reduction in branch size[e]

Sources: a. Davis 1967. b. Weir 1981. c. Talbert 1982. d. Arnold 1990. e. Shelbourne 1989.

- The base over which the gains will be applicable
- The length of rotation in improved plantations.

The base indicates how large the yearly planting is and how many years it will be planted. (Factors affecting the economic attractiveness of tree improvement are discussed more fully in the next section.) Accordingly, there is no simple rule of thumb for estimating financial returns based solely on physical gains. Finally, it is worth noting that the estimated value of the benefits is truly valid only where existing baseline data permit the manager to estimate the size of physical gains.

Due to the difficulty of estimating economic returns, published records of economic or financial returns are harder to obtain than records of volume gains. Not surprisingly, analytical techniques and economic assumptions vary widely. Also, most of the available evidence relates to results from public sector research, which is not as aggressive as that from some private sector sources. Thus, reported figures probably underestimate the potential financial returns of tree improvement methods.

Bearing in mind these caveats, a selection of published rates of return on investment (ROI) from tree improvement is presented in table 5.4. As with the volume gain data, most of the citations pertain to work with temperate softwood species.

Available studies indicate rates of return for the improvement of loblolly pine averaging at 10–15 percent. Three other southern pines—longleaf (*Pinus palustris*), slash (*P. elliottii*) and shortleaf (*P. echinata*)—show results comparable to loblolly. Some pines show financial returns from as low as 4 percent to as high as almost 30 percent. Caribbean pine was about average, with financial returns ranging from 9.9 to 15.25 percent. The only study on radiata pine shows a very impressive range of 19.6–28.6 percent. Pines from more-northerly climates generally yield lower returns.

Canadian white spruce show quite modest results, ranging from 2.3 to 9.3 percent. Douglas-fir is reported to be slightly better, with most programs and simulations in the 7.4 to 8 percent range.

With regard to tropical hardwoods, Brown (1987) reports results in eight developing countries using improved Australian seed of various *Eucalyptus, Acacia* and *Casuarina* species. Internal rates of return range from a low of 22 percent in Lesotho, up to 70–81 percent from two studies in China. The average return for these eight countries was 56 percent. Brown estimates that worldwide returns just from utilizing improved seed are about 39 percent.

It is no surprise to find far more impressive rates of return from tree improvement in tropical areas than in temperate zones. In general, higher rates of return can be expected from species that reach seed-bearing age more rapidly, since improved seed will be produced sooner. Fast-growing species also have shorter rotations, which hasten the realization of benefits and improve the rate of return. Finally, other factors being equal, greater percentage gains will also lead to higher rates of return. Tropical species tend to have all of these characteristics, hence the high rates of return.

Comparison of tree improvement strategies

The magnitude of financial value at stake in decisions relating to tree improvement can be illustrated by estimating the costs and benefits of each improvement option describe in the previous section, as shown in table 5.5. Before the example scenario is described, it should be emphasized that the costs and benefits will reflect the local conditions and the biological characteristics of the species. In practice, there are usually large variations in both costs and benefits.

Table 5.5 shows the range of percentage gain obtainable under each program option, plus the range of time periods until usable seed or cuttings are produced. (The derivation of these data is explained in the appendix.) In the case of alternative VIII, only the additional gain and time requirements are shown. The gain is additive, so that if alter-

Table 5.4 Economic gains from tree improvement

Species	*Return on investment (%)*	*Situation*
Loblolly pine (*Pinus taeda*)	12–20[a]	
	10–14	Progeny test/rogue[b]
	8–13	Roguing only[b]
	18	Improved stock[c]
	17	Tree improvement for pulp/paper[d]
	15–19	Single cycle[e]
	13	Aggressive breeding[d]
	18–20	Rogued seed orchard[e]
	18[f]	
	15.5–20[f]	
	17–19[f]	
	8–14[f]	
	10–13	Constant stumpage rate[g]
	12–16	Modest increase in stumpage[g]
Longleaf pine (*Pinus palustris*)	14	Improved stock[c]
	14[f]	
	12–16.5[f]	
Slash pine (*Pinus elliottii*)	19	Improved stock[c]
	19[f]	
	16.5–19.5[f]	
Shortleaf pine (*Pinus echinata*)	11.5–19.0[f]	
Red pine (*Pinus resinosa*)	8.1–9.2[f]	
	6.1–6.7[f]	
Jack pine (*Pinus banksiana*)	7.8–8.9[f]	
	6.7–6.8[f]	
Red and Jack pine	4–6.8[f]	
Pitch (*Pinus rigida*) and Loblolly pine	8–9[f]	
Sand pine (*Pinus clausa*)	14.5[f]	
White pine (*Pinus strobus*)	13.0–17.5[f]	
Ponderosa pine (*Pinus ponderosa*)	8+	Progressive program
Caribbean pine (*Pinus caribaea*)	14–15.2	Seed orchard
	9.9–13.0[f]	
Radiata pine (*Pinus radiata*)	19.6–28.6	Seed orchard (Australia)[j]
White spruce (*Picea glauca*)	6.7	Canada[a]
	8.4–9.3[f]	
	2.3–6.9[f]	
Douglas fir (*Pseudotsuga menziesii*)	8+	Progressive program
	6.1–7.8 (most 7.4+)	Simulation[k]
Poplar (*Populus*)	13.2	Netherlands[a]
Eucalyptus	22	Lesotho[l]
Acacia	35	Fiji[l]
Casuarina spp. (improved seed)	47	Nepal[l]
	49	Zimbabwe[l]
	53	Sri Lanka[l]
	56	Thailand[l]
	68	Bangladesh[l]
	70–81	China[l]
	56	Average of 8 countries[l]
	39	Worldwide estimate[l]
Canadian white spruce (*Picea glauca*)	2.3–9.3	Canada[a]

Sources: a. Carlisle and Teich 1975. b. Porterfield 1974. c. Swofford 1968. d. McKeand and Weir 1983. e. Talbert 1985. f. Steir 1986. g. Weir 1981. h. Ledig and Porterfield 1982. i. Reily and Nikles 1977. j. Wright and Eldridge 1985. k. Thomson and others 1978. l. Brown 1987.

Table 5.5 Representative costs and benefits associated with different levels of tree improvement

Option	*Description*	*Percentage gain*	*Time required*	*Cost @ 10% ($ thousands)*	*IRR*
I	Seed source testing and seed collection from original locations	10–30	7–20	175	20.2
II	I using clonal reforestation	15–35	9–22	200	17.5
III	I + conversion of trials to seedling seed orchards	11–33	9–23	200	18.2
IV	I + superior tree selection, progeny testing and conversion of trials to seed orchards	23–55	14–38	277	15.6
V	IV using clones to produce seed orchard	23–55	17–41	281	14.7
VI	Accelerated V	23–55	7–18	194	20.4
VII	IV where seed source and half-sib family tests provide clonal seed orchard material	24–57	10–21	208	18.9
VIII	Advanced generation tree improvement program[a]	+15–25	+9–23		

Note: Option VIII is not costed since it is essentially a second improvement generation that can be add onto options IV–VII. Option IX is the clonal reforestation approach to options III–VIII and therefore is excluded. Some of the options have advantages that do not show up in these calculations but are presented in the detailed descriptions of the alternatives in the appendix.

native VII were undertaken after alternative V, the potential total gains would range from 38 to 80 percent. The discounted value of the costs of each option was calculated using a discount rate of 10 percent and is shown in the third data column. This illustrates the relatively low costs involved in tree improvement. As a basis for comparison, a typical planting cost might be $300 per hectare. Therefore, the cost of undertaking alternative I is equivalent to the cost of planting roughly 600 hectares. The last column of table 5.5 shows the internal rate of return (IRR) for each option, which is independent of the prevailing discount rate.

Costs were estimated for an improvement effort designed to supply stock for a planting program of 5,000 hectares per year at 2,000 trees per hectare for fifteen years after the first usable planting stock becomes available. The size of seed orchard needed to support a program of this magnitude depends on the seed production characteristics of the trees. Here, it was assumed that each kilogram of seed will yield roughly 17,500 plantable seedlings and each seed tree will produce 1.36 kilograms (3 pounds) of seed per year. On this basis, a 3.4-hectare seed orchard would support the planned reforestation program. Land purchase costs and taxes are ignored in this example.

Separate costs were estimated for setting up and maintaining the seed source trials and seed orchard, selecting the trees, and testing the progeny. Costs for producing planting stock and for planting and tending it were excluded on the assumption that they are identical for improved and unimproved stock. The seed orchard was assumed to have approximately 125 trees per hectare (50 per acre) established at a cost of $5 per tree. Maintenance was assumed to cost $10,000 per year, including labor and equipment. One person-year of time was allocated to maintenance. In practice, labor costs are extremely variable, perhaps ranging from $1,000 to $2,000 per person-year in Bangladesh and some African countries to $15,000 and upwards in southern Europe and the southeastern United States.

Tree selection was assumed to require two person-years in each of the first two years before trial establishment. Progeny testing is a time- and knowledge-intensive activity. Labor requirements for four progeny test trials (on a total of 2 hectares) were estimated at twenty-five person-days for establishment, five person-days for annual maintenance, and ten person-days per measurement. The largest cost is for the salary (estimated at $35,000 per year) of a full-time manager who is expected to have training at the masters degree level.

The costs described above do not include capital for additional growth facilities, which may be particularly necessary when cuttings are used instead of seedlings. Also, costs for the cutting production can be two or even three times the costs of producing seedlings, and this factor has been ignored in option II (the only clonal reforestation alternative).

The benefits of tree improvement are assumed to be limited to an increased volume of wood. No other changes are considered here, since this is simply a representative example. However, this is likely to be a very conservative assumption. Wood is assumed to be worth $20 per cubic meter, and the base yield of unimproved stock is assumed to be 200 cubic meters per hectare at a twenty-year rotation age. For each program described in table 5.5, there is a fairly wide range of potential percentage gains and a range of time periods needed to produce usable seed or cuttings. The level of gain assumed in the economic calculations equalled the middle value in the range of potential gains, and it was assumed that seed or cuttings would be available at the earliest time specified. Thus, the value of the benefits of option I was calculated on the basis of a 20-percent gain, production of usable seed starting in seven years, and a first harvest of improved trees after twenty-seven years.

The rates of return shown in table 5.5 clearly support the argument that tree improvement is subject to diminishing marginal rates of return, yet the returns from more-expensive and sophisticated programs remain attractive. The time needed for producing usable seed was a primary factor influencing the financial returns of the alternatives. The accelerated programs described as alternatives VI and VII clearly show the economic value of reducing the program length.

The IRR values shown correspond to those for loblolly pine, Caribbean pine, and various southern pines. This reflects the fact that the seed production data correspond closely to the production rates of loblolly pine.

Opportunity costs of not practicing tree improvement

There has been widespread reporting of rates of gain due to tree improvement, and many efforts have been made to assess rates of return from improvement programs. However, comparatively little attention has been given to the value of benefits forgone by not undertaking tree improvement activities. These forgone benefits are known as opportunity costs, since they reflect the value of potential benefits that are unrealized.

This is important because even the most rudimentary tree improvement practices can generate substantial benefits and at least some of these practices can be adopted in almost all reforestation programs. Nevertheless, there are many nursery managers and forestry staff who continue to regard tree improvement strictly as a research activity. The costs of maintaining this viewpoint will be demonstrated in the following discussion.

The IRR figures do not reveal the magnitude of the financial gains at issue. A more-appropriate statistic is the present net worth (PNW), which is the difference between costs and benefits discounted at prevailing interest rates. Since the size of the PNW depends on the interest rate and since interest rates are difficult to predict, sensitivity analysis is often done. Here, the present net worth of alternatives I–VII was calculated using discount rates of 7 percent and 10 percent (see table 5.6). The discount rates used in this calculation were intended to be real rates, since inflation was not built into pro-

Table 5.6 Present net worth of options I–VII
(millions of dollars)

Option	Description	Present net worth @ 7%	Present net worth @ 10%
I	Seed source testing and seed collection from original locations	5.7	2.1
II	I using clonal reforestation	5.0	1.6
III	I + conversion of trials to seedling seed orchards	5.0	1.7
IV	I + superior tree selection, progeny testing and conversion of trials to seed orchards	5.5	1.5
V	IV using clones to produce seed orchard	4.7	1.2
VI	Accelerated V	9.1	3.2
VII	IV where seed source and half-sib family tests provide clonal seed orchard material	8.2	2.8
	Program[a]	+15–25	+9–23

jected future wood prices. These data were calculated on the basis of the entire project, not on a per hectare basis.

This table shows that the value generated by the genetic tree improvement program—the value of the additional fibre produced less the improvement costs—is substantial. The present net worth values also represent the loss of failing to undertake a tree improvement program (or of failing to manage the program effectively). Two other examples show that the values at stake can actually be much larger than those shown in table 5.6.

A study in Andhra Pradesh, India, reveals how these opportunity costs arise. The study identified outdated seedling production technologies as being one of the main impediments to forestry development in the state. The use of these technologies led to the production of low-quality eucalypt seedlings. Both public and private plantings were affected, as farmers often obtained low-quality seedlings from government nurseries. Poor seedlings led to poor physical yields and consequently to low financial returns. Low returns dampened private interest in forest plantations.

In a typical Andhra Pradesh eucalypt plantation, the incremental cost of using improved genetic material and adopting better nursery and planting technologies would be about $285 per hectare. But while traditional practices generate annual yields of about 7 cubic meters per hectare, the improved technologies are able to generate about 20 cubic meters per hectare, or an incremental financial rate of return of 34 percent. This is an extremely attractive incentive to invest in plantations. Even in a plantation established on poor land and yielding 12–16 cubic meters per hectare, the financial rate of return would range between 15 and 20 percent. Since some 110,000 hectares of eucalypts have been planted in Andhra Pradesh over recent years, obsolete practices have cost from about $73 million to $127 million. This example clearly illustrates the magnitude of the losses incurred because of the inability to implement tree improvement schemes and the associated stricter discipline in nursery production.

Williams (1992) investigated the opportunity costs of using cheap seed to regenerate black spruce on a 425,000-hectare forest in northern Ontario, Canada. The forest was assumed to be managed under a strictly even-flow harvest regimen. In this study, simulations were run to evaluate scenarios in which the inferior seed led to yield reductions of 10 and 20 percent of stand volume.

When cheap seed reduced yields by 10 percent, the maximum harvest level declined by 10 percent, and the benefits of planting were reduced by $8.8 million over the simulation period. This was equivalent to an annual reduction of $345 per hectare planted. When cheap seed caused a 20-percent reduction in yield, the maximum sustainable harvest fell by 25 percent. The financial cost was estimated at $15 million, which negated the value of the planting program and in fact caused a net loss of $3 million, as compared to a situation in which natural regeneration was employed. These estimates were conservative, since no additional mortality was assumed and the higher per cubic meter costs of logging lower volume stands were ignored.

Finally, table 5.6 shows the opportunity cost of selecting an inappropriate selection program. Option VI is an accelerated version of option V. Note that VI may provide less gain than V because the selection intensity is lower. In addition, V provides alternatives for producing much more seed than VI. If these two disadvantages of option VI are unimportant to the program, then the use of the shortcut option VI could have significant financial benefits. Table 5.6 shows that at a 7-percent discount rate, the opportunity cost of choosing option V when option VI would have been suitable is $4.4 million—a costly error.

Leverage factors and constraints to success

The choice of an appropriate strategy is strongly influenced by (a) the rotation length of the trees and the flo'v and value of products, (b) the extent of existing knowledge about the genetic control of the economic traits for the tree species, (c) the amount of tree improvement activity to date on the species of interest in a comparable environment (hence availability of improved and locally adapted seed or genotypes), and (d) the technology available for either seed or clonal propagule (rooted cuttings or tissue culture plantlets) production of planting stock. Seedling quality is of course a major factor in the success of the program.

Rotation length and product flow

Tree improvement activities are an investment that involves initial costs in research and development, although in some cases results from prior research can be adapted, significantly reducing these costs. The gains are realized at a later date when an increased amount and value of products are obtained from the improved plantations. The interval of time between the payment of costs and the receipt of benefits is of major importance to the economic feasibility of the activities. The rotation length of species and its product flow over time has an enormous influence on the economic feasibility of a reforestation or agroforestry project and the related tree improvement program. The most favorable returns will be obtained when there is a large-volume output per hectare of a high-value product beginning within a few years after planting and extending for a long period of time. The worst case is low-volume output per hectare of a low-value product beginning decades after planting and extending for only a few years. If product values are similar between two alternative rotation lengths and product flows, it is generally more profitable to have shorter rotations with intermediate harvests.

Plantation area

The amount of area reforested with the improved material is as important to the economic feasibility of improvement activities as the size of gain from improvement. Economic benefits are almost proportional to the size of the afforested area. Doubling the area of plantations established will probably double economic returns. Furthermore, a larger planting base reduces the average up-front improvement cost per hectare planted and can thus support a more-intensive program.

Fast-growing species that are afforested on a large scale are often well suited for tree improvement. Improvement of slow-growing species with valuable timber, such as *Tectona grandis*, however, may also yield large economic returns if they are planted on a large scale.

Product value

A general advantage from tree improvement is that not only do the resultant forest stands have more volume but, in addition, the individual tree value is increased. Published research results demonstrate a higher than normal percentage of large trees in improved plantations (van Wyk and van der Sijde 1983; Janssen and Sprinz 1987). Also the trees are straighter and have less taper, resulting in a higher proportion of high-value logs for the production of veneer as well as lumber (Spencer 1987) with reduced mill wastage.

Raw material from forests can be divided into three major categories: cellulose and fuelwood, construction wood (including construction plywood, particle board, lumber, and so forth), and decorative wood (including high-quality veneer and lumber, for furniture especially). Cellulose and fuelwood are used in large volumes but are characterized by relatively low quality requirements. Construction wood is also needed in large quantities, but wood quality is relatively more important. The quantity of decorative wood demanded is generally lowest of the three, but wood quality is of paramount importance.

Tree improvement programs have been developed for each of the three product types, and the financial investment and traits for emphasis are different in each. For example, since a unit of fiber for pulp and paper or fuelwood is of low value, lower financial investments are warranted. The traits for improvement in this category are usually limited to volume production and fiber quality per hectare. In programs geared to improve trees used for construction wood, tree straightness, bole size and quality, and wood strength traits are improved as well as the volume production per hectare. Where decorative woods such as teak, mahogany (*Swietenia* spp.), or walnut (*Juglans nigra*) are concerned, tree straightness, bole size and quality, wood color, and grain characteristics are strongly emphasized.

Knowledge about genetic control of traits

The level of current knowledge about the genetic control of the economic traits for species of interest will determine the need for research prior to beginning the tree improvement program. Much information is available for tropical and subtropical species such as radiata pine, *Eucalyptus grandis*, and teak, to name a few; but basic information is lacking for many less-known species. A tree breeder must know

- The degree to which traits of interest are controlled by genetics
- The type and relative magnitude of genetic control (that is, additive versus non-additive)
- Genetic relationships among traits of interest (for example, tree volume, straightness, and few, small branches)
- The relative economic value of the traits
- Whether the planting region must be subdivided into separate planting or breeding zones.

When basic genetic information is lacking, the tree improvement program can be postponed, possibly for years, or a joint research and more-general tree improvement program can be started simultaneously. There is, of course, the possibility that work on other related species will indicate short-cuts that could be risked while the tree improvement program is developed. Meanwhile management must predict productivity trends by synthesizing published results from field experience throughout the world.

Existing tree improvement programs

The amount of prior tree improvement work for the species of interest is crucially important, because it implies the availability of both basic genetic knowledge and genetically improved genotypes useful for tree improvement programs. Literally decades and vast sums of money can be saved by matching a species with a compatible environment that is already demonstrated in an existing advanced tree improvement program in another region or country. If this is possible, either seeds or cuttings could be directly purchased from the existing program, avoiding the necessity of another program, or at least genetically improved genotypes could be obtained and used to start the new program at an advanced stage. CSIRO, in Australia, has developed a number of innovative programs for matching species to sites (the early studies are described in Booth 1991).

Available technology for planting stock production

SEED. Establishment of seed production areas or seed orchards is a key element of most genetic tree improvement programs, since seeds and subsequent seedlings are the vehicles for exploiting the genetic superiority of the improved population. Efficient seed production, collection, and handling require an understanding of floral and seed biology, as the ease of seed production varies widely among tree species. Crucial factors in seed production include whether the floral habit of the species is monoecious (male and female flowers on the same tree) or dioecious (male and female flowers on different trees) and the seasonal timing of flowering.

When seed orchards are established, it is essential to monitor the phenology of flowering on individual trees in the orchard. Flower timing for a species in its natural environment tends to have a bell-shaped frequency distribution over time; that is, a few individuals form flowers early and a few relatively late but most of the flowering takes place during a (sometimes short) central period. If individual trees with vastly different flower timing were brought together in an orchard, the resultant seeds would be selfed rather than out-crossed.

Additional critical elements affecting seed production are insect or wind pollen dissemination, techniques for pollen collection and storage, seed dormancy, seed dispersal method, seed size, speed of germination, ability of seed to be stored, inherent level of seed viability, seed predators and their control, and ease of seed collection and processing. Seed production in seed orchards has been perfected for some species (especially radiata and loblolly pine) to such an extent that virtually all seed collected for reforestation comes from seed orchards. In New Zealand much of the orchard seed for *radiata* pine now comes from controlled pollination. Other species such as dipterocarps and teak present numerous problems with seed production, storage, and germination. Low seed viability and the inability to cold-store seeds severely limits large-scale tree improvement or seedling production programs in these species. Seeds or propagules with some level of improvement are needed to provide data for an initial financial evaluation of planting programs.

PLANTING STOCK. An ability to efficiently produce adequate numbers of planting stock (seedlings, rooted cuttings, or tissue culture plantlets) implies that a well-planned tree improvement program will not be constrained by this factor. Techniques of mass producing seedlings for planting stock are available for many species. However, rooted cuttings can be mass produced for only a few species, while mass plantlet production from tissue culture can currently be done for fewer than ten species.

SEEDLINGS. Seedlings are the most common type of planting stock, and appropriate production technology is available for many common species (Tinus and MacDonald 1979; Liegel and Venator 1987; Duryea and

Dougherty 1991). Depending on a number of factors, particularly the size and quality (or viability) of the seeds, seedlings can be raised by direct sowing into beds or containers, by sowing into seed beds or boxes and transplanting into beds or containers, or by pregerminating and pricking into beds or containers. Species that are less commonly regenerated by artificial planting may lack an efficient current technology; in such cases, general research procedures are available to investigate and develop the most appropriate production technology.

ROOTED CUTTINGS. Rooted-cutting production technology is available for fewer tree species than seedling production technology is. However, the state of the art is advancing rapidly (see Landis, Jones, and Smyle 1992; Ahuja and Libby 1993). Some hardwoods such as *Eucalyptus grandis* (Leakey 1987), *Paulownia* spp. (China Academy of Forestry 1986) or *Populus deltoides* (McKnight 1970; Farmer 1992) are routinely propagated as rooted cuttings for reforestation. Large-scale rooted cutting production technology is rapidly emerging for other tropical species (Barnes and Burley 1982) such as *Acacia mangium, G. arborea, Terminalia superba* and *Triplochiton scleroxylon*, as well as other *Eucalyptus* spp. (Leakey 1987). Low-cost procedures and equipment for producing rooted cuttings, specifically designed for the tropics, are available for some species (Leakey and others 1990).

A few *Populus* and *Salix* species can be field planted as unrooted cuttings and allowed to root in the field, but all others require rooted-cutting production. This procedure will initially be more expensive than seedling production, as it requires the establishment of cutting orchards adjacent to propagation facilities and significant reorganization of nursery management practices. The additional facilities and expenses vary tremendously by species. There are, however, a few strategies in which rooted cuttings are less expensive than comparable seedlings due to the nature of the practices applied and improved productivity of the stock (Dibley and Faulds 1991).

Successful mass production of rooted cuttings relates closely to the ability of nursery managers to manipulate the physiology of plant tissue maturation. Trees mature physiologically with age, and this maturation can reduce the rooting ability of cuttings and growth vigor of the subsequent rooted cuttings (Sweet 1973). Recently, researchers have concentrated on understanding the effects of maturation and have investigated techniques for rejuvenating plant tissue or at least slowing the rate of maturation. Most broadleaf tree species have the ability to develop new shoots from the stump of the cut tree, and these shoots are juvenile in nature. Conifers are most problematic in that most of them do not stump sprout. Hence, the best current techniques involve selection of juvenile trees and the use of techniques such as hedging and serial propagation to maintain the juvenile stage.

One clear advantage of using rooted cuttings rather than seedlings is that genetically improved planting stock is available sooner with a rooted cutting program (Matheson and Lindgren 1985). Seed orchards usually require at least ten years to reach full seed production, while rooted-cutting programs often reach full production in three to five years. All that is needed to produce rooted cuttings as planting stock is the selection of outstanding individual trees and establishment of cutting orchards adjacent to the propagation facilities. Hence, production of planting stock and the subsequent reforestation with genetically improved trees advances significantly faster with a rooted-cutting program as long as cuttings from the species can be induced to root.[3]

TISSUE CULTURE PLANTLETS. Production technology for tissue culture plantlets is just now becoming available for a few species. Given the newness of its large-scale planting stock production and field performance, the tissue culture process will remain primarily in the research and development stage for a few more years. Tasman Forestry Ltd. in New Zealand produces *P. radiata* planting stock through tissue culture for the bulk of their large planting program (Gleed 1991). In southern China some eucalypt clones are first multiplied through tissue culture, and then the resultant nursery stock is multiplied in the normal way as rooted cuttings. Tissue culture plantlets of teak have been produced successfully with a potential production of 500,000 plantlets annually in a program in Thailand (Kaosa-ard 1989).

The motivation for pursuing the tissue culture process is the potentially vast quantity of plantlets that can be produced. Some problems such has genetic mutation with the culturing of a clone and early maturation of the plantlets for unknown reasons have caused tree breeders to proceed more cautiously with operational use of plantlets. A large effort is being expended worldwide to solve these problems and to develop economical production systems. Hence, it is only a matter of time before such systems are available at least for a few species.

Seedling quality

The quality of seedling planting stock can be influenced dramatically by both seed quality and seed culture practices in the nursery. Increased quality of planting stock improves survival and increases forest stand growth in the field. The goal of nursery management is to produce a uniform crop of seedlings whose morphological and physiological attributes fall within a specified range known as the seedling "grade." For each trait, the specific ranges set for each grade vary by species and planting zone. Generally, grade 1 denotes the highest quality, with grade 2 acceptable and grade 3 a cull.

For example, seedling grades for loblolly pine were established by Wakeley (1954). Root collar diameter has been shown to be one of the crucial factors in the grade determination (South, Boyer, and Bosch 1985). Its ranges for loblolly pine are: 4.7 millimeters (grade 1), 3.2–4.7 millimeters (grade 2), and millimeters (grade 3) (Wakeley 1954). Factors that favor the production of a high percentage of grade 1 seedlings in a nursery include:

- A clean seedlot with high germinative capacity
- Seeds that have been properly treated prior to sowing
- Uniform seed sowing in the nursery bed or in containers
- Rapid uniform germination at the best time of year, leading to a highly uniform seedling stand at the optimum density per square meter
- Optimum, uniform nursery and seed culture conditions (including soil/media type, container type, irrigation uniformity, sunlight/shade ratio, fertilizer type and application, and pest control).

Research shows that a general trend has emerged among nursery managers toward lower seedling density in the nursery for bare root stock (South 1993), which results in greater average root collar diameters (Boyer and South 1988). Hence, a large percentage of the seedlings achieve grade 1 status. Successful nurseries not only use good seed but employ diligent workers who are carefully supervised. These resources cost money and this additional cost should be factored into the economic evaluation of alternate strategies.

Seedling uniformity within the nursery is crucial. Non-uniform seed germination or slower seed growth due to variability in vigor results in a large disparity in seedling size. In a study on loblolly pine, Boyer and South (1988) found that a one-day delay in seedling emergence from the seed caused a reduction in the final seedlings of 0.5–0.8 centimeters in height, 0.12–0.16 millimeters in diameter, 0.22–0.47 grams in shoot dry weight, 0.06–0.17 grams in root weight, and 0.3–0.6 grams in total weight. Therefore, a variable germination rate will lead to a lower percentage of high-quality seedlings. In a World Bank project in northern Sabah, Malaysia, the contracting company, Groome Poyry, developed a means by which all the *A. mangium* raised in the nursery were from the same germination peak, producing a homogeneous planting population.

Planting grade 1 seedlings improves survival, stand height, and wood production per hectare. In their summary of studies on loblolly pine, South, Boyer, and Bosch (1985) concluded that planting only grade 1 seedlings rather than a control mix of grades 1, 2 and 3 would yield real internal rates of return of 16–37 percent, especially on highly productive sites. In a similar study, South (1993) showed an increase of as much as 30 cubic meters of wood per hectare (at age ten to twenty years) per millimeter increase in root collar diameters, within the range of 1–6 millimeters. Similar results have been demonstrated in other species worldwide, and they underscore the large gains in forest productivity and economic return from planting only high-quality tree seedlings. Seedlings may cost $25 to $50 per thousand (depending on species)—a small fraction of the per hectare regeneration cost. Given the relatively low cost of seedlings and the major importance of seedling quality on forest productivity, paramount importance should be placed on both high-quality seeds and nursery operations. The real target for nursery managers is to produce only grade 1 plants and reject all others. Planting a substandard seedling where it will occupy a site for anywhere from twenty to perhaps eighty years results in the loss of substantial potential benefits.

Genetic improvement of planting stock, even employing all available shortcuts, will take time, but the physical quality of planting stock can be improved relatively quickly by introducing modern seed and nursery technologies. Seed grading and careful selection of germinants will lead to improved uniformity. Seedlings can be significantly improved if the watering system guarantees uniform application, now easily attainable by installing one of the many commercially available overhead or drip irrigation systems. Periodic undercutting of beds for bare root seedlings effectively encourages development of a good fibrous root system, which is further enhanced if the rooting substrate has a high organic content. This latter observation is particularly important if containerized planting stock is being raised. Many countries have problems in obtaining good organic matter for potting media, yet the art of composting is well documented and good organic matter can be made from a wide range of ingredients. Nursery managers must be encouraged to address this problem and develop suitable media.

Containers available on the market are made of material ranging from paper to inflexible polystyrene. Currently, nursery management usually choose containers for their low cost and easy availability. These criteria ignore the needs of the plant and the effect of the container on the final, as opposed to immediate, product. The immediate product is plant survival, while the final product may be anything from fuelwood to high-grade saw logs. The current state of the art indicates that root deformation inside containers can significantly effect survival and growth, so nursery researchers have developed containers that prevent root deformation. One type of these containers is known as "root-trainers." Although the cost of converting outdated nurseries to root-trainer nurseries may appear high, the benefits in growth in the field and value of the final crop will quickly repay investment in this modern technology.[4]

Deployment strategies

The deployment issue is a major one for operational tree improvement programs. After large quantities of genetically improved planting stock are available, the next question is how to plant them. Research results with agronomic crops have shown the promise of significantly greater productivity by using the optimum deployment method.

There are several alternative deployment strategies for outplanting genetically improved seedlings or clonal planting stock, but unfortunately, there are virtually no research results available on choosing the best alternative. Management, therefore, must select a strategy based on its particular circumstances. Alternative strategies include:

- Complete mixtures of the various genetic sources (seed sources, families or clones)
- Mixtures of subsets of the genetic sources in which the subsets are proven to grow better on the particular sites
- Mosaics of pure patches of the various genetic sources on each site
- A pure, single genetic source per site.

Seedling reforestation

These deployment strategies are being used throughout the world, yet few research studies comparing the strategies have been published. The few studies are very young or, at best, the test ages are only a small fraction of rotation ages, and the results are therefore still questionable (Williams and others 1983; Foster 1989). Thus, there is a major gap between the availability of scientific data on various gains and of financial data necessary for justifying investment.

The complete mixture option is most widely used in seedling reforestation programs. Under this approach, seeds from a seed production area or seed orchard are mixed and used to produce planting stock. A few companies in the United States have identified open-pollinated families from seed orchards that grow particularly well on certain sites (such as wet, dry, and disease-prone sites). These families are either mixed or planted as mosaics of pure family patches. Although a substantial difference in stand yield has been hypothesized on an operational level, evidence for it has yet to be published. The most advanced work in this field is in Australia and New Zealand, and many plantations are established strictly with control-pollinated seedling stock.

Both positive and negative features of the various strategies can be cited. Complete mixtures have the advantage of being easy to manage in the seed collection and processing, nursery seedling production, outplanting, and stand management stages since a single identity must be tracked. In addition, these mixtures may provide a more-predictable growth and yield at the stand level (due to greater genetic diversity) when subjected to pest attack or environmental stresses. However, this hypothesis has not been proven in forestry practice.

Using mosaics of pure patches of a single genetic source has the potential advantage of allowing the culture practices or the selection of planting sites to be tailored to the specific genetic source. As more information becomes available for specific genetic sources (such as open-pollinated families), greater growth and yield and enhanced forest health may be gained by growing pure patches of each genetic source. Uniformity of the stands will be greatly improved, thereby facilitating the harvesting and production of wood products. If a single source fails due to pest attack or maladaptation to the site, then the entire patch can be replaced rather than have that percentage of a mixed stand die and perhaps lower the stocking level below the economic threshold. Additional costs are incurred in the logistics of establishing the mosaics of pure sources, but the added cost may be offset by greater productivity.

In comparing the additional costs and greater productivity, mixtures of subsets of genetic sources fall somewhere between total mixtures and mosaics of pure genetic sources. A certain level of genetic diversity is needed to protect the forest stand against total losses due to pest attack or maladaptation to the site. However, forest trees are noted for their high degree of genetic diversity within a single tree and especially within a population. Planting a single genetic source on a site is not a good strategy, as it exposes the stand to too much risk. However, deploying mosaics of pure genetic sources (perhaps 10–50 hectares each and five to ten sources per site) helps reduce the risk associated with genetic monocultures while providing the benefits of crop uniformity.

Clonal reforestation

The deployment strategies available for clonal reforestation are similar to those described above for seedling reforestation: clones can be mixed, planted as subsets of similar clones, planted as mosaics of pure clones, or planted as a single clone on a site. Several papers have been published regarding the theoretical considerations of clonal deployment, but empirical results have been published from only a couple of studies (Foster and Bertolucci, in press; Lindgren 1993). Most of the positive and negative points that were raised in the previous section apply equally to clones. Of the two published field studies on clonal deployment, one found that the average volume of the pure clone plots was slightly lower than the volume of the mixed plots (Markovic and Herpka 1986) while the other study found both greater and less volume production from pure clones as compared to mixtures, depending on the site and clones involved (Foster and Bertolucci, in press). Currently, clones of *E. grandis* are planted in mosaics of pure clones in Brazil and in the Congo (Leakey 1987). In both cases, a single genetic source usually occupies no more than 25 hectares, and a single planting site contains five or more different clones. A clonal reforestation program with *Populus deltoides* in the United States has usually planted mixtures of clones (Portwood 1990).

Two examples of Southeast Asian companies faced with planting stock quality problems are illustrative. At Sabah Softwoods Sdn Bhd in southern Sabah, the form of *G. arborea* was very poor even though the company had purchased seed from a range of sources. The research team evaluated all their sources and chose one with significantly better tree form and growth than the rest. The best 10 percent of the trees in this stand were selected (approximately 3,000), the entire stand felled, and coppice regrowth from the selected trees used to set up a 20-hectare cutting orchard for planting stock production. No individual tree identities were retained in the orchard, but a separate research program was started in which identified clones were tested. Gradually the multiclone population will be replaced by identified clone mosaics (see Sim and Jones 1984).

The other company, Indah Kiat in Sumatra, Indonesia, decided to work with clonal propagation of *A. mangium*. Research results demonstrated that seed sources from the York Peninsula of Australia and the Western Province of Papua New Guinea gave the best growth, but it was impossible to purchase enough seeds at suitable prices for a large planting program. A few kilos were bought and a cutting orchard established (approximately 160,000 clones). Multiclone planting stock will be used for the initial planting period, and a concomitant research program is in place to identify the best individuals to clone from seedling populations established in trials (Wong 1991).

Conclusions

Evidence from the literature strongly shows that significant physical and financial benefits can be obtained from tree improvement. The bulk of this evidence involves temperate softwood species, but there is enough information to suggest that physical and financial gains may be even larger in the tropics. Plantation programs, some with genetic components, are expanding rapidly in many areas of Southeast Asia and Latin America.

Management is advised to review its planting programs in light of the new technologies and update where it is biologically and financially attractive to do so. At the same time, decisions should be made about whether it is worthwhile to undertake research on optimizing productivity. The planning required to initiate or refocus a tree improvement program makes use of financial data and estimates of predicted growth to properly analyze alternative investment strategies.

Reforestation operations that do not incorporate some level of improvement effort are likely missing out on opportunities to improve the performance of plantations and significantly increase the value being generated from investments in reforestation. The most basic tree improvement activities are common knowledge to all foresters and do not require great expense, yet may yield substantial returns. As more managers learn that many tree improvement activities have moved out of the research lab and are available for use, then the potential net benefits of tree improvement will begin to be realized and not counted as a loss of forgone opportunities.

Appendix: Alternative genetic tree improvement program designs

Option I: Seed source testing and collection of reforestation seed from the original locations.

This alternative is one of the simplest, yet most cost-effective, available for the initial stages of tree improvement. General guidelines for seed source movement are used to choose the appropriate part of the natural range of the species for sampling. If the natural range is small, then it may be sampled in its entirety. Economics and management limitations will dictate a maximum number of sources that can be sampled and tested. The forest stands sampled should be located as evenly as possible over the test area, and the latitude, longitude and elevation for each sample must be noted. At least twenty-five to fifty stands should be sampled. Ten or more dominant trees should be chosen in each stand and their seeds combined to form a single sample.

After the seed is collected, seedlings are produced and planted in statistically designed seed source trials in a variety of locations within the areas designated for future planting. Care should be taken to stratify the whole future afforestation area into site types with at least one trial located on every major site type. Based on results from the trials, the best seed sources are chosen. If there is no interaction between seed sources and test sites (that is, the ranking of seed sources does not vary significantly by site), one set of the best seed sources can be chosen for the entire area. If there is a significant interaction between the seed source and the test site, the site must be stratified into more or less homogenous areas in which there is no interaction. The best adapted seed sources are then chosen for each major area. Large-scale seed collection in the best originally sampled stands, within the natural range, is conducted for future afforestation.

This type of tree improvement program has several advantages. It is relatively simple to conduct and fairly inexpensive. Generally, seed can be collected, seedlings grown and seed source trials installed within two to five years. The tests are measured periodically and, depending on the stand rotation for the species, reliable seed source selection can be made when the field tests are five to fifteen years old. Therefore, reliable guidelines for large-scale reforestation can be made in seven to twenty years, depending on the species and commercial traits.

The level of genetic improvement anticipated from such a program depends on the species and traits of interest, but usually ranges from 10 to 30 percent at rotation length. Genetic gains from proper seed source selection are often relatively large. The proposed scheme also has the possible advantage of providing a ready supply of seeds in the existing natural stands.

The major disadvantages of this type of program relate to the future seed supply. Large amounts of seeds are often obtained by cutting trees, or during harvesting of entire stands, and picking the seeds from the felled trees. Obviously, as the available seed trees are cut, the future seed supply is jeopardized. If this alternative is chosen, all care should be taken to protect the seed source over the long term. The cutting of trees to gather seed should therefore be conducted judiciously. Alternatively, trees can be climbed to collect the seeds, but this method is expensive and, depending on the species, may not yield large quantities of seeds. The seed supply may thus limit future regeneration.

Option II: Seed source testing and collection of shoot cuttings for clonal reforestation from the best trees in either the best original locations or from the best trees in the seed source trial.

In this alternative, seed source trials are established as described for option I above, but future reforestation depends on the use of clones from rooted cuttings. This method will be successful only with species whose shoot cuttings root well, such as *Eucalyptus grandis*, *Gmelina arborea*, *Acacia mangium*, or *Triplochiton scleroxylon* (Leakey 1987).

Test results can be used to return to the best original sample stand locations. If the species produces stump sprouts, dominant trees are felled and subsequent sprouts are collected. Otherwise cuttings may be collected from juvenile trees in the stands. Alternatively, the best trees in the seed source trials can be used for either stump sprouts or direct collection of cuttings if they are still juvenile. The cuttings from either source are rooted and used to create cutting orchards (also called multiplication gardens) near the future regeneration area. Large quantities of rooted cuttings are developed from the cutting orchards for use in reforestation.

Advantages of this method include the same simplicity and cost effectiveness as for option I. Depending on the species and the ease of rooting cuttings and maintaining juvenility, this alternative could provide a more-reliable source of planting stock than option I. Due to individual tree selection and cloning, genetic gain will exceed that from option I by at least 5 percent, yielding a total of 15–35 percent. Collecting cuttings from the best trees in the best sources in the seed source trial represents an additional level of confidence since the trees to be cloned are already growing in the new environment. Hence, this method of clonal selection is probably more desirable. Once the cutting orchard is developed, a reliable source of planting stock is available.

Disadvantages, compared to option I, include some additional time needed to develop enough stock plants (the mother plants) to provide large quantities of cuttings for rooting. This process could add two or three years to the program (a total of nine to twenty-two years before reforestation can commence). Clones need to be rejuvenated periodically, otherwise the normal process of maturation causes a decline in the rooting ability and subsequent growth of the rooted cutting. Periodic stump sprouting is an effective rejuvenation technique for many broadleaf tree species. The cost of producing rooted cuttings is generally higher than that for seedlings for most species. This differential can reach as much as three times the cost of seedlings.

Option III: Seed source testing, conversion of at least some of the trials to seedling seed orchards, and collection of seed from the orchards.

This alternative has all of the features of option I above, but will provide a more-reliable supply of seed for reforestation. Many organizations have implemented this approach to tree improvement. After the final data are collected from the seed source trials, the best trees in the best sources are selected, and all other trees in the trials are cut. Then, seeds for reforestation are collected from the seedling seed orchards. Two levels of selection, seed source and individual within-seed source, are practiced in this approach. The additional level of superior individual selection yields gains of 1–3 percent added to the gain from the superior seed source selection, for totals of 11–33 percent depending on species and traits of selection. Because the individual trees from which reforestation seeds are collected are grown in the reforestation environment, the reliability of future performance is higher than in option I, in which reforestation seeds are collected from trees growing in the original stands in the natural range of the species. The average performance of seed sources is much less interactive with varying site types than the average performance of seedlings from seeds collected from a single tree (termed a half-sib family). Therefore, since the seed sources have been tested, their performance is known. The genetic gain from the individual select trees, however, will be more reliable in option III, since their seeds are components of the final seed collection.

Disadvantages to the program include a potential time lag for large-scale seed production and relatively small quantities of seed production from the seed orchards due to their size. After the final data from the trials are collected and analyzed, the poor quality trees are cut (rogued). A few years are required for the remaining trees in the orchard to expand their crowns and begin producing seeds. At least two or three years are needed before significant seed production begins, depending on the species and the age of the trees. If reliable selection of the best seed sources and the best individual within those seed sources can be made in five to fifteen years, then seed production should begin in seven to eighteen years from initiation of the seed source trials. Cultural treatments such as fertilization and reduction of competing vegetation hasten the onset of seed production.

Depending on the situation, this alternative may or may not be more expensive than I above. In option III, the trees are not cut in order to gather seed, so collection may be more expensive. The quantity of seed produced, even at a full orchard production, may be insufficient for the reforestation program because each of the initial trials is only a few hectares in size. Fewer select trees in the trial result in more genetic gain due to higher selection intensity. This general principle must be balanced with the requirement for seed production from the seedling seed orchard. In any event, such seedling seed orchards may retain fewer than one hundred trees at each location, hence total seed productivity could be limited. One possible solution is to establish larger seed production areas with only the best seed sources after reliable data are available from the trials. This could be accomplished either in the original country or region where the best stands arise or near the intended reforestation zone.

Another problem with option III is that parental identity of each seedling in the seed source trials is unknown. Therefore, final selection in the trial for establishing the seedling seed orchard inadvertently may favor selection of half-sibs (those with the same mother). If these trees pollinate each other in the orchard, seed production and the vigor of the resulting seedlings may decline.

Option IV: Seed source testing followed by superior tree selection in the natural stands, progeny testing, and conversion of trials to seedling seed orchards.

Option IV includes all features of seed source testing in I above, but it also includes superior individual tree selection in the best sources in the natural stands. This selection is followed by seed collection from the select trees and establishment of the progeny test in the future reforestation area, as with the former seed source trials. Once the trials reach sufficient age for reliable data to be collected and analyzed, the best individual trees in the best half-sib families are selected. The remainder of the trees in the progeny tests are cut. The progeny tests then become seedling seed orchards, and seeds for reforestation are collected in the orchards.

Four levels of selection (seed source, individual within seed source, half-sib family, and individual within half-sib family) result from this alternative. The genetic gain is additive. The expected gain from the selection of seed source is 10–30 percent; from individual within seed source, 1–5 percent; from half-sib family, 10–15 percent; and from individual within half-sib family, 2–5 percent. The gain may be 23–55 percent, as compared with an unimproved check lot. The range in genetic gain values depends on the species and trait.

Advantages of this alternative include the known pedigree of each tree in the improved population and the enhanced level of genetic gain. This alternative or similar ones are common worldwide for large tree improvement programs that will continue indefinitely into future generations.

The reduced seed production and subsequent seedling vigor from mating close relatives is termed "inbreeding depression." For most outcrossing tree species that have been tested, inbreeding depression has been severe and essentially debilitating, hence extreme measures have been taken in most tree improvement programs to identify the pedigree of each tree in the population. Steps are taken to minimize the chances of future mating of close relatives. Therefore, having a known pedigree of trees in the population is economically valuable. Obviously, the enhanced level of genetic gain yields high economic returns. Assuming a required field testing time of five to fifteen years for each of the two test phases (seed source trial and progeny tests) and two to three years for the trees in the rogued progeny test to reach seed production, it would take approximately twelve to thirty-three years from the initiation of the seed source trial to the collection of genetically improved seed for reforestation. Of course the seed source trials could also be converted to seedling seed orchards for an interim supply of seeds.

The major disadvantages to this alternative are the long period before seeds are available for reforestation and the potentially limited quantity of seeds that may be produced. The relatively long period is caused by the length of time needed for the field trials to reach an age at which their performance assessment is reliable. Limited seed production from seedling seed orchards has been discussed in III above.

Option V: Seed source testing followed by superior tree selection in the natural stands, progeny testing, and cloning (via grafting or rooting) the best trees in the progeny test into a seed orchard.

Option V is identical to option IV except for the seed production phase. One advantage of this alternative is that the production orchard can be as large as needed. Each selected tree in the progeny test is cloned into the orchard, usually by grafting or rooted cuttings. Such clonal orchards are often many hectare in size and may include fifty trees or more per hectare. The orchard is located on a site that is conducive to seed production and fairly intensive cultural treatments are applied. Grafts of the same tree should be spaced far enough apart to minimize the chance of cross pollination within the same clone, hence of losses due to inbreeding depression. Frequently, seed production per hectare of a clonal seed orchard exceeds that of a seedling seed orchard since the clonal seed orchard can be located on sites that may favor seed production instead of tree growth. For many species of trees, slightly droughty sites may be more conducive to flowering and seed production, but the tree growth per se may be reduced.

The major disadvantages of such a clonal seed orchard approach are a further delay in time before the first seed production and the additional cost of the orchard. The assumption has been made that progeny tests can be converted to seedling seed orchards with a delay of two to three years between the roguing of the progeny test and the initiation of significant seed production. With a clonal seed orchard, five to six years may be required from the time of superior tree identification in the progeny test until the trees in the clonal seed orchard begin to produce seeds. This delay would cause a further delay of fifteen to thirty-six years from the initiation of the seed source trial to the collection of genetically improved seeds for reforestation. The total cost of the clonal seed orchard may be the same as for a seedling seed orchard on a per hectare basis, but the clonal seed orchard may be larger. There are economies of scale in option V since a single large clonal seed orchard may replace many smaller seedling seed orchards, which have to be widely dispersed due to their initial function as progeny tests.

Option VI: Combined seed source and half-sib family testing, with conversion of the trials into seedling seed orchards.

This alternative combines the first three features of option V into a single step. Sample stands are located throughout the natural range of the species just as in all the previous alternatives, but in option V, more emphasis is placed on selection of individual sample trees in each stand. Seeds from the individual trees (half-sib families) are uniquely identified. When the seed source or progeny tests are established, all seedlings are identified as to seed source and family. After reliable test data are available (at the test age of five to fifteen years), the best individual trees within the best families within the best seed sources are selected, and all other trees are cut. In two to three years (or more depending on species), the seedling seed orchard will begin to produce significant quantities of seed for reforestation. Hence, the first genetically improved seed will be available for reforestation in seven to eighteen years.

Four levels of selection are involved in this alternative just as with alternatives IV and V. In fact, the level of genetic gain achieved in each of the three alternatives (IV, V, and VI) are similar at 23–55 percent, compared to an unimproved check lot.

Advantages of this alternative include a greatly reduced time until seeds are available for reforestation. In addition, the reliability of individual tree superiority will be greater in the final level of selection since the trees are growing on sites representative of future ones for reforestation, rather than in the natural range of the species. The time from program initiation to production of genetically improved seeds for reforestation in this alternative is half that in option V and significantly shorter than in IV.

The disadvantages with this alternative relate to the quantity of seed that can be produced for large-scale reforestation and also to the exact level of genetic gain that can be obtained. Limited seed production constraints arising from seedling seed orchards have been discussed in option III.

The exact level of genetic gain from this alternative may be somewhat lower than with alternative V due to a lower selection intensity for both seed sources and families within seed sources. In the previous alternatives, the seed source testing and family (select tree within the natural stand) testing have been accomplished in different tests. In option VI, both test types are combined. Unless the numbers of sampled seed sources or families are diminished, the test size will be too large to manage. Therefore, the reduced time for obtaining genetically superior seed in this alternative is achieved at the expense of testing fewer sources or families, which results in lower genetic gain from the program.

Option VII: Combined seed source and half-sib family testing, with selection of the superior individuals in the tests and cloning the select trees into a seed orchard.

This alternative is identical to option VI except that seeds for reforestation are obtained from a clonal seed orchard of the select trees from the combined seed source and half-sib family tests. The genetic gain is at least as large as in VI and could be even larger if fewer select trees were chosen (higher selection intensity). More trees have to be selected in a seedling seed orchard as compared to a clonal seed orchard, because the former also have to produce sufficient seeds. In a clonal seed orchard, as many grafts or rooted cuttings of the select trees can be made as needed for seed production purposes.

The advantage of option VII over VI is that it has a better chance of producing the quantity of seed needed for reforestation. In addition, there may be slightly higher, possibly 1–2 percent, genetic gain in this alternative. Hence, total genetic gain from this alternative will reach 24–57 percent as compared to an unimproved check lot.

The disadvantage to this alternative is that there will probably be a five- to six-year delay in seed production in the clonal seed orchard, compared to a two- to three-year delay in the seedling seed orchard. Therefore, it would be ten to twenty years before seeds were available for reforestation.

Option VIII: Advanced-generation tree improvement program in which superior selections from options IV, V, VI, or VII are intermated, progeny tested, superior selections made within the best full-sib families, and either the tests converted into seedling seed orchards or the superior trees cloned into a clonal seed orchard.

Option VIII is typical of many advanced tree improvement programs worldwide. There is a limit to how much genetic gain can be achieved in a single generation of a tree improvement program. As with agronomic crop species, the next step is to intermate the select individuals and begin a new generation of progeny testing, selection, and seed production. The amount of time needed to complete a mating design varies tremendously by species but will probably require two to five more years after superior trees have been selected within seed source trials or progeny tests. The trees can be either mated in place in the field via control pollination or cloned into a breeding archive and then control pollinated. Progeny tests are established, and five to fifteen years elapse before the next round of superior family and individual within family selection can occur.

Seed production can occur within the rogued progeny tests (seedling seed orchards), or a clonal seed orchard can be established. In this advanced-generation program, the same time is needed before seed production occurs as with the first-generation program (two to three years for a seedling seed orchard or five to six years for a clonal seed orchard). Therefore, an additional nine to thirty-three years are needed for an advanced-generation program with a seedling seed orchard, or twelve to twenty-six years for a clonal seed orchard.

The amount of additional genetic gain (added to first-generation gain) acquired through advanced-generation tree improvement varies tremendously by species and traits for improvement. This additional gain from both family and individual within family selection will range from 15 to 25 percent.

The advantage of such advanced-generation programs is mainly the additional genetic gain that can be achieved. Genetic diversity will also be enhanced in the trees used for reforestation since select trees from the often widely dispersed stands are intermated to form the advanced-generation trees in the progeny tests. These trees then serve as parents in the seed orchard. This type of program is initiated as quickly as possible following the first-generation program in order to hasten production of advanced-generation seedlings for reforestation. The chief disadvantages are the additional time and expense involved.

Option IX: Clonal propagation of select trees and reforestation with the clones.

Clonal propagation and reforestation has been considered only in option II above. In option II, a minimum of an additional 5-percent genetic gain because of the clonal selection and propagation procedure is expected. This happens as a result of being able to capture the total genetic variation rather than just the additive genetic variation. Both the theory and the practical aspects of this assertion have been tested and found to be valid (Ahuja and Libby 1993). Options III, IV, V, VI, VII, and VIII could use clonal propagation instead of seed orchards and seedlings for reforestation. Cutting orchards and large-scale rooted cutting propagation systems are available for *Eucalyptus* spp., *Gmelina arborea*, and *Triplochiton scleroxylon* (Leakey 1987) as well as *Populus* spp. and *Pinus radiata* (Shelbourne and others 1989; Arnold 1990) among others.

Various types of tissue culture can be used also to clone trees; however, large-scale application of these techniques are still under development. Tissue culture holds promise for developing an almost infinite number of propagules, but problems have surfaced such as premature maturation and chromosomal aberrations that cause some of the plantlets to grow abnormally. Solutions to these problems are currently being researched.

Notes

1. Detailed descriptions of a large variety of tree improvement programs for numerous species can be found in books such as Burley and Nikles (1972, 1973), Wright (1976), Zobel and Talbert (1984), and Gibson, Griffin and Matheson (1989) or in journals such as *Silvae Genetica* and *Commonwealth Forestry Review*.

2. "Sdn Bhd" indicates "Company Limited" in Bahasa Malay.

3. The present state of the art concerning commercial cloning of forest tree species is reviewed in Landis, Jones and Smyle (1992).

4. Josiah and Jones (1992) outline the benefits of using root trainer containers for planting stock.

Bibliography

Ahuja, M.R., and W.J. Libby, eds. 1993. *Clonal forestry*. Vols. I and II. New York: Springer-Verlag.

Bach, F.R. 1992. Improving arid and semi-arid zone arboreal genetic resources. *Unasylva* 43:31–39.

Barnes, R.D., and J. Burley. 1982. Vegetative propagation in the improvement of tropical forest trees. In *Proceedings of Symposium on Improvement of Vegetatively Propagated Plants*, Long Ashton Research Station, Bristol, United Kingdom.

Booth, T.H. 1991. Where in the world? New climatic analysis methods to assist species and performance selection for trials. *Unasylva* 42:51–7.

Borner, H. 1986. *Economic aspects of tree improvement*. Humleback, Denmark: Danish International Development Agency (DANIDA) Forest Seed Centre.

Boyer, J.N., and D.B. South. 1988. Date of sowing and emergence timing affect growth and development of loblolly seedlings. *New Forestry* 2:231–46.

Brown, A.G. 1987. *Seeds of Australian trees for developing countries project*. Canberra, Australia: CSIRO Division of Forest Research.

Burley, J., and D.G. Nikles. 1972. *Selection and breeding to improve some tropical conifers*. Vol. I. Oxford: Commonwealth Forestry Institute and Queensland: Department of Forestry.

———. 1973. *Selection and breeding to improve some tropical conifers*. Vol. II. Oxford: Commonwealth Forestry Institute and Queensland: Department of Forestry.

Carlisle, A., and A.H. Teich. 1971. *The cost and benefits of tree improvement programs*. Publication no. 1302. Ottawa: Department of the Environment, Canadian Forestry Service.

———. 1975. Economy and tree improvement. In *Proceedings of the fifteenth meeting of the Canadian Tree Improvement Society, Part 1—Minutes and reports*. Ottawa, Canada: Canadian Tree Improvement Association.

Chaperon, H. 1991. Open-pollinated seed orchards: Tested families or tested clones for tomorrow's forest? In *Proceedings: Clonal Forestry Workshop*. Forest Research Institute (FRI) Bulletin no. 160. Rotorua, New Zealand: FRI.

China Academy of Forestry. 1986. *Paulownia in China: Cultivation and utilization*. Singapore: Asia Network for Biological Sciences, and Ottawa, Canada: International Development Research Centre.

Cown, D.J. 1978. Comparison of the pilodyn and torsiometer methods for the rapid assessment of wood density in living trees. *New Zealand Journal of Forestry Science* 8:384–91.

Davis, L.S. 1967. Investment in loblolly pine clonal seed orchards. *Journal of Forestry* 65:882–87.

Dawson, D.H., and J.A. Pitcher. 1970. Tree improvement opportunities in the north central states as related to economic trends: A problem analysis. Research paper NC 40, U.S. Department of Agriculture, St. Paul, MN.

Dibley, M., and T. Faulds. 1985. Production and costs of juvenile radiata pine cutting. In I.M. Menzies, G.E. Parrott, and L.T. Whitehouse, eds., *Proceedings of IUFRO Symposium September 1989*. Rotorua, New Zealand: Forestry Research Institute.

Duryea, M.L., and P.M. Dougherty, eds. 1991. *Forest regeneration manual.* Boston, Massachusetts: Kluwer Academic Publishers.

Dutrow, G.F. 1974. *Economic analysis of tree improvement: A status report.* United States Department of Agriculture (USDA) Forest Service General Technical Report SO-6, Southern Forestry Experimental Station. New Orleans, LA: USDA.

Dutrow, G., and C. Row. 1976. *Measuring financial gains from genetically superior trees.* USDA Forest Service Research Paper SO-132, Southern Forestry Experimental Station. New Orleans, LA: USDA.

Falconer, D.S. 1989. *Introduction to quantitative genetics.* New York: Academic Press.

Farmer, R.E. 1992. Eastern cottonwood goes to China. *Journal of Forestry* 90:21–24.

Forest Research Institute (FRI). 1991. New Zealand Forestry Products. In Proceedings of the Clonal forestry workshop, 1–2 May 1989. FRI Bulletin no. 160, annex XI. Rotorua, New Zealand: FRI.

Foster, G.S. 1989. Inter-genotypic competition in forest trees and its impact on realized gain from family selection. In *Proceedings of the Twentieth Southern Tree Improvement Conference.* Springfield, Virginia: National Tree Improvement Society.

Foster, G.S., and F.L.G. Bertolucci. In press. Clonal development and deployment: Strategies to enhance gain while minimizing risk. In R. Leakey, ed., *Tropical trees: The potential for domestication.* London: Her Majesty's Office Publishing.

Gibson, G.L., A.R. Griffin, and A.C. Matheson, eds. 1989. *Breeding tropical trees: population structure and genetic improvement strategies in clonal and seedling forestry.* Oxford: Oxford Forestry Institute, University of Oxford.

Gleed. 1991. Personal communication.

Graudal, L.V., and A. Thomsen. 1992. Some preliminary results of any international evaluation of field trials established within the framework of the FAO project of conservation of forest genetic resources in dry zones. In C.C. Lambeth and W. Dvorak, eds., *Resolving tropical forest resource concerns through tree improvement, gene conservation, and domestication of new species.* Proceedings of IUFRO Conference in Cartegena and Cali, Columbia, October. Charlotte, North Carolina: CAMCOR and North Carolina State University.

Hoffmeyer, P. 1979. *Pilodyn used on Eucalyptus spp. pilot tests.* Copenhagen, Denmark: Danish Technical University.

Hollowell, R.R., and R.I. Porterfield. 1986. Is tree improvement a good investment? *Journal of Forestry* 84(2): 46–8.

House, A.P.N., and C.E. Harwood. 1991. *Australian dry-zone Acacias for human food.* Proceedings of workshop held in Glen Helen, Australia. Victoria, Australia: CSIRO Publications.

Janssen, J.E., and P.T. Sprinz. 1987. Modeling distributions of stem characteristics of genetically improved loblolly pine. In *Proceedings of the Nineteenth Southern Tree Improvement Conference.* Springfield, Virginia: National Tree Improvement Society.

Josiah, S.J., and N. Jones. 1992. Root trainers in seedling production systems for tropical forestry and agroforestry. Land Resources Technical Paper Series no. 4. World Bank, Agriculture Division of Asia Technical Department, Washington, D.C.

Kaosaard, A. 1989. Teak improvement strategy in Thailand. In G.L. Gibson, A.R. Griffin, and A.C. Matheson, eds., *Breeding tropical trees: Population structure and genetic improvement strategies in clonal and seedling forestry.* Oxford, United Kingdom: Oxford Forestry Institute, Oxford University.

Keiding, H., and E.B. Lauridsen. 1989. Utilizing the results of international trials of teak and

Gmelina. In G.L. Gibson, A.R. Griffin, and A.C. Matheson, eds., *Breeding tropical trees: Population structure and genetic improvement strategies in clonal and seedling forestry.* Oxford, United Kingdom: Oxford Forestry Institute, Oxford University.

Kjaer, E.D., and E.B. Lauridsen. 1992. Second evaluation of a series of provenance trials of Tectona grandis Lin and Gmelina arborea. In C.C. Lambeth and W. Dvorak, eds., *Resolving tropical forest resource concerns through tree improvement, gene conservation, and domestication of new species.* Proceedings of IUFRO Conference in Cartegena and Cali, Columbia, October. Charlotte, North Carolina: CAMCOR and North Carolina State University.

Laarman, J.G., and W.S. Dvorak. 1988. Financial feasibility of participating in an international seed cooperative for tropical pines. *New Forestry* 2:161–72.

Lambeth, C.C. 1980. Juvenile-mature correlations in Pinaceae and implications for early selection. *Forestry Science* 26: 571–80.

Landis, E., N. Jones, and J. Smyle. 1992. *Commercial applications of cloning for forest plantations.* Land Resources Technical Paper Series No. 5, World Bank, Agriculture Division of Asia Technical Department, Washington, D.C.

Lauridsen, E.B., H. Wellendorf, and H. Keiding. 1987. *Evaluation of an international series of Gmelina provenance trials.* Horshalim, Denmark: Danish Forest Seed Center.

Leakey, R.R.B. 1987. Clonal forestry in the tropics—A review of developments, strategies and opportunities. *Commonwealth Forestry Review* 66:61-75.

Leakey, R.R.B., J.F. Mesen, Z. Tchoundjeu, K.A. Longman, J.McP. Dick, A.C. Newton, A. Matin, J. Grace, R.C. Munro, and P.N. Muthoka. 1990. Low-technology techniques for vegetative propagation of tropical trees. *Commonwealth Forestry Review* 69: 247–57.

Ledig, F.T., and R.L. Porterfield. 1982. Tree improvement in western conifers: Economic aspects. *Journal of Forestry* 80:653–57.

Liegel, L.H., and C.R. Venator. 1987. A technical guide for forest nursery management in the Caribbean and Latin America. Unites States Department (USDA) of Forest Service General Technical Report SO-67. New Orleans, Louisiana: Southern Forest Experiment Station.

Lindgren. 1993. The population biology of clonal development. In M.R. Ahuja and W.J. Libby, eds., *Clonal forestry I: Genetics and biotechnology.* New York, New York: Springer-Verlag.

Lofgren, K.G. 1988. On the economic value of genetic progress in forestry. *Forestry Science* 34:708–23.

Markovic, J., and I. Herpka. 1986. Plantations in short rotation. In V. Guzina, ed., *Poplars and willows in Yugoslavia.* Novi Sad, Yugoslavia: Poplar Research Institute.

Matheson, A.C., and D. Lindgren. 1985. Gains from the clonal and the clonal seed-orchard options compared for tree breeding programs. *Theoretical Applied Genetics* 71:242–49.

Matheson, A.C., and A.C. Raymond. 1984. Provenance x environment interactions: Its detection, practical importance and use with particular reference to tropical forestry. In R.D. Barnes and G.L. Gibson, eds., *Provenance and genetic improvement strategies in tropical forest trees.* Oxford, United Kingdom: Oxford University Press.

McKeand S.E., and R.J. Weir. 1983. Economic benefits of an aggressive breeding program. In *Proceedings of the 17th Southern Forestry Tree Improvement Conference.* Springfield, VA: National Tree Improvement Society.

McKenney, D.W., W. van Vuuren, and G.C. Fox. 1989. An economic comparison of alternative tree improvement strategies: A simulation approach. *Canadian Journal of Agricultural Economics* 37:211–32.

McKnight, J.S. 1970. Planting cottonwood cuttings for timber production in the south. United States Department of Agriculture (USDA) Forest Service General Technical Report SO-60, Southern Forestry Experimental Station, New Orleans, LA: USDA.

Midgley, S. 1988. *Tree seed in forest development.* Canberra, Australia: CSIRO Division of Forestry and Forest Products.

Namkoong, G. 1969. Nonoptimality of local races. In *Proceedings of the 10th Southern Forestry Tree Improvement Conference.* Springfield, VA: National Tree Improvement Society.

Namkoong, G., H.C. Kang, and J.S. Brouard. 1988. *Tree breeding: Principles and strategies.* New York, New York: Springer-Verlag.

O'Regan, M., and L. Sar. 1989. *The vegetative propagation of radiata pine: Economic gains and policy implications.* Australian Bureau of Agriculture and Resource Economics. Discussion Paper 89.2. Canberra.

Paques, L.E. 1989. Tree improvement strategies: modelling and optimization: The model. *Silvae Genetica* 38:101–107.

Plumtre, R.A., and R.D. Barnes. 1982. Economic significance of research and training in the unit of tropical silviculture at the Commonwealth Forestry Institute, Oxford University, Oxford, United Kingdom.

Poole, B. 1991. Personal communication.

Porterfield, R.L. 1974. *Predicted and potential gains from tree improvement programs—A goal programming analysis of program efficiency.* North Carolina State University, School of Forest Resources Technical Report no. 52. Greenville, North Carolina: North Carolina State University.

Porterfield, R.L., and F.T. Ledig. 1977. The economics of tree improvement programs in the northeast. In: *Proceedings of the 25th Northeastern Forest Tree Improvement Conference.* University of Maine, July 27–29, 1977.

———. 1977. Economic evaluation of tree improvement programs. In *Proceedings of the 3d World Consultation on Forest Tree Breeding.* Canberra, Australia: CSIRO.

Portwood, J. 1990. Personal communication.

Reilly, J.J., and D.G. Nikles. 1977. Analyzing benefits and costs of tree improvement: Pinus caribaea. In *Proceedings of the 3d World Consultation on Forest Tree Breeding.* Canberra, Australia: CSIRO.

Shelbourne, C.J.A. 1989. *A comparison of gains and costs of breeding and seed orchard strategies for the improvement of eucalypts and other minor species.* Genetics and Tree Improvement Project no. 62. Rotorua, New Zealand: New Zealand Forestry Research Institute.

Shelbourne, C.J.A., M. Carson, and M. Wilcox. 1989. New techniques in the genetic improvement of radiata pine. *Commonwealth Forestry Review* 69(3): 191–201.

Sim, B.L., and N. Jones. 1984. Improvement of Gmelina arborea in Sabah Softwoods plantations. In R.D. Barnes and G.L. Gibson, eds., *Provenance and genetic improvement strategies in tropical forest trees.* Oxford, United Kingdom: Oxford University Press.

South, D.B. 1993. Rationale for growing southern pine seedlings at low seedbed densities. *New Forests* 7:63–92.

South, D.B., J.N. Boyer, and L. Bosch. 1985. Survival and growth of loblolly pine as influenced by seedling grade: Thirteenth-year results. *Southern Journal of Applied Forestry* 9:76–81.

Spencer, D.J. 1987. Increased yields of high quality veneer and sawn timber from cuttings of radiata pine. *Australian Forestry* 50:112–7.

Srimathi, R.A., and C.J.S.K. Emmanuel. 1986. Improved teak seeds-management and economics. *Journal of Tropical Forestry* 2:261–66.

Stewart, J.L., A.L. Dunsden, J.J. Hellin, and C.E. Hughes. 1992. *Wood biomass in Central American dry zones. Tropical Forestry Paper 26. Oxford, United Kingdom: Oxford Forestry Institute.*

Sweet, G.B. 1973. The effect of maturation on the growth and form of vegetative propagules of radiata pine. *New Zealand Journal of Forestry* 3:191–210.

Talbert, J.T., R.J. Weir, and R.D. Arnold. 1983. *Loblolly pine tree improvement: An attractive forestry investment.* Raleigh, NC: North Carolina State University, Industry Pine Tree Improvement Cooperative.

———. 1985. Costs and benefits of a mature first-generation loblolly pine tree improvement program. *Journal of Forestry* 83(3): 162–6.

Thomson, T.A. 1989. Evaluating some financial uncertainties of tree improvement using the capital asset pricing model and dominance analysis. *Canadian Journal of Forestry Research* 19:1380–88.

Thomson, T.A., D.T. Lester, J.A. Martin, and G.S. Foster. 1989. Using economic and decision making concepts to evaluate and design a corporate tree improvement program. *Silvae Genetica* 38:21–8.

Tinus, R.W., and S.E. Macdonald. 1979. *How to grow seedlings in containers in greenhouses.* USDA Forest Service General Technical Report

RM-60. Fort Collins, Colorado: USDA Rocky Mountain Forest and Range Experiment Station.

Van Buijtenen, J.P., and W.W. Saitta. 1972. Linear programming applied to the economic analysis of forest tree improvement. *Journal of Forestry* 70:164–67.

Van Wyk, G., and H.A. van der Sijde. 1983. The economic benefits of forest tree breeding. *Southern Africa Forestry Journal* 126:48–54.

Wakeley, P.C. 1954. *Planting the southern pines.* USDA Monograph no. 18. Washington, D.C.: United States Government Printing Office.

Weir R.J. 1981. *Genetic gains and economic considerations.* Tree Improvement Short Course. Raleigh, NC: North Carolina State University.

White, T.L., and G. Hodges. 1989. *Predicting breeding values with application in forest improvements.* Dordrecht, The Netherlands: Kluwer Academic Publishers.

Willan, R.L. 1988a. Benefits from tree improvement. Technical Note no. A-2. Humlebaek, Denmark: DANIDA Forest Seed Centre.

———. 1988b. *Economic returns from tree improvement in tropical and subtropical conditions.* Technical Note no. 36. Humlebaek, Denmark: DANIDA Forest Seed Centre.

Williams, J. 1992. *Wood supply simulations on two management units in the absence of seed sourcing control.* Sault Ste. Marie, Ontario: Applied Science and Technology Section, Ontario Ministry of Natural Resources.

Williams, C.G., and J.E. de Steiguer. 1990. Value of production orchards based on two cycles of breeding and testing. *Forestry Science* 36:156–68.

Williams, C.G., F.E. Bridgwater, and C.C. Lambeth. 1983. Performance of single family versus mixed family plantation blocks of loblolly pine. In Proceeding of the Seventeenth Southern Forestry Tree Improvement Conference. Springfield, VA: National Tree Improvement Society.

Wong, C.Y. 1991. Personal communication.

Wright, J.W. 1976. *Introduction to forest genetics.* New York: Academic Press.

Wright, P.J., and K.G. Eldridge. 1985. Profitability of using seed from the Tallaganda radiata pine seed orchard. *Appita* 38:341–44.

Zobel, B.J., and J.T. Talbert. 1984. *Applied forest tree improvement.* New York: John Wiley & Sons.

Zobel, B.J., G. van Wyk, and P. Stahl. 1987. Growing exotic forests. New York: John Wiley & Sons.

Distributors of World Bank Publications

ARGENTINA
Carlos Hirsch, SRL
Galeria Guemes
Florida 165, 4th Floor-Ofc. 453/465
1333 Buenos Aires

Oficina del Libro Internacional
Alberti 40
1082 Buenos Aires

AUSTRALIA, PAPUA NEW GUINEA, FIJI, SOLOMON ISLANDS, VANUATU, AND WESTERN SAMOA
D.A. Information Services
648 Whitehorse Road
Mitcham 3132
Victoria

AUSTRIA
Gerold and Co.
Graben 31
A-1011 Wien

BANGLADESH
Micro Industries Development Assistance Society (MIDAS)
House 5, Road 16
Dhanmondi R/Area
Dhaka 1209

BELGIUM
Jean De Lannoy
Av. du Roi 202
1060 Brussels

BRAZIL
Publicacoes Tecnicas Internacionais Ltda.
Rua Peixoto Gomide, 209
01409 Sao Paulo, SP

CANADA
Le Diffuseur
151A Boul. de Mortagne
Boucherville, Québec
J4B 5E6

Renouf Publishing Co.
1294 Algoma Road
Ottawa, Ontario K1B 3W8

CHINA
China Financial & Economic Publishing House
8, Da Fo Si Dong Jie
Beijing

COLOMBIA
Infoenlace Ltda.
Apartado Aereo 34270
Bogota D.E.

COSTA RICA, BELIZE, GUATE -MALA, HONDURAS, NICARAGUA, PANAMA
Chispas Bookstore
75 Meters al Norte del Hotel Balmoral en calle 7
San Jose

COTE D'IVOIRE
Centre d'Edition et de Diffusion Africaines (CEDA)
04 B.P. 541
Abidjan 04 Plateau

CYPRUS
Center of Applied Research
Cyprus College
6, Diogenes Street, Engomi
P.O. Box 2006
Nicosia

CZECH REPUBLIC
National Information Center
P.O. Box 668
CS-113 57 Prague 1

DENMARK
SamfundsLitteratur
Rosenoerns Allé 11
DK-1970 Frederiksberg C

EGYPT, ARAB REPUBLIC OF
Al Ahram
Al Galaa Street
Cairo

The Middle East Observer
41, Sherif Street
Cairo

FINLAND
Akateeminen Kirjakauppa
P.O. Box 23
FIN-00371 Helsinki

FRANCE
World Bank Publications
66, avenue d'Iéna
75116 Paris

GERMANY
UNO-Verlag
Poppelsdorfer Allee 55
53115 Bonn

GREECE
Papasotiriou S.A.
35, Stournara Str.
106 82 Athens

HONG KONG, MACAO
Asia 2000 Ltd.
46-48 Wyndham Street
Winning Centre
7th Floor
Central, Hong Kong

HUNGARY
Foundation for Market Economy
Dombovari Ut 17-19
H-1117 Budapest

INDIA
Allied Publishers Private Ltd.
751 Mount Road
Madras - 600 002

INDONESIA
Pt. Indira Limited
Jalan Borobudur 20
P.O. Box 181
Jakarta 10320

IRAN
Kowkab Publishers
P.O. Box 19575-511
Tehran

IRELAND
Government Supplies Agency
4-5 Harcourt Road
Dublin 2

ISRAEL
Yozmot Literature Ltd.
P.O. Box 56055
Tel Aviv 61560

R.O.Y. International
P.O. Box 13056
Tel Aviv 61130

Palestinian Authority/Middle East
Index Information Services
P.O.B. 19502 Jerusalem

ITALY
Licosa Commissionaria Sansoni SPA
Via Duca Di Calabria, 1/1
Casella Postale 552
50125 Firenze

JAMAICA
Ian Randle Publishers Ltd.
206 Old Hope Road
Kingston 6

JAPAN
Eastern Book Service
Hongo 3-Chome, Bunkyo-ku 113
Tokyo

KENYA
Africa Book Service (E.A.) Ltd.
Quaran House, Mfangano St.
P.O. Box 45245
Nairobi

KOREA, REPUBLIC OF
Daejon Trading Co. Ltd.
P.O. Box 34
Yeoeida
Seoul

MALAYSIA
University of Malaya Cooperative Bookshop, Limited
P.O. Box 1127, Jalan Pantai Baru
59700 Kuala Lumpur

MEXICO
INFOTEC
Apartado Postal 22-860
14060 Tlalpan, Mexico D.F.

NETHERLANDS
De Lindeboom/InOr-Publikaties
P.O. Box 202
7480 AE Haaksbergen

NEW ZEALAND
EBSCO NZ Ltd.
Private Mail Bag 99914
New Market
Auckland

NIGERIA
University Press Limited
Three Crowns Building Jericho
Private Mail Bag 5095
Ibadan

NORWAY
Narvesen Information Center
Book Department
P.O. Box 6125 Etterstad
N-0602 Oslo 6

PAKISTAN
Mirza Book Agency
65, Shahrah-e-Quaid-e-Azam
P.O. Box No. 729
Lahore 54000

Oxford University Press
5 Bangalore Town
Sharae Faisal
P.O. Box 13033
Karachi-75350

PERU
Editorial Desarrollo SA
Apartado 3824
Lima 1

PHILIPPINES
International Book Center
Suite 720, Cityland 10
Condominium Tower 2
Ayala Avenue, H.V. dela Costa Extension
Makati, Metro Manila

POLAND
International Publishing Service
Ul. Piekna 31/37
00-577 Warszawa

PORTUGAL
Livraria Portugal
Rua Do Carmo 70-74
1200 Lisbon

SAUDI ARABIA, QATAR
Jarir Book Store
P.O. Box 3196
Riyadh 11471

SINGAPORE, TAIWAN
Gower Asia Pacific Pte Ltd.
Golden Wheel Building
41, Kallang Pudding, #04-03
Singapore 1334

SLOVAK REPUBLIC
Slovart G.T.G. Ltd.
Krupinska 4
P.O. Box 152
852 99 Bratislava 5

SOUTH AFRICA, BOTSWANA
Oxford University Press Southern Africa
P.O. Box 1141
Cape Town 8000

SPAIN
Mundi-Prensa Libros, S.A.
Castello 37
28001 Madrid

Libreria Internacional AEDOS
Consell de Cent, 391
08009 Barcelona

SRI LANKA & THE MALDIVES
Lake House Bookshop
P.O. Box 244
100, Sir Chittampalam A. Gardiner Mawatha
Colombo 2

SWEDEN
Fritzes Customer Service
Regeringsgatan 12
S-106 47 Stockholm

Wennergren-Williams AB
P.O. Box 1305
S-171 25 Solna

SWITZERLAND
Librairie Payot
Case postale 3212
CH 1002 Lausanne

Van Diermen Editions Techniques
P.O. Box 465
CH 1211 Geneva 19

TANZANIA
Oxford University Press
Maktaba Street
P.O. Box 5299
Dar es-Salaam

THAILAND
Central Books Distribution Co. Ltd.
306 Silom Road
Bangkok

TRINIDAD & TOBAGO, JAMAICA
Systematics Studies Unit
#9 Watts Street
Curepe
Trinidad, West Indies

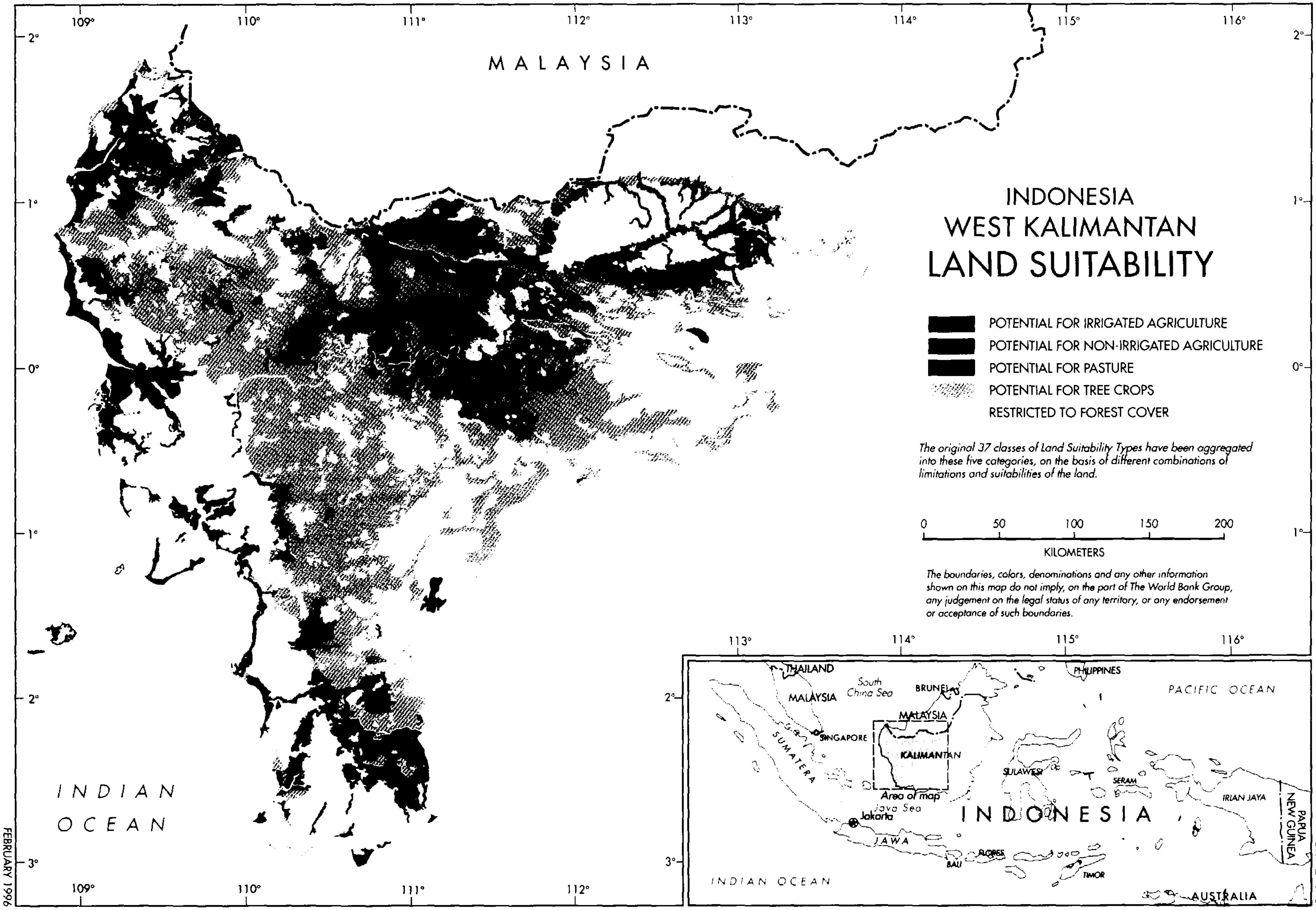
UGANDA
Gustro Ltd.
1st Floor, Room 4, Geogiadis Chambers
P.O. Box 9997
Plot (69) Kampala Road
Kampala

UNITED KINGDOM
Microinfo Ltd.
P.O. Box 3
Alton, Hampshire GU34 2PG
England

ZAMBIA
University Bookshop
Great East Road Campus
P.O. Box 32379
Lusaka

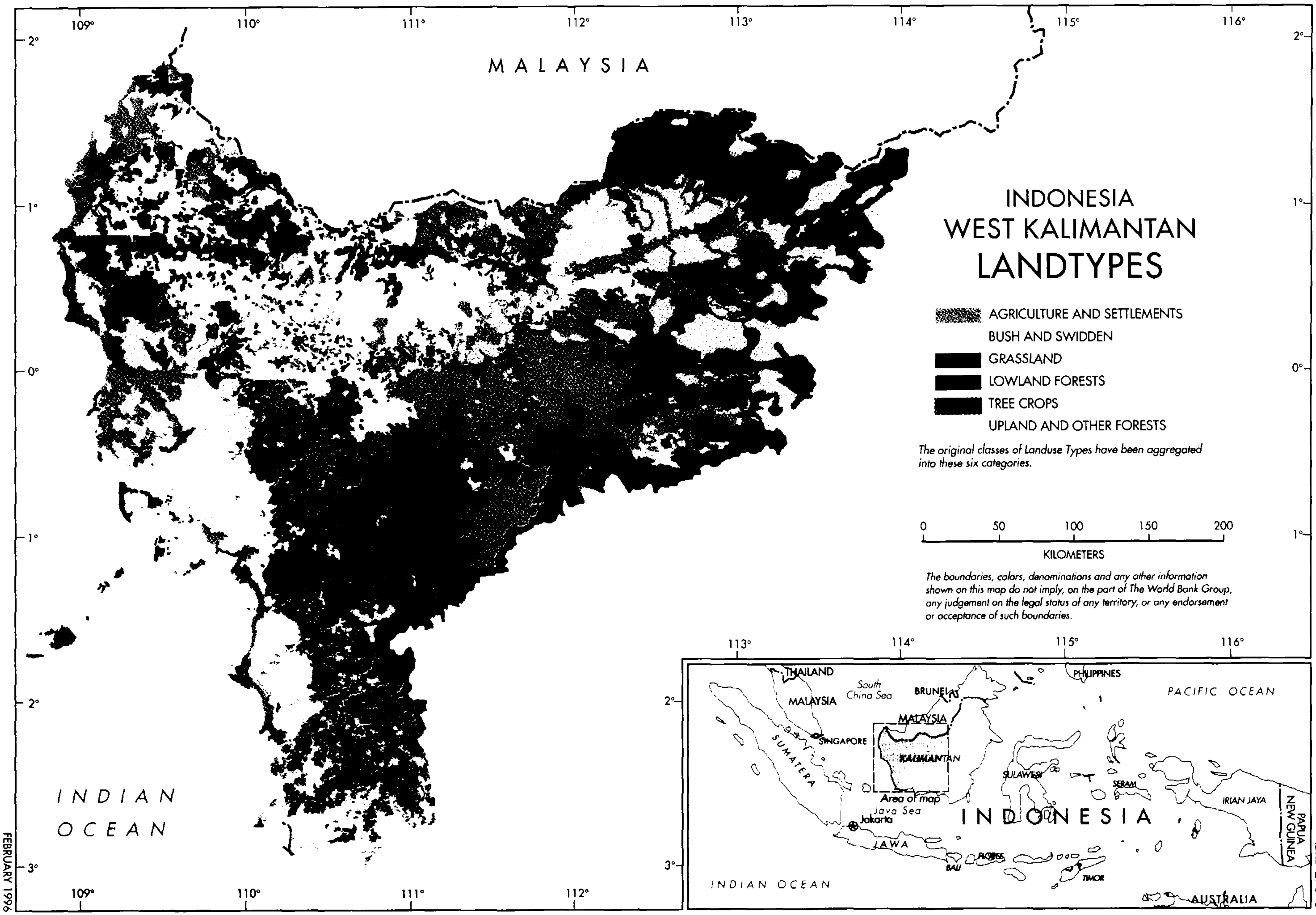
ZIMBABWE
Longman Zimbabwe (Pte.) Ltd.
Tourle Road, Ardbennie
P.O. Box ST 125

Maps



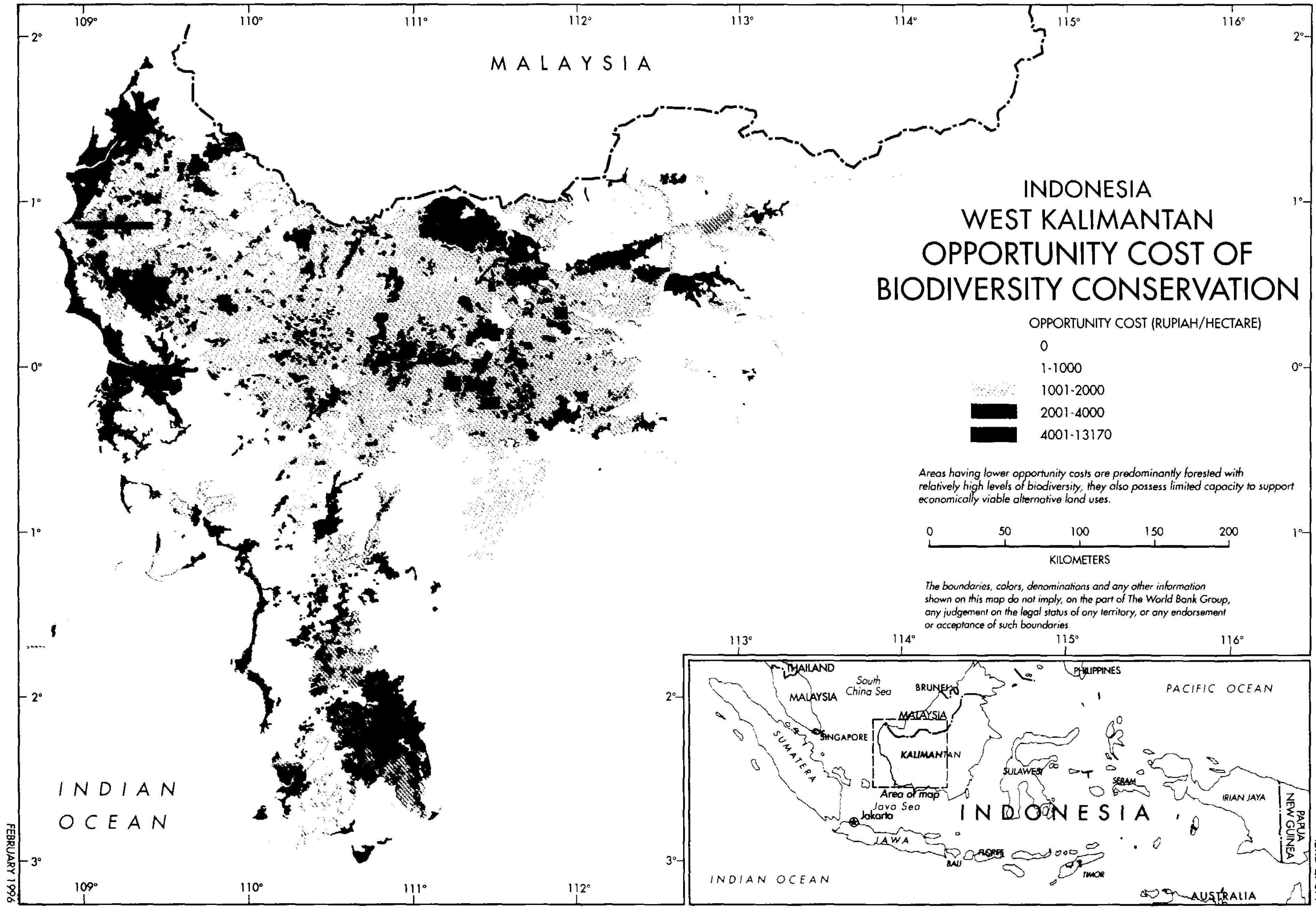
FEBRUARY 1996

IBRD 27675



FEBRUARY 1996

IBRD 27676


INDONESIA
WEST KALIMANTAN
OPPORTUNITY COST OF
BIODIVERSITY CONSERVATION
OPPORTUNITY COST (RUPIAH/HECTARE)
0
1-1000
1001-2000
2001-4000
4001-13170
Areas having lower opportunity costs are predominantly forested with relatively high levels of biodiversity, they also possess limited capacity to support economically viable alternative land uses.
0 50 100 150 200
KILOMETERS
The boundaries, colors, denominations and any other information shown on this map do not imply, on the part of The World Bank Group, any judgement on the legal status of any territory, or any endorsement or acceptance of such boundaries
MALAYSIA
INDIAN OCEAN
THAILAND
PHILIPPINES
South China Sea
BRUNEI
MALAYSIA
PACIFIC OCEAN
SINGAPORE
SUMATERA
KALIMANTAN
SULAWESI
SERAM
IRIAN JAYA
PAPUA NEW GUINEA
Area of map
Java Sea
Jakarta
INDONESIA
JAWA
BALI
FLORES
TIMOR
INDIAN OCEAN
AUSTRALIA
FEBRUARY 1996
IBRD 27677

RECENT WORLD BANK TECHNICAL PAPERS *(continued)*

No. 254 Frischtak, *Governance Capacity and Economic Reform in Developing Countries*

No. 255 Mohan, editor, *Bibliography of Publications: Technical Department, Africa Region, July 1987 to April 1994*

No. 256 Campbell, *Design and Operation of Smallholder Irrigation in South Asia*

No. 257 Malhotra, Sinsukprasert, and Eglington, *The Performance of Asia's Energy Sector*

No. 258 De Geyndt, *Managing the Quality of Health Care in Developing Countries*

No. 259 Chaudry, Reid, and Malik, editors, *Civil Service Reform in Latin America and the Caribbean: Proceedings of a Conference*

No. 260 Humphrey, *Payment Systems: Principles, Practice, and Improvements*

No. 261 Lynch, *Provision for Children with Special Educational Needs in the Asia Region*

No. 262 Lee and Bobadilla, *Health Statistics for the Americas*

No. 263 Le Moigne, Subramanian, Xie, and Giltner, editors, *A Guide to the Formulation of Water Resources Strategy*

No. 264 Miller and Jones, *Organic and Compost-Based Growing Media for Tree Seedling Nurseries*

No. 265 Viswanath, *Building Partnerships for Poverty Reduction: The Participatory Project Planning Approach of the Women's Enterprise Management Training Outreach Program (WEMTOP)*

No. 266 Hill and Bender, *Developing the Regulatory Environment for Competitive Agricultural Markets*

No. 267 Valdés and Schaeffer, *Surveillance of Agricultural Prices and Trade: A Handbook for the Dominican Republic*

No. 268 Valdés and Schaeffer, *Surveillance of Agricultural Prices and Trade: A Handbook for Colombia*

No. 269 Scheierling, *Overcoming Agricultural Pollution of Water: The Challenge of Integrating Agricultural and Environmental Policies in the European Union*

No. 270 Banerjee, *Rehabilitation of Degraded Forests in Asia*

No. 271 Ahmed, *Technological Development and Pollution Abatement: A Study of How Enterprises Are Finding Alternatives to Chlorofluorocarbons*

No. 272 Greaney and Kellaghan, *Equity Issues in Public Examinations in Developing Countries*

No. 273 Grimshaw and Helfer, editors, *Vetiver Grass for Soil and Water Conservation, Land Rehabilitation, and Embankment Stabilization: A Collection of Papers and Newsletters Compiled by the Vetiver Network*

No. 274 Govindaraj, Murray, and Chellaraj, *Health Expenditures in Latin America*

No. 275 Heggie, *Management and Financing of Roads: An Agenda for Reform*

No. 276 Johnson, *Quality Review Schemes for Auditors: Their Potential for Sub-Saharan Africa*

No. 277 Convery, *Applying Environmental Economics in Africa*

No. 278 Wijetilleke and Karunaratne, *Air Quality Management: Considerations for Developing Countries*

No. 279 Anderson and Ahmed, *The Case for Solar Energy Investments*

No. 280 Rowat, Malik, and Dakolias, *Judicial Reform in Latin America and the Caribbean: Proceedings of a World Bank Conference*

No. 281 Shen and Contreras-Hermosilla, *Environmental and Economic Issues in Forestry: Selected Case Studies in India*

No. 282 Kim and Benton, *Cost-Benefit Analysis of the Onchocerciasis Control Program (OCP)*

No. 283 Jacobsen, Scobie and Duncan, *Statutory Intervention in Agricultural Marketing: A New Zealand Perspective*

No. 284 Valdés and Schaeffer in collaboration with Roldos and Chiara, *Surveillance of Agricultural Price and Trade Policies: A Handbook for Uruguay*

No. 285 Brehm and Castro, *The Market for Water Rights in Chile: Major Issues*

No. 286 Tavoulareas and Charpentier *Clean Coal Technologies for Developing Countries*

No. 287 Gillham, Bell, Arin, Matthews, Rumeur, and Hearn, *Cotton Production Prospects for the Next Decade*

No. 289 Dinar, Seidl, Olem, Jorden, Duda, and Johnson, *Restoring and Protecting the World's Lakes and Reservoirs*

No. 290 Weijenberg, Dagg, Kampen Kalunda, Mailu, Ketema, Navarro, and Abdi Noor, *Strengthening National Agricultual Research Systems in Eastern and Central Africa: A Framework for Action*

THE WORLD BANK

A partner in strengthening economies
and expanding markets
to improve the quality of life
for people everywhere,
especially the poorest

Headquarters
1818 H Street, N.W.
Washington, D.C. 20433, U.S.A.

Telephone: (202) 477-1234
Facsimile: (202) 477-6391
Telex: MCI 64145 WORLDBANK
MCI 248423 WORLDBANK
Cable Address: INTBAFRAD
WASHINGTONDC
World Wide Web: http://www.worldbank.org
E-mail: books@worldbank.org

European Office
66, avenue d'Iéna
75116 Paris, France

Telephone: (1) 40.69.30.00
Facsimile: (1) 40.69.30.66
Telex: 640651

Tokyo Office
Kokusai Building
1-1, Marunouchi 3-chome
Chiyoda-ku, Tokyo 100, Japan

Telephone: (3) 3214-5001
Facsimile: (3) 3214-3657
Telex: 26838

Cover design by George Parakamannil

ISBN 0-8213-3233-3