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REGIONAL  
SEMINAR  
ON**

**FORESTS OF THE HUMID  
TROPICS OF SOUTH AND  
SOUTH EAST ASIA**

**MAB**



**NATIONAL MAB COMMITTEE  
&  
THE NATURAL RESOURCES, ENERGY  
AND SCIENCE AUTHORITY  
SRI LANKA**



**PROCEEDINGS**

**OF THE**

**REGIONAL SEMINAR ON FORESTS OF THE  
HUMID TROPICS OF SOUTH AND  
SOUTH EAST ASIA**

**KANDY, SRI LANKA**

**19 – 22 March 1996**

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**Natural Resources, Energy & Science Authority of Sri Lanka  
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**Regional Seminar On Forests Of The  
Humid Tropics Of South And  
South East Asia**

**ORGANIZED BY**

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## CONTENTS

|                                                                                                                                          |       |
|------------------------------------------------------------------------------------------------------------------------------------------|-------|
| List of Participants                                                                                                                     | ix    |
| Acknowledgements                                                                                                                         | xv    |
| Address by the Director General Natural Resources Energy and Science Authority<br><i>Prof. Priyani E. Soysa</i>                          | xvi   |
| <i>Address by Hon. Bernard Soysa</i><br>(Minister of Science, Technology & Human Resources Development)                                  | xvii  |
| Felicitations at the regional seminar on forests of the humid tropics of South<br>and South East Asia<br><i>Prof. B. A. Abeywickrama</i> | xxi   |
| <i>Mr W.R.H. Perera</i>                                                                                                                  | xxiii |
| Address by the UNESCO Representative<br>Humid tropics research and UNESCO: an introduction and overview<br><i>Dr M. Hadley</i>           | xxv   |

## TECHNICAL SESSIONS

|                                                                                                                                      |    |
|--------------------------------------------------------------------------------------------------------------------------------------|----|
| <b>FOREST BIODIVERSITY IN HUMID TROPICS</b>                                                                                          | 1  |
| Forest biodiversity in the humid tropics: who cares? Adapting to changing conditions.<br><i>J. A. McNeely</i>                        | 3  |
| Understanding long term vegetation dynamics for management of biodiversity:<br>a Sri Lankan perspective<br><i>C.V.S. Gunatilleke</i> | 19 |
| In-situ conservation of biodiversity and a network of conservation areas<br>for Sri Lanka<br><i>A.H. M. Jayasuriya</i>               | 27 |

|                                                                                                                                 |    |
|---------------------------------------------------------------------------------------------------------------------------------|----|
| Distribution of the indigenous orchids of Sri Lanka and some proposals<br>for their conservation<br><i>R. H. Wickramasinghe</i> | 49 |
|---------------------------------------------------------------------------------------------------------------------------------|----|

|                                                                                    |    |
|------------------------------------------------------------------------------------|----|
| <b>ECOLOGICAL CHARACTERISTICS AND ENVIRONMENTAL FUNCTIONS<br/>OF HUMID FORESTS</b> | 55 |
|------------------------------------------------------------------------------------|----|

|                                                                                                         |    |
|---------------------------------------------------------------------------------------------------------|----|
| Ecological characteristics and environmental functions of tropical rain forests<br><i>T.C. Whitmore</i> | 57 |
|---------------------------------------------------------------------------------------------------------|----|

|                                                         |    |
|---------------------------------------------------------|----|
| The deciduous forest of Thailand<br><i>U. Kutintara</i> | 69 |
|---------------------------------------------------------|----|

|                                                                                                                        |    |
|------------------------------------------------------------------------------------------------------------------------|----|
| Floral diversity of Kaiatuwawa – Labugama forest reserve<br><i>G.I. Seneviratne, K. Abeynayake and M.R.K. Lenagala</i> | 95 |
|------------------------------------------------------------------------------------------------------------------------|----|

|                                                                                                                                                               |     |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| Seedling growth of four co-occurring canopy tree species on different<br>Light and soil moisture environments<br><i>B.M.P. Singhakumara and P.M.S. Ashton</i> | 107 |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|

|                                                                                                                                                                                                                     |     |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| Seedling leaf-structure of some late-successional canopy tree species in simulated<br>Light and soil moisture environments of a Sri Lankan rain forest<br><i>H.K. Gamage, B.M.P. Singhakumara and P.M.S. Ashton</i> | 121 |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|

|                                                                                                       |     |
|-------------------------------------------------------------------------------------------------------|-----|
| Southern African forests: their biogeography, conservation and utilization<br><i>C. J. Geldenhuys</i> | 143 |
|-------------------------------------------------------------------------------------------------------|-----|

|                                               |     |
|-----------------------------------------------|-----|
| <b>CONSERVATION OF TROPICAL HUMID FORESTS</b> | 171 |
|-----------------------------------------------|-----|

|                                                                                                        |     |
|--------------------------------------------------------------------------------------------------------|-----|
| Conservation and sustainable management of forest resources in Sri Lanka<br><i>H.M. Bandaratillake</i> | 173 |
|--------------------------------------------------------------------------------------------------------|-----|

|                                                                          |     |
|--------------------------------------------------------------------------|-----|
| Long term research sites in tropical forests of India<br><i>S.N. Rai</i> | 183 |
|--------------------------------------------------------------------------|-----|

|                                                                                                                                                                                       |     |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| Tree population dynamics of a riverine mixed forest in Ketambe Research<br>Station, G. Leuser Biosphere Reserve, Sumatra, Indonesia<br><i>R. Abdulhadi, R. Yusuf &amp; Suhardjono</i> | 193 |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|

|                                                                                                      |     |
|------------------------------------------------------------------------------------------------------|-----|
| Spatial dynamics of canopy breakdown and recovery in forests ecosystems<br><i>D. Mueller-Dombois</i> | 209 |
|------------------------------------------------------------------------------------------------------|-----|

|                                                                       |     |
|-----------------------------------------------------------------------|-----|
| <b>SUSTAINABLE UTILIZATION OF TROPICAL HUMID<br/>FOREST RESOURCES</b> | 223 |
|-----------------------------------------------------------------------|-----|

|                                                                                                                                                          |     |
|----------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| The effect of income among the communities of Sinharaja on the extraction of<br>non-timber forest products: a preliminary study<br><i>D. Kariyawasam</i> | 225 |
|----------------------------------------------------------------------------------------------------------------------------------------------------------|-----|

|                                                                                                                                                                                |     |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| Floristics of soil seed banks in relation to light and topographic position in a<br>Sri Lankan rain forest<br><i>R.S.J.P. Uduporuwa, B.M.P. Singhakumara and P.M.S. Ashton</i> | 235 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|

|                                                                                                   |     |
|---------------------------------------------------------------------------------------------------|-----|
| Conservation of genetic resources of important tree species in Sri Lanka<br><i>D. Tilakaratna</i> | 249 |
|---------------------------------------------------------------------------------------------------|-----|

|                                                                                                           |     |
|-----------------------------------------------------------------------------------------------------------|-----|
| Medicinal plants : understanding the ground situation to develop strategy<br><i>D.B. Sumithraarachchi</i> | 257 |
|-----------------------------------------------------------------------------------------------------------|-----|

|                                                                                                                     |     |
|---------------------------------------------------------------------------------------------------------------------|-----|
| Sustainable development through sustainable use of biodiversity: economic<br>policy options<br><i>H.B. Kotagama</i> | 269 |
|---------------------------------------------------------------------------------------------------------------------|-----|

|                                                                                                       |     |
|-------------------------------------------------------------------------------------------------------|-----|
| <b>LINKS BETWEEN SUSTAINABLE DEVELOPMENT OF FOREST RESOURCES<br/>AND CONSERVATION OF BIODIVERSITY</b> | 289 |
|-------------------------------------------------------------------------------------------------------|-----|

|                                                                            |     |
|----------------------------------------------------------------------------|-----|
| Conservation and development in humid tropical forests<br><i>M.Batisse</i> | 291 |
|----------------------------------------------------------------------------|-----|

|                                                                                                      |     |
|------------------------------------------------------------------------------------------------------|-----|
| Sustainable development of forest resources and conservation of biodiversity<br><i>A.S. Tamrakar</i> | 299 |
|------------------------------------------------------------------------------------------------------|-----|

|                                                                                                                                                                                                   |     |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| Conversion of <i>pinus</i> plantations in the buffer zone of the Sinharaja MAB<br>reserve to rain forest analogs<br><i>A.G. Sunil, P.M.S. Ashton, C.V.S. Gunatilleke and I.A.U.N. Gunatilleke</i> | 303 |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|

**INTERNATIONAL COOPERATION ON ISSUES RELEVANT TO  
CONSERVATION AND DEVELOPMENT OF FORESTS IN  
ASIAN HUMID TROPICS** 315

Deforestation and its implications for conservation of Elephants in Sumatra and  
Sri Lanka 317  
*C. Santiapillai*

Changing relationships between forestry research and landscape management in  
The humid tropics 327  
*M. Hadley and N. Ishwaran*



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**Prof. Kapila Dahanayake**  
Chairman  
National Science Foundation

January 1999



**ADDRESS BY THE DIRECTOR GENERAL****NATURAL RESOURCES, ENERGY AND SCIENCE AUTHORITY**

*Professor Priyani E. Soysa*

It is my duty and great privilege to welcome the Hon. Minister, members of the NARESA Board, members of the National Committee on Man and the Biosphere, foreign and local participants and all you distinguished invitees. This is a very special occasion for the National Committee on Man and the Biosphere, because it was a proposal by the Sri Lankan representative, to the 8th General Meeting of UNESCO held in Montevideo, Uruguay in 1954, that initiated UN involvement in humid tropics studies. The proposal was made by Prof. Abeywickrama representing the Sri Lanka Association for the Advancement of Science in his capacity as the General Secretary. In spite of western opposition, funding had been finally unanimously approved. Next in 1955 Prof. Abeywickrama had highlighted the problems in the humid tropics and subsequently in 1956 an international seminar had been convened in Kandy as the venue. This is the fortieth anniversary of that meeting which UNESCO thought fit to celebrate with another meeting, this meeting at the same location.

In a way this is then a celebration. Much thought and effort had been pooled to make this possible locally, with foreign experts travelling from India, Thailand, Nepal, Paris, South Africa, Switzerland, United Kingdom, Indonesia and Hawaii to join us to make this an event. Dr Batisse present here today since 1964 combined the Humid tropics with the arid zone project. He had highlighted the fragility of the Humid tropics. Now the UN General body has taken over the environmental issue with the 2nd conference in 1972 creating General Global awareness.

I have unfolded this long history as a back drop to today's occasion.

Hon. Bernard Soysa our Minister of Science, Technology and Human Resources Development, you have graced this occasion, spending time and effort to travel up to Kandy. I know that you have to rush back for the parliamentary debate this morning. Nevertheless we are delighted to have you at this inauguration. I, on behalf of the National Committee on Man and the Biosphere, welcome you.

Your worship the Mayor we are pleased to see you this morning. We have chosen Kandy for this meeting. Our foreign guests have complimented us in making a journey, the potential hazards of which you have discounted in your desire to contribute at this seminar. We had only one country which did not permit their delegates to come. But as you can see it is quite quiet up here. We hope you enjoy the meeting, your trip to Sinharaja and perhaps a little bit of the country side. I welcome you.

Last but not least the local participants and our scientists present here add strength, wisdom and loyalty to this occasion. Thank you.

**ADDRESS BY THE MINISTER OF SCIENCE, TECHNOLOGY &  
HUMAN RESOURCES DEVELOPMENT**

*Hon. Bernard Soysa*

Prof. Priyani Soysa, Chairperson and Director General of NARESA, His Worship the Mayor of Kandy, Dr Hadley and other distinguished invitees, ladies and gentlemen. A discussion with regard to humid forests and a prolonged seminar for the purpose of discussing the problems attendant upon the preservation of these forests is in fact a very important occasion but also a very sad one. Sad because we are witnessing the disappearance of forest cover in this country at a very rapid rate. Dr Hadley mentioned the Sinharaja forest and the richness of its biodiversity and the need for preservation of the Sinharaja along with other similar areas in the tropical world. Now, the Sinharaja forest is an area which I have never penetrated far deep into, but I can testify to the fact that the forest repays every person making a visit with the real pleasure and joy of being in the midst of nature. The richness of the wildlife that you find there, the botanical richness -- all that has been described many many times before this. The biodiversity of the area has certainly not been improved by the addition of two species of humanity in recent times! viz. one, the timber loggers who have invaded the area to destroy large parts of the Sinharaja forest; the other is the armed terrorists who have now adopted the Sinharaja forest as a possible territory for their activity. These two sections of humanity have certainly not added to the diversity in any rich way! Be that as it may, the fact remains that the forest cover in this country has been threatened for quite a long time, in particular, on account of the erroneous notions of development that have persisted in our midst. Ever since 1948 when a large part of the responsibility of managing the affairs of this country (though not complete independence) was obtained by the people of Sri Lanka, all governments and particularly Ministers of Finance and Agriculture and Industry have talked about development and been animated by development. They have been talking of plans -- 4 year plans, 5 year plans, and so on. But the impact of this upon the natural resources of the country, the environmental damage that some of these things can do were never properly considered. I know there is just resentment when those in the developed countries preach lessons to us in the developing countries about the necessity of protecting our environment and object to various industrial projects on the grounds of environmental damage. I know there is a just resentment against that because these are people who have destroyed their own environment over the centuries and achieved a certain degree of wealth and riches and now are suspected of preventing others reaching their own standards. The question of protecting the environment and natural resources is part of the business of protecting the common heritage of humanity as a whole irrespective of whether you are in a developed country or in a developing country. However the fact remains that we have not been truly conscious of the need to preserve what we have. "I remember some years ago I mentioned this question in Parliament of the possible effect of the destruction of our forests

and what impact it might have upon the monsoons that visit this country and the rainfall that Sri Lanka has the benefit of from two monsoons". This question was addressed to the then Dept. of Meteorology and the answer came that the acre-feet of water that falls upon this country through rain had not diminished in any way as a result of development efforts. It was a considerable relief to learn that the acre-feet of water had not diminished but there was no attention paid to the distribution of that supply, and to the question of periods of drought and periods of floods. I know there are countries in this region that suffer more than we do on these problems, Bangladesh for instance. But we ourselves have our own quota of these two problems of long drought periods and periods of floods. The acre-feet of water can remain stable but the distribution can remain so uneven that you get both these calamities. This is a matter that we have to attend to. There is a problem which is connected with one of the subjects given to my Ministry, and that is this question of renewable sources of energy. There is a frightening crisis that looms over this country and very few of us are aware of it. The principal source of energy in a developing country like Sri Lanka is wood. We have also been importing fossil fuels from abroad and there has been an increasing dependence on fossil fuels, particularly for transport. Now the world's resources in fossil fuels are getting exhausted. There are all kinds of projections on when they would be fully exhausted--some say in another 50 years, some say about a hundred years, and so on. I do not know the tables in regard to these matters or how scientific these calculations are. They seem to be almost as bad as the calculations made by our local astrologers on the expectation of life of the individual! Therefore while not speculating on that, we can accept the fact that there is an exhaustion and coupled with that we will find that gradually it will become almost impossible for countries like this to obtain the necessary quantities of fossil fuels for their industrial requirements, transport requirements, and so on. What then is the future for energy in this country? We have an increasing population and a large rural population. The rural population has depended very much upon the forest cover for sustenance. We must have properly oriented policies carried out in regard to reforestation. I know that there is at the moment a ground plan of strategies in regard to Forestry. The document is very good but I should like to see some implementation commenced. And that is very slow. I mentioned this for the reason that the dependence of our rural population is largely upon fuelwood and the demand for fuelwood threatens the extent of forest cover in this country. That has really not been properly estimated. We are supposed to be clearing 30,000 - 40,000 hectares of land per year and what impact that has on the climatic changes has also not been properly estimated. The consumption of fuelwood and what kind of reforestation would be required to maintain that supply has also not been properly calculated. I know it is difficult to do that because one cannot be quite sure and speculate about the activities of rural households in that way particularly with the civil war going on and migration of populations as refugees and so on. But the consumption of fuelwood which is the principal source of energy for our people has to be controlled in some way. One cannot abolish it. It can't be done, but we can at least reduce it. And for that it is necessary to have a campaign of making our people aware and taking the proper action for more economical use of fuelwood for domestic purposes (cooking), community purposes like the cremation of a body. In local authorities crematoria are constructed which consume a tremendous amount of fuelwood. By getting away from the traditional three stone hearth cooking place in rural households into

something that conserves heat in a better way, fuelwood consumption can be minimized. I have been trying to get a number of industrialists and entrepreneurs to invest in making these rural cookers, solar cookers and gasifiers but at the moment we are not quite sure of the market, and like all entrepreneurs even the venture capitalists in our country are not particularly venturesome, and therefore, looking at the bottom line they are afraid to invest yet. However I have some hope that at least two, a banker and somebody else, have shown some interest in what our National Engineering Research and Development Centre has been doing in this field and they promised to come and have a look and see what they could develop by way of sales of the products that they could manufacture. Well, gasifiers and better systems of cooking that can reduce the dependence on fuelwood, solar cooking and solar heating methods, these are all renewable sources of energy which we have to explore. I mention this because the energy crisis can be very serious for us. Unless we preserve our fuelwood resources and develop alternative ones like solar and wind energy we are going to be in real difficulties. Some years ago we thought that we would be able to export electricity to our neighbours with the major hydro-electric schemes that were planned. That dream has disappeared. We are now in the situation of possibly having to import electricity from outside. Mini hydro schemes are possible on a fairly widespread scale but that will not solve the problem. Mini hydro schemes will also add to the means of controlling the denudation of forests for fuelwood. To some extent it can have an impact. This is one of the things that I would like the local scientists here to get together to plan the means of giving increasing public awareness of the dangers that are inherent in this situation, and the problem of where we are going to get our energy resources without destroying our forests completely. How is this increasing population going to obtain the necessary energy? That is one of the problems, I think, to which we have to address ourselves. I would like our local scientists to see what they could borrow from what others have learnt outside this country and join in a programme of increasing public awareness on this matter, sensitizing the rural population to the dangers that are inherent in this entire situation. Fortunately we have given up chena cultivation or we are discouraging chena cultivation which is also one of the means of destroying forest cover. But there has been no proper concept of what might be called social forestry or agroforestry. These ideas have not been pursued in any scientific or proper way in this country. It has been largely the property of persons like Prof. Abeywickrama and one or two others. I may not be aware of all of them but without any insult to anybody I just mentioned that the numbers are very few. It is very necessary to sensitize public opinion on this matter so that we can preserve our natural resources in a proper and scientific manner. The future can be disastrous on this question of energy unless we are conscious of the actual problems that are involved, the complexity of the problems and address ourselves to them. I have not always been very happy about this phrase which the World Bank and the International Monetary Fund seek to promote-the phrase "sustainable development". Have we been trying to develop in a manner that cannot be sustained? This is nonsense! Sustainable development is only another alibi for not giving the resources for a proper conclusion to the development programme of a developing world. There is so much patronising talk of safety nets and so on when they really don't want to address themselves to the problems of rural poverty. While I would like to come back to this idea I don't want to make that the central point of activity by government or any movement. The fact remains

that what we are faced with is unsustainable underdevelopment. We are underdeveloped and we can no longer sustain our society on that basis. So it's not a question of sustainable development but unsustainable underdevelopment that is the real problem that we have got to address ourselves to. That is why I would like the scientists who have come here as our guests to give of their knowledge and their experience to enable us to solve our problems. And I wish to make this appeal to the local scientists here of the universities and other research organisations to get together and this meeting is to help you to get together and carry out a programme for sensitizing the public, increasing public awareness to the dangers inherent in the situation and spreading the methods of reducing the dependence on fuelwood and the destruction of forest cover that goes along with it. There is much to be said both from the point of view of science as well as from the arts of the necessity of protecting our forest cover. I don't need to go on much further. I want to keep these thoughts with you and to recommend to you the first line of one of Paul Robeson's songs—"I have never seen anything lovely as a tree"

## FELICITATIONS AT THE REGIONAL SEMINAR ON FORESTS OF THE HUMID TROPICS OF SOUTH AND SOUTH EAST ASIA



*Professor B. A. Abeywickrama*

Prof. B.A. Abeywickrama after graduating from the University of London in 1941, proceeded to Cambridge for post-graduate studies on a Government Science Scholarship in 1946 and obtained his Ph.D Degree in 1949. He returned to Sri Lanka and served the University of Colombo as a Lecturer until his appointment as the Professor of Botany of the University of Ceylon in 1965.

Prof. Abeywickrama's contribution to the University system in Sri Lanka in general and to the University of Colombo in particular is without parallel. His contribution to the advancement of science in Sri Lanka is equally praiseworthy. He has held positions in many Scientific Associations and Statutory bodies. He was the Chairman of the International Biological Programme Committee for Sri Lanka from 1968-1973, the UNESCO Man and the Biosphere Committee from 1974 - 1983, the Coconut Research Board from 1977 - 1983, and the Coconut Cultivation Board from 1977-1979. He has given his services to NARESA and through NARESA to science in general, through the Steering Committees of which he has been an active member and Chairman from its inception when he became a member of the Sri Lanka National Science Council.

In addition to many appointments held, he has also served as a member of the UNESCO Advisory Committee to the Director General on Humid Tropics Research from 1959 - 1964, and the Fauna and Flora Advisory Committee from 1958 - 1981.

Prof. Abeywickrama is a renowned authority on Plant Taxonomy and Ecology and more recently he has shown a great interest in conservation aspects. He has over fifty publications to his credit, a true indication of his scholarship.

In appreciation of his 47 years of active, dedicated service to the University system in Sri Lanka, the Senate of the University of Colombo appointed him Professor Emeritus in September 1958. He continues to assist in the teaching and research programmes in the Department of Botany, University of Colombo, even after his retirement, an indication of his dedication to the University and to Science.

I have the greatest pleasure in extending our warm felicitations to him on this occasion.



*Mr W.R.H. Perera*

We wish to extend our warm felicitations to Mr W.R.H. Perera, former Conservator of Forests, Sri Lanka. He served with the Forest Department as Conservator of Forests for eleven years from 1968 to 1979.

Mr W.R.H. Perera joined the Department in 1950 as Junior Assistant Conservator of Forests, and on completion of his period of apprentice training he went to Indian Forest College Dehra-Dun to follow the Diploma course in Forestry. In 1959 he went to the United Kingdom to follow the post graduate course in Forestry at the Imperial Forestry Institute, Oxford. On his return to the island he served in the Forest Department in various capacities until 1968 when he became Conservator of Forests. During his tenure of service as head of the Department his modest, patient and enduring personality guided the affairs of the Department smoothly. A Plan for forest development in Sri Lanka was prepared during his period as Conservator. He had the knack of a good leader in getting each one to contribute his best.

In 1969, under the auspices of UNESCO a plan was prepared for a long term inter-governmental and inter disciplinary programme on the rational use and conservation of the natural environment and its resources. In 1975 this programme was named "Man and the Biosphere Programme". A Committee on Forests and Forest ecology was formed and Mr Perera became its Chairman. Under this programme he made large areas of natural forests and some plantations as Man and Biosphere Reserves.

In 1971 he was appointed as Chairman State Timber Corporation in addition to his duties as Conservator of Forests. He made an immense contribution to the development of forestry in Sri Lanka during his period as Conservator. He retired from government service in March 1979.



Since his retirement he has worked in the Environment and Policy Institute of the East-West Centre Hawaii.

We thank him for his wise leadership and wish him all the best in the years to come.

**ADDRESS BY THE UNESCO REPRESENTATIVE****HUMID TROPICS RESEARCH AND UNESCO: AN INTRODUCTION AND  
OVERVIEW**

*Malcolm Hadley*

On behalf of the Director General of UNESCO, Mr Federico Mayor, it is my pleasure and honour to present fraternal greetings to this Regional Seminar on Forests of the Humid Tropics of South and South East Asia. We were very glad to receive, some eighteen months ago, preliminary proposals from the Sri Lankan Natural Resources, Energy and Science Authority (NARESA) concerning the seminar, which among other aims would commemorate the fortieth anniversary of the launching of UNESCO's Humid Tropics Research Programme. Following the initial contacts, the UNESCO Offices in New Delhi and in Jakarta, and the Natural Sciences Sector of UNESCO, have been delighted to have been able to provide support to the initiative of NARESA, the Sri Lankan National Committee for the Man and the Biosphere (MAB) Programme, and other national institutions, in planning and organizing this regional seminar. We also thank NORAD and the MacArthur Foundation for their contributions to the seminar, and wish all participants a stimulating, productive and enjoyable week.

Among the aims of the seminar are to provide an occasion to discuss recent progress in the study of the vegetation of humid tropical zones, particularly in the Asian region. A number of the invited contributions attempt to place recent progress and current understanding in a historical context. Of particular significance in providing both a stimulus and reference point for the present seminar was the convening in Kandy in late March 1956 of a symposium on the "Study of tropical vegetation", which marked the inauguration of the UNESCO programme on Humid Tropics Research. This programme was to run from 1956 until the mid 1960s, representing an important and distinctive component in UNESCO's long standing involvement in scientific work on the environment and its natural resources.

That involvement dates back to the very early days of the organization in the late 1940s, with biologist Julian Huxley as the first Director General. Among its early activities was the setting up in 1948, in concertation with the French Government, of the International Union for the Protection of Nature, later to become the International Union for the Conservation of Nature, now the World Conservation Union, IUCN. Among UNESCO's early staff members in the late 1940s, were tropical botanist E.J.H. Corner and biochemist Joseph Needham - the person who is widely recognized as being responsible for the "S" for Science in UNESCO (Goldsmith 1995). Among the early proposed projects was one to establish an Institute of Hylean Ecology - "Hylean" being the term that Humboldt used for the Amazonian region. The proposal in the late 1940s to set up an Institute of Amazonian Ecology was one that did not come to fruition, at least in the form it was being discussed at that period. It was perhaps an idea whose time had not yet come.

The early 1950s saw the launching of the Arid Zone Programme, later to be known as the Major Project on Arid Zones. Among its accomplishments was a series of regional and international symposia aimed at taking stock of existing knowledge on the ecology and natural resources of arid zones, with the results compiled in a collection of thirty four volumes - the Arid Zone Research Series - the contents of many of which remain a store of still valid information to this day. The Major Project on Arid Zones also had an important capacity building and training programme, reflected in the setting up of such institutes as the Centre for Arid Zone Research in Jodhpur.

In the light of the enthusiasm generated by the launching in 1951 of the Major Project on Arid Zones, the eighth session of the General Conference of UNESCO held in Montevideo in 1954, authorized the Director-General to promote the co-ordination of research on scientific problems relating *inter alia* to the humid tropical zone and to promote international or regional measures to expand such research. By virtue of this authorization, the Director-General convened a preparatory meeting of specialists in humid tropics research in Kandy from 22 to 24 March 1956. The preparatory meeting recommended to the Director-General, among other things, the creation of an International Advisory Committee for Humid Tropics Research. The Director-General accepted this recommendation and the Advisory Committee of nine members came into being at the end of 1956.

The purpose of this committee was to consider matters pertaining to research in the fundamental aspects of the natural sciences, of interest in the humid tropical zones; and to stimulate the carrying on of such research in areas considered at the time as important for long-term action, specifically:

- \* Tropical herbaria and key zoological collections.
- \* The termite problem.
- \* The preparation of regional floras.
- \* The problem of laterization.
- \* The scientific problems related to the delta areas of the humid tropics.
- \* The principles and methodology of integrated research in the humid tropics.
- \* The advance of the savanna into the tropical forest.
- \* The chemistry and biology of tropical soils.

Organization of symposia on well-defined aspects of humid tropics research was one of the means adopted in realizing the objectives of the Humid Tropics Research Programme. The first such symposium was held immediately prior to the preparatory meeting, on the topic "Study of Tropical Vegetation". It was jointly organized by UNESCO's Science Co-operation Offices in South Asia (New Delhi Office) and South-East Asia (Jakarta Office), in collaboration with the National Commission for UNESCO. The symposium was opened on the morning of 19 March 1956, in the ballroom of the Queen's Hotel, Kandy, by Mr H. Jinadasa, Permanent Secretary to the Ministry of Education, who in his opening speech referred to two problems which had engaged popular imagination in the country —

"the threatened extinction of the elephant and the menace of the cancerous weed, salvinia" - and recommended them for the consideration of scientists taking part in the symposium.

It is fascinating to leaf through the proceedings of the 1956 Kandy Symposium, to look over the papers in that volume and to reflect on the contributions that the participants at that Kandy symposium of forty years ago made during their professional careers to science, and to studies on tropical vegetation in particular. Thus, thirty or so papers were presented and discussed. Taking the order of the papers in the proceedings volume, authors included Puri, Dilmy, Kostermans, de Rosayro, Wyatt-Smith, Richards, Bedard, Fosberg, Chatterjee, van Steenis, Misra, Purseglove, Bharucha, MacFadden, Holmes, Mangelot, Taylor, Stewart, Janaki, Hedayetullah, Browne, Wood, Webb, Senaratne, Schmid and Anderson.

The Kandy symposium saw the presentation and discussion of several ideas and concepts which have contributed to the development of understanding of humid tropical vegetation. One example is the seminar paper by van Steenis on "Rejuvenation as a factor for judging the status of vegetation types: the biological nomad theory", including the distinction between the stationary species or dryads of the climax rain forest and the temporary species or nomads which "cannot rejuvenate in the rain forest and can maintain themselves only at its borders". A specific output of the field trip associated with the symposium was the discovery and naming of a new species of subcanopy tree in the rain forest (*Cullenia rosayroana* Kostermans., Bombacaceae), following discussions in the field between Kostermans and de Rosayro (I.A.U.N. Gunatilleke, personal communication).

Following the Kandy symposium of March 1956, the Humid Tropics Research Programme entailed a series of somewhat similar symposia and seminars (Table 1), including those organized in Tjiawi (1958), Abidjan (1959), Goroka (1960), New Delhi (1960), Kuching (1963), Dacca (1964). In addition to the proceedings volumes (see list of references at the end of this paper) outputs of the programme included a directory of zoology (and entomological) specimen collections of tropical institutions (1962) and a manual for tropical herbaria (1965) prepared under the auspices of the UNESCO Visiting Committee on Tropical Herbaria.

Looking back at the various publications generated within the programme, once again one is struck - as for the founding conference in Kandy - by the participation of scientists whose work has marked the pages of scientific understanding of the humid tropical regions. Thus, in addition to many of those who attended the Kandy symposium of March 1956, the participants of the seminar held in Tjiawi (Indonesia) in December 1958 included Ashton and Whyte; that in Goroka (Papua New Guinea) in September 1960, Corner and Smitinand; that in Kuching in July 1963, Brunig, Greig Smith, Kartawinata and Whitmore.

The Humid Tropics Research Programme came to an end in the mid-1960s. It was followed by several other UNESCO initiatives related to the environment and its natural resources,

which have continued to include work in humid tropical regions. Examples include the International Hydrological Programme, the Convention for the Protection of the World's Cultural and Natural Heritage, and the Man and the Biosphere (MAB) Programme and its World Network of Biosphere Reserves.

**Table 1: UNESCO Humid Tropics Research Programme: Examples of activities and publications**

| Year |                                                                                                                                                                                                                                                                                               |
|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1954 | UNESCO General Conference, eighth session (Montevideo). Recommendation on promoting scientific co-operation in the humid tropical zone.                                                                                                                                                       |
| 1956 | Kandy symposium on Humid Tropics Vegetation. Preparatory Meeting of Specialists.                                                                                                                                                                                                              |
| 1957 | Advisory Committee for Humid Tropics Research - First session (Manaus).                                                                                                                                                                                                                       |
| 1958 | Tjiawi symposium. Vegetation Map of Malesia (1:5 million)                                                                                                                                                                                                                                     |
| 1959 | Abidjan symposium (Tropical soils and vegetation). Advisory Committee - Second session (Abidjan). Vegetation Map of Africa (1:10 million)                                                                                                                                                     |
| 1960 | Goroka symposium (Human impact on humid tropics vegetation). New Delhi symposium (Termites).                                                                                                                                                                                                  |
| 1961 | Tropical herbaria meeting (Leiden). Advisory Committee - Third session (Honolulu). Report on key zoological collections in the tropics.                                                                                                                                                       |
| 1962 | Flora Neotropica preparatory meeting (Sao Paulo). Directory of zoological (and entomological) specimen collections of tropical institutions. Eight-week training course for systematic botanists (Ibadan). Seminar on humid tropical soils (Caracas-Maracary).                                |
| 1963 | Kuching symposium. Advisory Committee - Fourth and final session (Bandung). Fourth South East Asia Botanical Training Expedition (Vegetation on limestone hills of southern Thailand).                                                                                                        |
| 1964 | Dacca symposium (Deltas). Caracas symposium on problems of savannah/tropical forest boundary. First meeting of Flora Neotropica Commission (Sao Paulo). Symposium on African termites (Congo). Inauguration of Charles Darwin Research Station in the Galapagos, under sponsorship of UNESCO. |
| 1965 | Manual for tropical herbaria. Close of UNESCO programmes relating to the arid zone and the humid tropical zone. Setting up of Advisory Committee on Natural Resources Research, covering essentially the fields of ecology, conservation, geology and soil science.                           |

Through initiatives such as these, UNESCO has continued to be involved in the bringing together, synthesis and diffusion of technical information on humid tropical systems. Examples in the 1970s-early 1980s included a wide-ranging review of the natural resources of humid tropical Asia (UNESCO 1974), a state of knowledge report on tropical forest ecosystems prepared by UNESCO, UNEP and FAO (UNESCO 1978) and an interagency study of the agroclimatology of the humid tropics of South East Asia (Oldeman & Frere 1982). In the last decade, a diversity of more finely focused topics have been addressed often through joint activities with collaborating national, regional and international bodies. Subjects taken up have included: Rain forest regeneration and management (Hadley 1988, Gomez-Pompa *et al.* 1991); Traditional crop improvement techniques (Aumeeruddy & Pingio 1989); Reproductive ecology of tropical forest plants (Bawa *et al.* 1989, Bawa & Hadley 1990); Rehabilitation of degraded tropical forest areas (Adisoemarto 1989, Lamb *et al.* 1995); Food and nutrition in the tropical rain forest (Hladik *et al.* 1990, Hladik *et al.* 1993); Contributing to sustained resource use in the humid tropics (Hadley & Schreckenberg 1989); Hydrology of moist tropical forests and effects of conversion (Bruijnzeel 1990, Bonell *et al.* 1993, Bruijnzeel & Critchley 1995); Carbon, nutrient and water balances of tropical rain forest ecosystems subject to disturbance (Anderson & Spencer 1991); Long-term monitoring of biological diversity in tropical forest plots (Dallmeier 1992); Forests and cultures in Asia (UNESCO 1992); Integrated conservation strategies in tropical forest areas and the concept of critical mass (Muul 1993); Domestication of tropical trees for timber and non-timber products (Leakey & Newton 1994); Regional development in the Brazilian Amazon (Clusener-Godt & Sachs 1994, 1995); Ethnobotany (Martin 1994); Ecology of tropical rain forest seedlings (Swaine 1996).

Qualitatively, an important shift in focus has occurred during the last two decades in UNESCO's overall programme in the humid tropics, with priority being given to field activities undertaken by national institutions at sites contributing to such international frameworks as the World Heritage Convention and List and the World Network of Biosphere Reserves. As of early 1996, the World Heritage List includes 102 natural sites and 17 mixed natural and cultural sites, while the World Network of Biosphere Reserve comprises 324 sites in 82 countries. A number of these areas is of importance to tropical forest conservation and research, as reflected in the sampling of sites in Table 2.

Very appropriately, the field visit that has been arranged as part of the present seminar takes in a site - Sinharaja, the Forest of the Lion King - which figures on the World Heritage List as well as contributing to the World Network of Biosphere Reserves. Sinharaja is a site where a substantial effort has been and is being made to address the central biosphere reserve aims of reconciling conservation and development and underpinning those goals with research, monitoring, education and training. This has entailed building-up a programme with multiple objectives and activities - conserving genetic material, testing of approaches to more sustainable use of natural resources, combining long-term strategic studies with more finely focused problem-oriented research, vocational and professional training, contributing to education and public awareness programmes, involving local people in reserve planning and management. Such a spectrum of activities almost inevitably entails

a wide range of co-operative activities and partnership arrangements, and the involvement of a suite of local, national, regional and international bodies and programmes, at governmental and non-governmental levels as well as the private sector. Such an involvement of multiple stakeholders and interest groups characterizes approaches to environment-development issues in the complex, globalized world of the mid-late 1990s, and contrasts perhaps with the somewhat less complex geopolitical and socio-economic setting in which the 1956 Kandy symposium took place.

These multiple dimensional and multiple-actor characteristics of approaches to conservation and resource management were well reflected in a contribution based on work at Sinharaja (Gunatilleke *et al.* 1995), made to an international conference on biosphere reserves held in Seville (Spain) in March 1995. The Seville conference brought together some 400 participants from 102 countries, who took stock of what had been achieved in nearly two decades of trying to put the biosphere reserve concept into action -- what had worked and what had not worked, and why. Among the tangible outputs of the conference was the Seville Strategy on Biosphere Reserves, which was subsequently adopted by UNESCO's General Conference at its twenty-eighth session in late 1995.

In brief, the Seville Strategy for Biosphere Reserves (UNESCO 1995, 1996) includes ten key directions for the future development of biosphere reserves in the context of the twenty-first century. One example is that of strengthening the contribution that biosphere reserves can make to the implementation of international agreements promoting conservation and sustainable development, such as the Convention on Biological Diversity. The Strategy also includes a number of recommendations at different levels (international, national, individual biosphere reserve), grouped around four main goals: first, use biosphere reserves to conserve natural and cultural diversity development; second, utilize biosphere reserves as models of land management and of approaches to sustainable development; third, use biosphere reserves for research, monitoring, education and training; fourth, implement the biosphere reserve concept.

UNESCO considers that the vigorous and inventive implementation of the Seville Strategy for Biosphere Reserves could make a distinctive substantive contribution to achieving several of the aims charted by the UN Conference of Environment and Development. Looking back forty years to the Kandy Symposium of March 1956, implementation of the Seville Strategy could also contribute to advancing one of the subjects for long-term action identified within the Humid Tropics Research Programme -- that of advancing the principles and methodology of integrated research in the humid tropics -- and (what was perhaps missing in the Humid Tropics Programme) linking that research to the practical needs of management and development.

**Table 2: Examples of Biosphere Reserves and World Heritage sites of importance in tropical forest conservation and research**

| Country                  | Site                            | Area extent (ha) | Date of approval                      |
|--------------------------|---------------------------------|------------------|---------------------------------------|
| Australia                | Wet Tropics <sup>2</sup>        | 920000           | 1988                                  |
| Bolivia                  | Beni <sup>1</sup>               | 135000           | 1986                                  |
| Brazil                   | Atlantic Forest <sup>1</sup>    | 29714000         | 1993                                  |
| Cameroon                 | Dja <sup>1,2</sup>              | 500000           |                                       |
| Central African Republic | Basse-Lobaye <sup>1</sup>       | 18200            | 1981 <sup>1</sup> , 1987 <sup>2</sup> |
| China                    | Dinghushan <sup>1</sup>         | 1200             | 1977                                  |
|                          | Xishuangbanna <sup>1</sup>      | 241700           | 1979                                  |
| Congo                    | Dimonika <sup>1</sup>           | 62000            | 1993                                  |
| Costa Rica               | Amistad <sup>1</sup>            | 585000           | 1988                                  |
| Cordillera               | Cordillera                      | 144000           | 1988                                  |
|                          | Volcanica Central <sup>1</sup>  |                  | 1988                                  |
| Cote d'Ivoire            | Tai <sup>1,2</sup>              | 330000           |                                       |
| Cuba                     | Sierra del Rosario <sup>1</sup> | 10000            |                                       |
| Ecuador                  | Yasuni <sup>1</sup>             | 680000           | 1977 <sup>1</sup> , 1982 <sup>2</sup> |
| Gabon                    | Ipasa-Makokou <sup>1</sup>      | 15000            | 1984                                  |
| Guatemala                | Maya <sup>1</sup>               | 1400000          | 1989                                  |
| Honduras                 | Rio Platano <sup>1,2</sup>      | 500000           | 1983                                  |
| India                    | Kaziranga <sup>2</sup>          | 43000            | 1990                                  |
|                          | Manas <sup>2</sup>              | 39100            |                                       |
| Indonesia                | Cibodas <sup>1</sup>            | 14000            | 1980 <sup>1</sup> , 1982 <sup>2</sup> |
|                          | Gunung Leuser <sup>1</sup>      | 792700           | 1985                                  |
| Mexico                   | Calakmul <sup>1</sup>           | 723000           | 1985                                  |
|                          | El Triunfo <sup>1</sup>         | 120000           | 1977                                  |
|                          | Montes Azules <sup>1</sup>      | 331000           | 1981                                  |
|                          | Sian Ka'an <sup>1,2</sup>       | 528000           | 1993                                  |
| Nigeria                  | Omo <sup>1</sup>                | 460              | 1993                                  |
| Panama                   | Fronterizo Darien <sup>1</sup>  | 597000           | 1979                                  |
| Peru                     | Manu <sup>1,2</sup>             | 1881000          | 1986,                                 |
| Philippines              | Puerto Galera <sup>1</sup>      | 23500            | 1987 <sup>2</sup>                     |
|                          | Palawan <sup>1</sup>            | 1150800          | 1977                                  |
| Rwanda                   | Volcans <sup>1</sup>            | 15000            | 1983                                  |
| Sri Lanka                | Sinharaja <sup>1,2</sup>        | 8,880            |                                       |
| Thailand                 | Sakaerat <sup>1</sup>           | 7200             | 1977 <sup>1</sup> , 1987 <sup>2</sup> |
|                          | Thungyai-Hua Kha                | 320000           | 1977                                  |
|                          | Khaeng <sup>2</sup>             |                  | 1990                                  |
| Uganda                   | Bwindi <sup>2</sup>             | 32100            | 1983                                  |
| U.S.A.                   | Luquillo <sup>1</sup>           | 11300            |                                       |
| Venezuela                | Alto Orinoco-                   | 8700000          | 1978 <sup>1</sup> , 1988 <sup>2</sup> |
| Zaire                    | Casiquiare <sup>1</sup>         | 250000           | 1976                                  |
|                          | Yangambi <sup>1</sup>           | 3656000          | 1991                                  |
|                          | Salonga <sup>2</sup>            |                  |                                       |
|                          |                                 |                  | 1994                                  |
|                          |                                 |                  | 1976                                  |
|                          |                                 |                  | 1993                                  |
|                          |                                 |                  | 1976                                  |
|                          |                                 |                  | 1984                                  |

1. Biosphere Reserves

2. World Heritage sites



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## TECHNICAL SESSIONS

### FOREST BIODIVERSITY IN HUMID TROPICS

**FOREST BIODIVERSITY IN THE HUMID TROPICS:  
WHO CARES?  
ADAPTING TO CHANGING CONDITIONS**

*Jeffrey A. McNeely*

**ABSTRACT**

*Forests in the tropics are often seen primarily, or even exclusively, in terms of their timber. But scientists have a very different perspective, recognizing numerous values of biodiversity in the humid tropics. This paper describes a number of the interest groups involved and the kinds of values that might motivate their behaviour towards conservation. It indicates how science can help in improving both policy and management. It often seems that a basic problem is the lack of communication between scientists and policy makers. A number of suggestions is provided on how this communication can be improved.*

**INTRODUCTION**

In the hope of helping our society achieve a balance between nature's productivity and its limits - in other words, sustainable development - the conservation movement has come up with a new approach, characterized by the word, "biodiversity". Simply stated, biodiversity is the measure of the world's variety of genes, species, and ecosystems (WRI, IUCN & UNEP 1992). "Biodiversity" entered the public vocabulary about 10 years ago, striking a very responsive chord among scientists, decision-makers, and even the informed public. It has stimulated a comprehensive approach to conservation, bringing information, knowledge, awareness, and ethics into a complex mixture of forestry, protected areas, agriculture, economics, intellectual property rights, land tenure, trade, and so forth. It has enabled us to break out of our old approaches, such as excluding people from their traditional lands in the name of "conservation" or focusing on one forest benefit to the exclusion of others. It led to the Convention on Biological Diversity which was signed by 157 governments at the Earth Summit in Rio in June 1992, entered into force at the end of 1993, and has now been ratified by over 140 countries. A *Global Biodiversity Strategy* was published by the World Resources Institute, IUCN and UNEP in 1992, numerous biodiversity studies and strategies have been prepared, and literally dozens of meetings have been held in all corners of the earth to develop further the concept of biodiversity and build global consensus for the actions required. What does all this mean for forests, and the biodiversity they contain?

**ECONOMIC ROOTS OF FOREST DEPLETION**

The Earth Summit had an environmental agenda, but it was basically an economic summit, seeking ways to finance sustainable development. For it is now clear that

development cannot long continue if it is reducing diversity and promoting non-sustainable use of resources. Economists consider the production of a “good” - such as timber or pulp - to be economic only when the total benefits exceed the total costs. However, the production of the “good” may well be profitable in a commercial sense even if it is not economic. For example, the way many tropical forests are being harvested is not economic if the costs - including the long-term costs to local communities, disruption of watersheds, pollution of rivers, loss of genetic resources, and so forth - exceed the benefits, but it is certainly profitable for some individuals or corporations who earn considerable commercial benefits through the process. However, those individuals or corporations do not pay the full costs of their exploitation, and indeed those who are able to externalize most environmental costs may be able to earn the highest profits.

Numerous economic factors are driving the loss of forests, or at least a great reduction of their biomass and biodiversity. Three are particularly worth mentioning here.

- *Subsidized energy:* Vast amounts of energy are being provided to modern forestry in the form of oil, pesticides, transportation, and so forth. Most of this is a one-time-only windfall, depending on the productivity of species which died long ago and are now fossil carbon. These energy subsidies enable the true costs of exploiting the forests to be hidden, because the prices paid for timber (for example) do not include the costs of replacing the oil consumed in harvesting, processing, and marketing.
- *Focus on single products:* Where forests were once used to provide a whole range of benefits, including wildlife, medicinal plants, watershed protection, construction materials, firewood, and so forth, today many forests are being used to provide a single product: timber and its derivatives. This single-use focus tends to promote even-aged stands of secondary growth or large plantations of genetically-similar trees, often of exotic species in some parts of the world, because they are more commercially attractive (though not necessarily more economic).
- *Response to global economic forces:* Much of the loss of native forests in various parts of the world has been due to the demand for commodities for export, responding to a global, rather than a local, system of supply and demand. Because they are not responding to local conditions of supply and demand, traders do not experience the limits which agrarian forest managers learned to address through management systems developed over long periods, and that tended to limit over-exploitation.

It can be seen that most of the economic forces driving the loss of forests are global in nature. The scale is no longer local, where local people benefit or lose depending on the appropriateness of their practices; now the scale is global, and the “feedback loops” are far wider than they were previously. Some contend that the increased consumption facilitated by this higher productivity is also encouraging land-use practices which are



unsustainable, especially deforestation and use of land for agriculture that would be more suitable for forests or other uses (Poffenberger, 1990).

## ECONOMIC ROOTS OF FOREST CONSERVATION

Economics is also driving the conservation of forests. While the timber industry tends to dominate the discussion in most of the Asian tropics, many other benefits also come from forests. Examples include:

- *Water* : Water is becoming an increasing concern for all societies. The importance of forests in the water cycle is reasonably well known, and some people even consider forests as “water factories”. Both agriculture and industry depend on the high quality water provided by forested watersheds.
- *Climate*: Forests and global climate change are closely related, particularly the role of forests in carbon sequestration. While the dimensions of this relationship remain somewhat controversial, it is clear that global carbon dioxide is increasing at a rapid rate, and that forests are being looked to as at least a short-term carbon sink. Forests sequester around 90 percent of the world’s terrestrial carbon and store between 20 and 100 times more carbon per hectare than agricultural lands. Old-growth forests store up to 350 tons per hectare of carbon, far more than most less mature forest types. Although young plantation forests sequester carbon at a higher rate than mature forests, mature forests conserve much more carbon per hectare, preventing its release to the atmosphere. It may well be that to achieve objectives of carbon sequestration, conserving at least some areas of old-growth forests may be more efficient and have fewer long-term negative ecological, social, and political impacts than plantations established for carbon sequestration.
- *Amenity* : This is a fancy name for the various pleasures that people gain from visiting the forest, as international tourists or as local vacationers. Tourism is now the world’s leading industry, involving nearly US\$ 350 billion per year, and much of the tourism is based on nature; one has only to visit any tourism office to observe that this is the case. According to one estimate, the total net economic value of outdoor recreation activities in the US is US\$ 122 billion annually.
- *Timber* : The global timber trade amounts to some US\$ 80 billion per year, most of which comes from the temperate countries, not the tropical countries (contrary to the impression that might be gained from the publicity given to tropical deforestation). On the other hand, in the tropics, about 80 percent of the estimated 1 billion cubic metres of wood removed annually is used for fuel, providing a significant proportion of energy in rural areas.
- *Medicines* : Forests are the source of many medicines of very considerable economic value worth billions of dollars per year. Farnsworth & Soejarto (1991) estimate that



some 28% of all plants have been used medicinally, that 121 clinically useful prescription drugs are derived from higher plants, and that half of the 40 species of flowering plants that yield prescription drugs valued at over US\$ 8 billion in 1980 originally came from tropical forests. Principe (1991) estimates the pharmaceutical economic value of plant-based drugs in all OECD countries at between US\$ 200 billion and US\$ 1.8 trillion annually.

- *Non-wood forest products* : Other than medicinal plants, these include game, fish, nuts, mushrooms, resins, and so forth. Many of these products are available especially from old-growth forests, while others come from earlier serial stages. In total, these have considerable economic importance; for example, Peters *et al.* (1989) found that the fruits, nuts and latex produced in part of the Amazonian rainforest near Iquitos in Peru was worth more than the timber produced on the same hectare.
- *Aesthetic values* : I have separated these from amenity values to make the point that many of the aesthetic values can be experienced indirectly, for example through television, cinema, books, and so forth. Many people therefore earn benefits from the forest without ever having visited one; or have their aesthetic feelings about forests reinforced from a distance.
- *Research* : Many scientists are involved in research into one or more aspects of forests, an indication that these habitats are useful for elucidating a whole range of issues of great importance to society; many of UNESCO's Biosphere Reserves, such as Sinharaja in Sri Lanka, make good use of forests for research.
- *Education* : Many people also value the forests as an educational resource, teaching students everything from ecology to philosophy to anthropology, forest management and aesthetics.

This is not meant to be a comprehensive list of forest benefits, and the mix of benefits received by any country or locality will depend on its own perspectives, needs, and history. But this perhaps is sufficient to indicate the range of benefits that forests provide, and illustrates the conflicts that are generating the growing public concern over forest management (Table 1).

**Table 1: Compatibility of forest uses**

|                       | <i>Clear-cuts</i> | <i>Selective-cuts</i> | <i>Non-Timber</i> | <i>Water</i> | <i>Biodiv.</i> | <i>Tourism</i> | <i>Carbon Storage</i> | <i>Fisheries</i> |
|-----------------------|-------------------|-----------------------|-------------------|--------------|----------------|----------------|-----------------------|------------------|
| <b>Clear-cuts</b>     | -                 | 5                     | 3                 | 5            | 4              | 5              | 3                     | 5                |
| <b>Selective cuts</b> | 5                 | -                     | 2                 | 2            | 2              | 2              | 3                     | 2                |
| <b>Non-Timber</b>     | 3                 | 2                     | -                 | 1            | 1              | 1              | 1                     | 1                |
| <b>Water</b>          | 5                 | 2                     | 1                 | -            | 1              | 1              | 1                     | 1                |
| <b>Bio-diversity</b>  | 4                 | 2                     | 1                 | 1            | -              | 1              | 1                     | 1                |
| <b>Tourism</b>        | 5                 | 2                     | 1                 | 1            | 1              | -              | 2                     | 1                |
| <b>Carbon</b>         | 3                 | 3                     | 1                 | 1            | 1              | 2              | -                     | 1                |
| <b>Fisheries</b>      | 5                 | 2                     | 1                 | 1            | 1              | 1              | 1                     | -                |

1: Highly compatible; 5: Not compatible; - Not a consideration

## WHO WANTS WHAT FROM FORESTS? THE GOVERNMENT SECTORS

As one result of this growing public interest, many sectors of government are taking an interest in forests. However, each of the “constituencies” within the government sector has a somewhat different perspective about what goods or services - broadly considered, “benefits” of forests - are of greatest interest to them. For example, the following government sectors might have the following interests (see Table 2):

- *Ministry of Forestry* : In most countries, this ministry has the “command and control” function over the nation’s forests, often establishing guidelines and oversight for the private sector involved in logging. Most forest ministries give their greatest attention to timber, with much less attention to amenity and aesthetic values, or non-wood forest products; they may support research to support their major objectives, and occasionally make an input to education.
- *Ministry of Finance* : This ministry is interested in income and expenditure, and therefore is also especially interested in timber. But it may also look to the amenity values of forests because they provide economic gains through tourism; and products such as medicinal plants, non-wood forest products and water all may yield returns for the exchequer.
- *Ministry of Trade* : Timber is the most important tradeable commodity from forests, but medicinal plants and non-wood forest products may also be important.

The Ministry of Trade may also be concerned about climate, as this can have an influence on terms of trade.

- *Ministry of Research* : This ministry (or research departments within other ministries) may be interested in the full range of forest benefits, though its interests will tend to focus on the economically most important aspects of the forests.
- *Ministry of the Environment* : This ministry tends to be more concerned with ecosystem function, including production of water, climate effects, absorption of pollutants, and amenity values. Its concerns are often supported especially by the aesthetic benefits of forests. Research and education are of great importance, while the productive or extractive uses of forests are primarily a matter of control or monitoring.
- *Ministry of Agriculture* : This ministry is often interested above all in high quality water from forests, as an essential input into agricultural production; where it is also responsible for fisheries, it often values forests above all for the quality of water and the maintenance of appropriate conditions for optimal fisheries production. This often brings them into conflict with the timber production objective. Agriculture depends to an extent on forest products as part of the overall agro-ecosystem, as well as research and education.
- *Ministry of Foreign Affairs* : Such ministries have been deeply involved in the climate related discussions, including; carbon sequestration and so forth; but timber is also a matter for international negotiations, for example the idea for a forest convention being discussed in the International Tropical Timber Organization. These ministries have also been involved in amenity issues, particularly as relating to biodiversity. Where water flows internationally, the relationship between water and forests may also be important to them.
- *Ministry of Industry*: The objective of such ministries in most governments is the promotion of industry, so the main concern is often the uses such as timber, medicine, and non-wood forest products. The amenity value may be important as it relates to the tourism industry (see below) and many industries require high quality water as a major input.
- *Ministry of Tourism* : This ministry tends to promote tourist uses of forests, and since tourism is now the world's leading industry, this value is becoming increasingly important. It is supported by the aesthetic appreciation of forests. Much of tourism is water-oriented, including water sports.
- *Ministry of Education* : This ministry is involved in educating the population to be effective citizens, and while relatively few countries have effectively built forestry

concerns into their national curriculum, this is probably an appropriate objective to aim for.

This is only a partial list, and it could be extended much further, with considerably more detail. For example, some ministries of defence may use forests as defence against invasion from neighbours, while others (as in Brazil) may propose clearing wide areas of forests along international boundaries as a sort of *cordon sanitaire*. Ministries of transport might see forests as good potential sites for highways because land acquisition costs may be low. Local authorities have a particular interest in forests as providers of domestic water, and so forth.

Table 2 : Who wants what from forests? 1. Government sector

| Constituency         | Forest Benefit |         |         |        |        |          |           |          |           |
|----------------------|----------------|---------|---------|--------|--------|----------|-----------|----------|-----------|
|                      | Water          | Climate | Amenity | Timber | Medic. | Non-wood | Aesthetic | Research | Education |
| Ministry of Forestry | 4              | -       | 4       | 1      | -      | 4        | 4         | 3        | 4         |
| Finance              | 5              | -       | 2       | 1      | 3      | 3        | -         | -        | -         |
| Trade                | -              | 5       | -       | 1      | 3      | 3        | -         | -        | -         |
| Research             | 4              | 3       | 4       | 4      | 3      | 3        | 4         | 1        | 3         |
| Environment          | 1              | 1       | 2       | 5      | 4      | 4        | 1         | 2        | 2         |
| Agriculture          | 1              | 1       | 4       | 5      | 4      | 3        | -         | 3        | 4         |
| Foreign Affairs      | 3              | 1       | 4       | 2      | -      | -        | -         | -        | -         |
| Industry             | 2              | 5       | 2       | 1      | 3      | 2        | 5         | 4        | 5         |
| Tourism              | 2              | 3       | 1       | -      | -      | 2        | 2         | 5        | 3         |
| Education            | -              | 5       | 4       | 5      | 5      | 5        | 3         | 2        | 1         |

1: Maximum importance; 5: Minimum importance; - Not a consideration

But the general point is clear: many different ministries within a government have significant and legitimate interests in forests, but they perceive the mix of forest benefits in rather different and sometimes contradictory ways.

## WHO WANTS WHAT FROM FORESTS? THE PRIVATE SECTORS

The private sectors also vary in their interests. Following a similar approach as taken above, the following is an indicative list (summarized in Table 3).

- *Indigenous peoples* : These are often forest-dwellers who have long historical claims on forest lands. While not necessarily paragons of ecological virtue, indigenous peoples have special claims on the forest because their livelihood historically depends on earning sustainable benefits from them. They may consider non-timber forest products, including game, medicinal plants, various types of food, and so forth to be

of the greatest importance, while timber is a relatively minor product. They often have a special identity with the forest (aesthetic and amenity values), and depend on the water for domestic use, fishing, and irrigation.

- *Nearby communities* : While not living in the forest, the nearby communities have an intimate economic link with it. Many people choose to live near the forest because it offers employment, as in the timber industry. Others may value amenity or non-timber products such as game.
- *Urban communities* : People who live in cities have a very different perspective, often giving particularly high value to aesthetics - the "forest chic" approach. They may especially value the forest for its amenity values during their vacations; and their quality of life depends greatly on forest products, though they are not always aware of this dependence.
- *Pharmaceutical firms* : They often benefit from medicines from the forests, including such well-known examples as quinine. They may also value some of the research done in forests as it relates to their interests.
- *Timber firms* : They depend above all on the supply of timber from forests (whether owned by the State or by the firm) but have tended to view water especially as transport or a way of disposing of effluents. They have tended to give relatively little value to other benefits, though this may be changing in response to public interest; some firms are giving far more attention to tourism and other amenity values.
- *Academics* : Many academics look on the forest as a good place to do research on a very wide range of topics, as is evidenced by the numerous published articles in scientific literature (often related to UNESCO's MAB)
- *Conservation NGOs* : Conservation NGOs tend to give very high value to amenity and aesthetic concerns, as well as climate and water. They also tend to be very critical of the timber industry, and especially of some management practices currently being practised (such as clear-felling).
- *Tourists* : Tourists relish the amenity and aesthetic values of forests, as well as water and climate; when they are playing their tourist role, they tend to be relatively little concerned with timber and medicinal plants, but may value non-wood products especially as they relate to hunting and fishing.
- *Posterity* : It is impossible to predict what future generations will want from forests, but many will argue that it is reasonable to maintain open options so that the future generations can decide for themselves how to utilize the resources available to them. Education and research may be especially important to future generations, making knowledge from the forest available to them. The future generations may be

relatively uninterested in our generation's consumer needs for timber and pulp, though, if the income from these uses is reinvested in ways that benefit future generations, then they may well earn considerable benefits from our current forest exploitation.

**Table 3 : Who wants what from forests? 2. Private sector**

| Constituency         | Forest Benefit |         |         |        |        |          |            |          |           |
|----------------------|----------------|---------|---------|--------|--------|----------|------------|----------|-----------|
|                      | Water          | Climate | Amenity | Timber | Medic. | Non wood | Aesth-etic | Research | Education |
| Indigenous Peoples   | 1              | 3       | 2       | 5      | 1      | 1        | 3          | 5        | 2         |
| Nearby Communities   | 1              | 4       | 2       | 2      | 4      | 1        | 2          | 5        | 3         |
| Urban Communities    | 3              | 2       | 2       | 3      | 3      | 4        | 2          | 4        | 4         |
| Pharmaceutical firms | -              | -       | -       | -      | 1      | -        | -          | 2        | -         |
| Timber firms         | 5              | -       | 5       | 1      | 5      | 4        | 4          | 3        | 4         |
| Academics            | 3              | 3       | 3       | 4      | 4      | 4        | 4          | 1        | 2         |
| Conservation NGOs    | 1              | 1       | 1       | 5      | 3      | 3        | 1          | 3        | 3         |
| Tourists             | 2              | 2       | 1       | 5      | 5      | 3        | 1          | 5        | 3         |
| Posterity            | 3              | 1       | 1       | 4      | 2      | 2        | 1          | 2        | 2         |

1: Maximum importance; 5: Minimum importance; - Not a consideration

As with the government sector, this brief analysis of private sector interests in the forests is only partial and indicative and many people play multiple roles in relation to forests. But I think that the message is clear: many constituencies have a great interest in how the forest is to be managed. Tables 2 and 3 give a rough suggestion as to which of the many benefits provided by forests are of particular concern to which constituency or interest group, suggesting why multiple use of forests is such a topical issue.

#### **FOUR APPROACHES TO FOREST MANAGEMENT FOR THE 21<sup>ST</sup> CENTURY**

The Statement of Forest Principles approved by governments at the United Nations Conference on Environment and Development in Rio de Janeiro in June 1992 recognized the new political appreciation of multiple use, stating that "Forest lands should be sustainably managed to meet social, economic, ecological, cultural, and spiritual human needs of present and future generations." Ecological science supports this change away from the dominance of clear-felling for chips or timber and towards a more sensitive and diverse approach to forest management. As Holling (1986) has pointed out, forest



ecosystems are dynamic, with multiple futures that are uncertain and unpredictable, so forest management must itself be flexible, adaptive, and experimental at scales compatible with the scales of critical ecosystem functions such as nutrient flows, hydrological flows, and evolution. Where the forest industry once exploited a seemingly endless timber supply, political demands for sustainability may eventually force it to seek greater benefits out of a smaller quantity of higher quality wood, or out of lower quality second growth and plantations. Foresters therefore must seek combinations of forest uses which are compatible (as indicated in Table 1). They may find, for example, that conserving biodiversity and storing carbon are highly compatible forest services, and that such uses can also allow the production of non-timber forest products, the conservation of soil and water, and amenity values. These uses are usually incompatible with clear-felling, but may be more compatible with well-managed selective logging. The various levels of compatibility suggested in Table 1 are open to debate, and they will vary with the locality and the specific management method being applied; but the global trends are clearly away from single-product forestry (at least in principle), and back to diversity and more benefits for people living in and around the forests.

Given the wide range of interests concerned with the goods and services produced by forests, a mixture of management approaches will be required. In general terms, these might include four main categories: protected areas carefully selected on the basis of clearly defined criteria; multiple-use forests managed by local people; natural forests managed primarily for timber production, but with other benefits accommodated to the extent possible; and forest plantations intensively managed for the wood products needed by society. Each of these types of forests may be managed by different institutions, or any one type might itself be managed by a range of institutions; each delivering a different range of benefits (Table 4).

This section of the paper will describe the characteristics of each type of forest landscape, provide a few examples, and suggest the kinds of skills needed in each instance.

## **1. Preservation and Protected Areas**

Since the first national park was created at Yellowstone in the USA in 1872, over 20,000 protected areas have been established worldwide, now amounting to over 5 percent of the land surface of our planet. Some regions of the world have well over 10 percent of their land area under protected status; while the exact extent of land dedicated to conservation objectives will vary from country to country and biome to biome, a figure of 10 to 12 percent is often considered to be a useful guideline. However, many protected areas are suffering from a combination of threats including pollution, over-exploitation, encroachment, poaching, and many others. In a period of growing demands on resources and shrinking government budgets, new approaches are required to ensure that protected areas can continue to make their contributions to society. Meeting in Caracas, Venezuela, from 10 to 21 February 1992, the IV World Congress on National Parks and Protected Areas recommended that first and foremost, protected areas must be designed and

managed in order to provide tangible and intangible benefits to society. This will involve integrating protected areas into larger planning frameworks, expanding support for protected areas, strengthening the capacity to manage protected areas, and expanding international cooperation in the finance, development and management of protected areas (McNeely, 1992).

**Table 4 : Indicative benefits provided by different approaches to forest management**

| Forest Management Approach                             | Forest Benefit |         |         |        |        |          |              |          |              |
|--------------------------------------------------------|----------------|---------|---------|--------|--------|----------|--------------|----------|--------------|
|                                                        | Water          | Climate | Amenity | Timber | Medic. | Non-wood | Aes - thetic | Research | Educa - tion |
| Preservation                                           | 1              | 2       | 1       | 5      | 3      | 2        | 1            | 2        | 1            |
| Multiple-use areas managed by local people             | 1              | 3       | 2       | 3      | 2      | 1        | 2            | 3        | 1            |
| Natural forest extensively managed for sustainable use | 3              | 2       | 3       | 1      | 2      | 2        | 3            | 3        | 3            |
| Forest plantations                                     | 4              | 2       | 5       | 1      | 3      | 3        | 5            | 3        | 3            |

1: Maximum importance; 5: Minimum importance

Protected area managers have a special responsibility for conserving the Earth's vitality and diversity. The mission of protected area managers is to defend the integrity of the protected areas for which they are responsible so that all values are sustained in perpetuity, and that human use of the protected areas does not compromise that integrity. In carrying out this mission, protected area managers should ensure that the management of a protected area is of the highest standards appropriate to its management objective, build good relationships with the local community, and enhance the level of protection for the area.

## **2. Multiple-Use Areas Managed by Local People**

In many parts of tropical Asia, people live in and around the forest and have a particular concern for ensuring that they receive its benefits in a sustainable manner. Ecologically and economically sustainable forest management practices carried out by local people can provide them with goods and services while preserving forest-use options for future generations as well. This is an age-old relationship between people and forests, and is as old as our species. In its more modern form, this approach is often called "social forestry", or "community forestry", to specify forestry programmes which are implemented with the participation of the people who will be the ultimate beneficiaries of



the programmes. This requires foresters to change, sometimes rather radically, their preferred role as a technocratic elite responsible for solving society's forest management problems and therefore having the major say in setting the management priorities of society. When seeking to support forests managed by local people, the forester begins to play a role as the servant of the community, a catalytic professional who works to support the community as it seeks to solve its own forest management problems and to set its own forest management priorities (Poffenberger, 1990). Under various names, the "social forestry movement" is now gaining support from foresters in all parts of the world; the desire of local people to have the dominant voice in determining their own priorities have not changed, only become more effective, but foresters working in this field have tended to change their concerns from the quantity of production (and monetary gains) to issues of the general quality of human life and the need for providing sustainable benefits to local people.

While the detailed practice of social forestry is by definition designed for a specific site, and foresters will need to "tune" their advice to the specific requirements of the people living in and around that forest, a number of general principles are relevant:

- The merging in the same community-based institutions of responsibilities for natural resource management and people's welfare, and the internalization of regulations and incentives by which these responsibilities have been fulfilled, requires foresters who understand the needs of rural communities and how they have developed their own forest management practices.
- The long-term success of rural communities depends on fostering political autonomy, preserving social cohesion, mitigating the dramatic effects of development (including out-migration) and promoting both local jobs and a sound use of resources. This requires foresters who understand the politics of rural communities, principles of social organization, impacts of development, and issues of sustainability.
- Cultural pride and environmental conservation will often require the local foresters to have a detailed understanding of the culture of the people among whom they are working. They therefore need to fully understand the cultural significance of forests to those people, and especially the role of the full range of goods and services that are provided to the local people. When the forester is from a different culture from the people managing the land, the forester would also need good communications and inter-cultural skills.
- The wide variety and details of the rules of membership, transference of rights, tenure of land and resources, and benefits provided by the community call for foresters who have been trained in adaptive management that can modify approaches to changing political, economic, and ecological conditions. It means that in addition to providing local people with advice and inputs needed to grow seedlings, to plant, manage and protect their own resources, and to extract the maximum sustainable benefit from

those resources, the forester interested in working at the community level will also need to understand economics, tenure systems, and conflict resolution.

To this idyllic picture, a dose of reality must be added: the demands of more powerful centralized governments can have profound impacts on such community-based systems, often in the name of "economic development". Even so, as budget cuts constrain central governments, communal institutions may become increasingly important in areas where forestry is the optimum use of the land, and where these forests need to provide multiple environmental and socio-cultural benefits (Dove, 1993).

### 3. Natural Forest Extensively Managed for Sustainable Production of Commodities

"Natural forest management" is gaining increasing attention, with a focus on sustainable timber production but with other benefits accommodated to the extent possible. Such forests will often be under private ownership, or under concession on government-owned lands, with government providing oversight and infrastructural support.

Managing natural forests for sustainable production is more than the venerable idea of "maximum sustainable yield". In many parts of the world, the focus on sustained yield has simplified the forest structure, replacing natural mixed forest with single-species and even-aged monocultures. Commercial tree species have been bred for high productivity and appropriate form for harvesting and conversion, which has resulted in narrowing other genetic diversity of the forest. Intensifying forest management has involved eliminating competing species, draining wetlands, suppressing natural fires, and greatly accelerating rotation cycles. All of these have led to an overall increase in productivity, at least in the short run, but at the cost of a decline of forest quality, including threats to various species of forest-dwelling fauna and increasing vulnerability to various kinds of pests. It is clear, therefore, that "sustained yield forestry" is not synonymous with "sustainable forestry", as the latter needs to give greater attention to sustaining various ecological processes and producing a range of other goods and services.

For example, figs are of exceptional importance to many frugivorous bird species in Malaysian forests. During selective logging operations epiphytic and strangling *Ficus* are particularly prone to loss because of their tendency to grow on commercial timber species of harvestable size. The conservation of important *Ficus* species within logging concession areas or other areas of degraded forest is recommended as a measure to assist the survival of vulnerable fig-eating bird species. According to Lambert (1991): "At Kuala Lumpur 73.5% of bird-dispersed *Ficus* were growing on trees with girths larger than 50 cm dbh while between 60.5% and 68.6% of bird-dispersed *Ficus* were growing on commercial tree species". .. "Bird-dispersed *Ficus* populations, and in particular with large figs, are likely to be severely depleted following logging. Support for this is provided by three other studies in the region. Johns (1983) estimated that the density of *Ficus* was reduced from two trees/ha to only 0.5 during a selective logging operation in

the Malaysian peninsula. An 8-year-old logged forest plot (25/ha) in Sabah, east Malaysia, contained 1.7 strangling figs/ha, compared with 2.5/ha in a similar primary forest plot nearby. Species that are fig eating specialists are likely to face severe food shortages in logged-over forest. Johns (1986, 1989) documented the population decline of some species of large fruit eating birds following selective logging in the Malaysian peninsula. Lambert (1991) concludes that small areas where mature *Ficus* and other important fruit trees have been previously identified should be allocated for preservation within logging concession areas.

Therefore, managing natural forests may require the establishment of ecological reserves or small protected areas within commercial forests, for example banning logging within 50 or 100 metres of a river, thereby enabling commercial forests to continue to provide wildlife habitat, wilderness travel, aesthetics, erosion control, and so forth. The exact mix of goods and services to be provided from any particular forested region should be based on dialogue among industry, government, academia, hunters, local municipalities, and the environmental community, thereby bringing a measure of democracy to the forests.

#### 4. Forest Plantations

As society's demands increase, forest plantations will need to be more intensively managed for the wood products needed by people. The theoretical maximum timber yield for trees from the perspective of their biochemical efficiency in converting sunlight into wood is still far from being reached. For example, Weyerhaeuser Company practises some of the most intensive plantation forestry in the world, but is able to achieve only 40-50% of the theoretical yield (natural stands in these areas grow at about 10% to about 25% of the theoretical yield) (Farnum *et al.*, 1983). Modern technology is providing additional tools which need to be mastered by forest managers whose major interest is increasing production of timber, pulp, and paper. This is where modern technological advances, including genetic engineering, whole-tree harvesting, and application of various chemical inputs, will likely be the most effective and where innovation can lead to significant increases in growth rate and yield. In many countries, it may well be that this land use will come to dominate the productive forestry sector.

It is clear that the technology for accelerating production of timber will need to continue to adapt to changing conditions, and this will require training foresters who are able to apply the latest technologies to growing, harvesting, and processing forests with significant inputs. However, even these "high-tech-foresters" will need to be sensitive to the larger needs of society, and present their case to the public in an effective way.

## CONCLUSIONS

It is apparent that the values which different sectors of the community attach to these different goods and services provided by forests have changed more rapidly and profoundly in the past few decades than ever before. Few of us can reasonably expect these changes to slow down, and in fact many expect them to continue accelerating. It is therefore apparent that the challenges scientists, conservationists, and foresters face today are likely to be very different in the future, and that the values society gives to the various goods and services provided by the forest will similarly change profoundly.

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# UNDERSTANDING LONG TERM VEGETATION DYNAMICS FOR MANAGEMENT OF BIODIVERSITY: A SRI LANKAN PERSPECTIVE

C.V.S. Gunatilleke

## INTRODUCTION

On the threshold of moving into the 21st century, Sri Lanka has gathered much information on her natural biological wealth and is at the cross roads of identifying a protected area network based on scientific criteria (Anon. 1995, Scott 1989). Among floristic information documented are those of Trimmen (1893-1900), Dassanayake and Fosberg (1980-1995) and Jayaweera (1980-1982). More recently island wide surveys on natural forests are being carried out by the National Conservation Review through the auspices of the International Union for the Conservation of Nature, Department of Wildlife Conservation for the wildlife reserves under their jurisdiction and the Wetland Conservation Project for the wetland sites in the country. Information on biological diversity and associated cultural values are being gathered through these projects for management planning and implementation.

Most of the forest reserves in the country are degraded due to anthropogenic influences in the past. Most reserves that have already been or will be identified as worthy of conservation, will be subject to participatory management in the near future. A pre-requisite to management is the understanding of long term dynamics of the vegetation both within the protected area and its buffer zones. Only if dynamic information is available can reserves be subject to adaptive management. This paper highlights specific examples to stress the need to understand long term dynamics of vegetation to maintain the island's rich biodiversity.

### Example 1: Non-Timber Species in Wet Lowland Rain Forests

The lowland rain forests in Sri Lanka are home to a large number of non-timber forest species (Gunatilleke *et al.* 1993, 1994; Gunatilleke & Gunatilleke 1993, Ratnayake *et al.* 1991, Senerath 1990, Attygalle 1988). Studies carried out in some of these forests have shown that a number of rain forest species like *Calamus ovoideus*, *C. zeylanicum*, *C. rotang*, the medicinal wine - *Coscinium fenestratum*, the fish tail palm - *Caryota urens* the medicinal wild cardamom - *Elletaria cardamomum* which is also a spice, several liana species used by villagers, *Nepenthes distillatoria* are all gap specialists. It is our observation that the population size of all these species, is relatively low in the undisturbed parts of the forest compared to the forest fringe or selectively logged areas. Furthermore, though some of them are shade tolerant and grow extremely slowly in the understorey of the undisturbed forests, they show relatively fast growth rates in disturbed sites, e.g. *Calamus* spp., and *Coscinium fenestratum*. A demographic study of this last species carried out in Sinharaja clearly depicts this. In this study 5 transects were sampled along a disturbed to undisturbed gradient near

the fringe of the forests. Each transect 5 m x 125 m long, was sub-divided into 5 sub-plots, each 5 m x 20 m size. The distribution of seedlings, juveniles and adults of *Coscinium fenestratum* was examined in each of the sub-plots. The results showed that sub-plots closer to the fringe had a higher numbers of juveniles and adults. Those towards the forest interior did not have any juveniles, and much fewer adults (Senerath, 1990).

These observations are important for the sustainable management and harvesting of non-timber resources in rain forests. A prerequisite to sustainable management is a good understanding of the resource stock available, their growth rates, breeding biology, pollination ecology, fruit and seed dispersal and predation, seed viability germination and establishment.

### **Example 2: Timber Species in Wet Lowland Rain Forests**

At present some of the wet lowland forest are being identified as production forests, which will be subjected to selective felling. If selective felling is to be carried out sustainably then, an ecological understanding of the distribution, density size classes and growth rates of these timber tree species is essential.

Studies carried out at Sinharaja over the past 10 years provide some information on the canopy dominant *Shorea* spp., some of which are used for plywood (*Shorea affinis*, *S. trapezifolia*, *S. congestiflora* and *S. zeylanica*) and others as medium hardwood (*S. megistophylla* and *S. disticha*). In the wet lowlands, even within small altitudinal ranges, the topography of the land is highly dissected, with valleys, slopes of different steepness and ridges. Similarly, the soils show much variation (Hafeel 1991, Gunatilleke *et al.* 1996). On ridges the soil is shallow and relatively poor in nutrients, compared to deeper and nutrient richer soils in the valleys. The ridges are also exposed to more wind than the valleys. Consequently, trees on ridge tops are shorter than those growing in the valleys. As a result, tree falls give rise to smaller gaps on ridge tops and larger gaps in the valleys. This in turn creates gaps with different light levels on ridge tops and valleys (Ashton *et al.* 1995, Ashton 1990, 1992a, 1992b, 1994). Smaller gaps located on ridge tops experience shorter duration of sunlight with a lower intensity. On the other hand, larger gaps in the valleys experience longer duration of sunlight with greater intensity. These micro variations in soil, light and wind across small altitudinal gradients give rise to distinct micro sites. It has been demonstrated that the *Shorea* species in Sinharaja are site specific. *Shorea trapezifolia* and *S. megistophylla* are generally abundant in valleys while *S. worthingtonii* occupies the ridges and *S. affinis* the midslopes. In contrast *S. disticha* has a wider ecological amplitude and occurs right along the gradient. Understanding this spatial variation is very important for sustainable harvesting of timber. Generally in timber harvesting the more accessible lower slopes and valleys are logged heavily and the ridge tops are relatively less damaged. It's generally assumed that ridge tops will harbour the mother trees for regeneration of species in the valleys. As a large number of rain forest species appear to be site specific and a number have restricted ranges, unless adequate mother trees of these species are left behind in these areas, the opportunities for their survival are little.



**Example 3: Forest Die Back in Horton Plains**

Horton Plains represents one of Sri Lanka's most aesthetic sites, at an average elevation of 1800 m - 2300 m. The landscape is undulating with montane forests restricted to the ridges and upper slopes, wet patana grasslands occupying the lower slopes and wetland habitats, streams and fresh water marshes, occupying the valleys (Gunatilleke, in press). Forest die back in Horton Plains has been reported by W.R.H. Perera, former Conservator of Forests, about 24 years ago. Yet, long term studies to understand the causal factors of this phenomenon, its impact on the biodiversity of this system and the water balance in this important catchment area have not been launched. Preliminary observations also show that the regeneration of forest canopy species is suppressed by the luxuriant growth of understorey species. Reduction in structural diversity resulting from forest die back most certainly will influence the floristic diversity of the epiphytes, orchids, bryophytes and ferns in this habitat. Could anything be done to arrest this situation? Long term interdisciplinary studies in this site would help to resolve some issues related to forest die back, while understanding cyclical phenomena operating in this complex ecosystem.

**Example 4: Disturbance to Wet Patana Grasslands by the Potato Cultivation Project and the Invasion of the Dwarf Bamboo Species**

In 1961, a part of the wet patana grasslands dominated by the tussock grass *Chrysopogon zeylanicum*, was converted to seed potato cultivation beds. After a few years of cultivation, the potato project was abandoned and the land left to regenerate. To this day the tussock grasses have not returned to these areas. Instead, the present vegetation of these sites represents a closed cropped carpet grassland. The herbaceous flora characteristic of the wet patana grassland cannot grow among the carpet grasses, which do not provide the moist shady micro environment required for their growth. The flora in the two types of grasslands are quite distinct; one predominantly harbours a large number of exotic species while the other harbours the indigenous flora. The effect of one on the other, the effect of the carpet grasses on the sambur population in Horton Plains and how the two different grasslands affect the soil micro organisms, and water balance in the area all need urgent investigation.

Another more recent phenomenon on Horton Plains is the population explosion of the endemic dwarf bamboo species (*Arundinaria densifolia*). Upto a few years back it was confined to the stream sides and was only about 30-90 cm tall. Today, not only have they taken over a large part of the patana grasslands on the lower slopes but, they form a 2-3 m tall, dense almost impenetrable vegetation. Is the panoramic view of Horton Plains, as we have known it in the past, changing? How are these changes affecting the ecosystem and species diversity in this area?



### **Example 5: Changing Ecosystem Diversity in Wildlife Reserves of the Intermediate and Dry Zones**

Most of Sri Lanka's wildlife reserves are located in the intermediate and dry zones of the country, and they harbour large populations of herbivores (elephants, deer, sambur, wild boar among other species) in them. At present apart from affording protection to the animals and preventing encroachments and fires, little else is done to manage these reserves. As agricultural activities and urbanization have taken over most of the wastelands in Sri Lanka, the island's natural fauna are now more or less restricted to the wildlife reserves. With increase in human population, conflicts between wildlife and man too have exacerbated. Furthermore, man's activities have also influenced some of the wildlife reserves. Invasive exotic weeds like *Lantana camara* are spreading widely in these reserves. In others, grasslands and savannahs are getting converted into thorn shrubs. All these changes may adversely affect the herbivore populations, because habitats which in the past provided good feeding grounds to the herbivores cannot provide food to them any more. In some of the sanctuaries like Randenigala, fire initiated by villagers maintained the savannahs. Now that villagers have been removed from the sanctuary, fires are less frequent and the savannahs are changing into woody vegetation types (Kularatne *et al.* 1994). Consequently, the quantity of fodder available to herbivores is being greatly reduced. Should not these wildlife reserves be studied so that the importance of different habitats and species in maintaining herbivore populations be understood? Should fires be completely prevented or should controlled fires be used to maintain the balance among different habitats in these reserves? Another phenomenon is also now in progress in these savannahs. In the past, savannahs were dominated by *Imperata cylindrica* and *Cymbopogon nardus*. Now the aggressive exotic *Panicum maximum* appears to have completely replaced the indigenous grasses. Though *P. maximum* is a good fodder species, it out competes other herbaceous species as well. Thus, floristic diversity in these savannahs is slowly but surely being reduced. All these dynamic changes taking place need urgent long term investigation and monitoring, so that these wildlife reserves can be adaptively managed to meet the many goals that have been identified for each of them.

In all the examples highlighted above, the prevailing vegetation represents herbaceous and/or woody perennials, some with quite long life spans. The changes in ecological interactions taking place in these examples cannot be studied in a few years. All of them need to be monitored over decades of years. Therefore, all require well planned research projects, which include continuous monitoring, data gathering and documentation. For this reason, it is best that institutions are responsible for implementing long term projects, rather than single individuals. Only then could Sri Lanka play an active role in protecting and managing her biodiversity.

Lastly, an agency that would advocate long term studies in natural habitats must be identified. As the reserves are administered by different departments and basic ecological research capabilities lie with the Universities and/or other educational and research institutions, the agency should be one that could liaise with all of them.

In my view, the national Man and Biosphere Programme through NARESA could indeed play this vital role, by selecting a few sites for long term studies, and facilitating research in them. The Seville Strategy (UNESCO 1996) recommends this for the future development of biosphere reserves in the 21st century. In this strategy, Goal III advocates the use of biosphere reserves for research, monitoring, education and training. More specifically, in objective III.1, activities for individual reserves recommended include, among others, use of biosphere reserves for basic and applied research, particularly projects with a focus on local issues, interdisciplinary projects incorporating both the natural and social sciences, and projects involving rehabilitation of degraded ecosystems, the conservation of soil and water, and the sustainable use of natural resources. It also recommends the development of a functional system of data management for rational use of research and monitoring results in the management of biosphere reserves.

Goal IV of the Seville Strategy recommends the implementation of the Biosphere Reserve Concept. Under this goal, objective IV.1, among other activities, recommends the identification, mapping, preparation of management plans, their implementation and monitoring for all the zones identified in biosphere reserves. It also encourages community participation and management, and private sector initiatives to establish and maintain environmentally and socially sustainable activities in the reserves and surrounding areas.

The expectations of and future directions for biosphere reserves for the 21st century have been clearly laid out in the Seville Strategy. A number of recommendations advocated in it are being followed for most of the protected areas in Sri Lanka. Therefore, the role of the National Man and Biosphere Programme could be to act as a catalyst and facilitator, giving long term direction to long term research to address some of the changes that may adversely affect the island's biodiversity. Among the MAB reserves in Sri Lanka, Sinharaja alone remains as an active site, where much progress has been made. The success of Sinharaja as a long-term study site must be emulated in other reserves as well. Now more than ever before, our protected areas and production forests must be scientifically managed to ensure the conservation and sustainable use of the island's rich biodiversity.

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# IN-SITU CONSERVATION OF BIODIVERSITY AND A NETWORK OF CONSERVATION AREAS FOR SRI LANKA

*A.H. Magdon Jayasuriya*

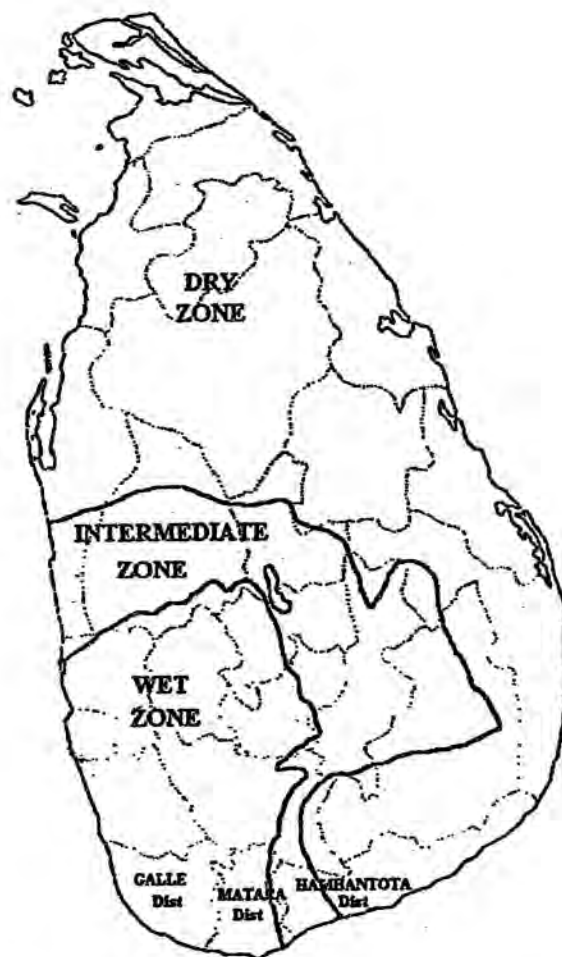
## INTRODUCTION

The identification of an optimum network of conservation areas for Sri Lanka is presently being conducted by the National Conservation Review Project (NCR) which deals with the estimation of relative conservation values of all remaining natural forest areas in the island. It addresses the biological importance of natural forests, largely in terms of their species diversity, together with their value for soil conservation and hydrology. It is being carried out by a team comprising three national consultants : A.H.M. Jayasuriya (Botanist), P.B. Karunaratne (Zoologist) and E.N.R. Gunawardena (Hydrologist) and an Assistant Conservator of Forests - S.D. Abayawardena (Database Specialist) - with technical assistance provided by an international Consultant - M.J.B. Green. This project is carried out by IUCN - The World Conservation Union - for the Forest Department and commissioned by the Food and Agriculture Organization of the United Nations.

The survey of the plant biodiversity and use of plant data in ranking of various forest areas in the Southern Province are summarily presented in this paper which is mainly based on a report prepared by IUCN (1993). However, the conclusions reached at this stage are essentially preliminary as analysis of the whole database for all provinces surveyed is still in operation.

## Physio-climatic characteristics of the Southern Province

The Southern Province consists of Galle, Matara and Hambantota districts which lie within the wet, wet and intermediate, and dry zone (Fig.1). The wet zone receives a mean annual rainfall of 2000-5000 mm, with substantial rain falling during both the south-west and north-east monsoons. In the dry zone, which receives 1000-2000mm annually, rain falls principally during the north-east monsoon. The mean annual rainfall in the intermediate zone is 1300-3500 mm. Considerable variation in the magnitude and timing of the monsoons can result in persistent wet and dry periods which may extend over several years. In the dry zone, months of zero rainfall are very common.



**Figure 1 :** Main climatic zones and districts of Sri Lanka

The availability of water has a major influence on the nature of the vegetation. The vegetation is most luxuriant in the wet zone, which supports rain and montane forests. By contrast the intermediate and dry zones tend to support jungle or scrub vegetation as a result of the high water deficit. Water deficits of up to 500 mm may be experienced from July to December and in February in the intermediate zone, and up to 800 mm from February to September in the dry zone.

In Galle and Matara districts, the terrain consists of steeper hills towards the north and low hills and undulating plains close to the coast. The main rivers are the Gin and Nilwala which originate from within Galle and Matara districts respectively, and drain southwards. Discharge is sustained throughout the year, with peak flows during the south-west monsoon.

Hambantota lies almost entirely in the dry zone except for the extreme north-western corner, which comprises 5% of the district. Its highest hills lie along the western boundary.

## METHODOLOGY

It was necessary to develop a method of surveying biological diversity that is both comprehensive and cost-effective (i.e. rapid) in order to meet the overall objective of the NCR. Therefore, gradsect sampling, which is explicitly described in IUCN (1993), was selected as being the most appropriate technique for rapidly assessing the diversity of species contained within natural forests. In this a group of 100 x 5 m plots, placed at regular intervals along a 'gradient-directed transect' are surveyed for all woody flowering plant species.

The National Conservation Review covers all natural forests administered by the Forest Department (i.e. forest reserves, proposed reserves and national heritage wilderness area) and by the Department of Wildlife Conservation (i.e. national reserves and sanctuaries). In the case of proposed reserves and other state forests, only those exceeding 100 ha in size are surveyed unless they are known to be of particular biological importance.

The analysis has two main objectives. The first is to assess the diversity of each forest (or forest complex) in term of species richness. This is done by totalling the number of species of woody plants and animals within each site. The second objective is to identify a minimum conservation areas network, in which each species is represented in at least one forest complex using the woody plant data. It is achieved by means of an algorithm which comprises the following iterative procedure :

- (i) The forest complex with the most species is selected as the first site.
- (ii) The forest complex with most species not already represented in the first complex is selected as the second site.
- (iii) The forest complex with the most species not already represented in the previously selected complexes is selected as the next site.
- (iv) The previous step (iii) is repeated until all species are represented in one or more forest complexes.

Various modifications to this algorithm were explored to demonstrate the range available. For example, in order to reduce the risk of species extinction the algorithm was modified to ensure, that each species is represented within at least two forest complexes. Another option is to restrict the analysis to endemic species.

A second algorithm was used to weight for rare species using similar steps. The concept of unique species (i.e. species recorded only in a particular site) was used to represent rare species.

## RESULTS

A total of 52 forests (including three mangroves) of 50 ha and above were surveyed for biological diversity in and adjacent to the Southern Province (Table 1). Sinharaja and Ruhuna, in the wet and dry zones, respectively, lie mostly outside the Province but they are included in the analysis because they are large and diverse, providing useful standards against which other forests can be evaluated.

Of the 52 forests, only 16 are considered to have been adequately surveyed (Table 1), based on a 5% threshold for the number of new woody species recorded in the penultimate and last plots, expressed as a percentage of the total number of species. In order to accommodate this constraint, forests in close proximity to each other and lying within the same catchment were treated as a single forest complex. The data were combined accordingly for a total of 18 forest complexes, each meeting the 5% criterion for the last two plots. Beraliya (Akuressa) was treated singly, being adequately sampled and somewhat isolated from other forests.

**Table 1:** List of natural forests surveyed for biological diversity in Southern Province, together with the number of transects and plots in each. Forests in bold are considered to have been adequately surveyed (i.e. number of new woody plant species recorded in penultimate or last plot  $\leq$  5% total number of species); the rest have been insufficiently sampled.

| Forest No.         | Name                | Designation | Not. area (ha) | Present area* (ha) | Transects (no.) | Plots (no.) | New species |           |      |      |
|--------------------|---------------------|-------------|----------------|--------------------|-----------------|-------------|-------------|-----------|------|------|
|                    |                     |             |                |                    |                 |             | Pen. (%)    | Last. (%) |      |      |
| WET ZONE DISTRICTS |                     |             |                |                    |                 |             |             |           |      |      |
| GALLE (N=19)       |                     |             |                |                    |                 |             |             |           |      |      |
| 509                | Auwegalakanda       | OSF         | 250.0          | 250.0              | 1               | (2)         | 4           | (8)       | 10.9 | 3.7  |
| 511                | Bambarawana         | OSF         | 248.0          | 248.0              | 1               | (1)         | 4           | (8)       | 17.6 | 7.7  |
| 37                 | Beraliya (Akuressa) | PR          | 1859.9         | 1645.5             | 2               | (3)         | 20          | (24)      | 2.1  | 1.5  |
| 38                 | Beraliya (Kudagala) | PR          | 4241.1         | 2571.8             | 1               | (1)         | 8           | (16)      | 3.0  | 2.4  |
| 62                 | Darakulakanda       | PR          | 457.6          | 141.7              | 1               | (3)         | 6           | (8)       | 16.9 | 4.6  |
| 65                 | Dediyagala          | FR          | 3789.9         | 3789.9             | 1               | (1)         | 17          | (24)      | 0.0  | 0.0  |
| 69                 | Dellawa             | PR          | 2034.0         | 2236.3             | 3               | (3)         | 15          | (40)      | 3.5  | 2.4  |
| 120                | Habarakada          | PR          | 209.6          | 209.6              | 1               | (0)         | 4           | (0)       | 13.3 | 11.1 |
| 503                | Hindelnatu          | OSF         | 200.0          | 200.0              | 1               | (2)         | 4           | (8)       | 20.8 | 7.4  |
| 507                | Homadola            | OSF         | 300.0          | 300.0              | 1               | (0)         | 5           | (0)       | 6.8  | 5.8  |
| 173                | Kandawattogoda      | PR          | 404.7          | 358.6              | 1               | (1)         | 5           | (8)       | 6.5  | 11.6 |
| 175                | Kanneliya           | FR          | 6114.4         | 6024.5             | 1               | (2)         | 24          | (32)      | 1.3  | 0.4  |
| 208                | Kombala-Kottawa     | PR          | 2289.7         | 1624.6             | 2               | (2)         | 14          | (16)      | 0.0  | 1.6  |
| 253                | Malambure           | FR          | 1012.3         | 929.8              | 1               | (2)         | 7           | (16)      | 8.5  | 1.2  |
| 303                | Naldyadeniya        | PR          | 2292.1         | 2235.5             | 2               | (3)         | 12          | (16)      | 2.1  | 0.8  |
| 369                | Polgahakanda        | FR          | 862.3          | 577.4              | 1               | (0)         | 8           | (0)       | 1.2  | 0.0  |
| 414                | Sinharaja           | NHWA        | 11187.0        | 11187.0            | 8               | (4)         | 48          | (42)      | 0.5  | 0.5  |
| 505                | Tawalama            | OSF         | 1000.0         | 1000.0             | 1               | (0)         | 5           | (0)       | 8.0  | 8.0  |
| 506                | Tiboruwakota        | OSF         | 600.0          | 600.0              | 1               | (1)         | 7           | (8)       | 2.9  | 5.5  |



Table 1 : Contd...

| Forest<br>No. Name        |                      | Design-<br>nation | Not.<br>area<br>(ha) | Present<br>area*<br>(ha) | Transects<br>(no.) |      | Plots<br>(no.) |       | New species<br>Pen. Last.<br>(%) (%) |      |
|---------------------------|----------------------|-------------------|----------------------|--------------------------|--------------------|------|----------------|-------|--------------------------------------|------|
| MATARA (N=19)             |                      |                   |                      |                          |                    |      |                |       |                                      |      |
| 501                       | Aninkanda            | OSF               | 75.0                 | 75.0                     | 1                  | (0)  | 5              | (0)   | 14.4                                 | 9.0  |
| 24                        | Baduliakela          | FR                | 182.3                | 147.7                    | 1                  | (1)  | 5              | (4)   | 3.8                                  | 8.1  |
| 60                        | Dandeniya-Aparekka   | FR                | 560.0                | 348.3                    | 1                  | (1)  | 5              | (12)  | 2.2                                  | 7.2  |
| 500                       | Derangala            | OSF               | 50.0                 | 50.0                     | 1                  | (1)  | 4              | (4)   | 12.9                                 | 4.1  |
| 77                        | Diyadawa             | FR                | 2578.2               | 2447.7                   | 2                  | (3)  | 17             | (28)  | 2.0                                  | 1.5  |
| 138                       | Horagala-Paragala    | OSF               | 1800.0               | 1800.0                   | 1                  | (1)  | 4              | (24)  | 12.5                                 | 8.9  |
| 497                       | Kalubowitiyana       | OSF               | 100.0                | 100.0                    | 1                  | (1)  | 5              | (4)   | 14.5                                 | 3.8  |
| 178                       | Kanumuldeniya        | FR                | 678.7                | 678.7                    | 1                  | (1)  | 5              | (8)   | 2.5                                  | 10.1 |
| 190                       | Kekanadura           | FR                | 401.7                | 379.9                    | 1                  | (1)  | 5              | (8)   | 8.9                                  | 3.7  |
| 201                       | Kirinda Mahayayakele | FR                | 374.1                | 252.7                    | 1                  | (1)  | 6              | (8)   | 11.5                                 | 3.3  |
| 498                       | Kurulugala           | OSF               | 175.0                | 175.0                    | 1                  | (1)  | 4              | (8)   | 12.5                                 | 8.9  |
| 263                       | Masmullekele         | FR                | 805.4                | 618.0                    | 1                  | (1)  | 6              | (16)  | 7.4                                  | 7.7  |
| 293                       | Mulatiyana           | FR                | 3277.5               | 3148.9                   | 4                  | (4)  | 29             | (40)  | 0.5                                  | 1.9  |
| 329                       | Oliyagankela         | FR                | 488.6                | 486.0                    | 1                  | (1)  | 6              | (8)   | 8.1                                  | 8.3  |
| 343                       | Panilkanda           | FR                | 588.1                | 588.1                    | 1                  | (3)  | 5              | (20)  | 6.9                                  | 7.3  |
| 388                       | Rammalakanda         | FR                | 1698.1               | 1406.7                   | 2                  | (3)  | 16             | (16)  | 1.0                                  | 3.4  |
| 499                       | Silverkanda          | OSF               | 1000.0               | 1000.0                   | 1                  | (2)  | 5              | (16)  | 8.8                                  | 2.6  |
| 453                       | Viharekele           | FR                | 825.1                | 625.1                    | 1                  | (1)  | 6              | (12)  | 7.8                                  | 7.3  |
| 471                       | Welihena             | FR                | 333.1                | 296.8                    | 1                  | (1)  | 6              | (12)  | 8.7                                  | 4.6  |
| ADJOINING DISTRICTS (N=1) |                      |                   |                      |                          |                    |      |                |       |                                      |      |
| 129                       | Haycock              | FR                | 362.0                | 362.0                    | 1                  | (0)  | 6              | (0)   | 10.3                                 | 3.8  |
| TOTAL (WET ZONE) :        |                      |                   | 55,705.5             | 51,116.8                 | 56                 | (58) | 367            | (522) |                                      |      |
| DRY ZONE DISTRICTS        |                      |                   |                      |                          |                    |      |                |       |                                      |      |
| HAMBANTOTA (N=9)          |                      |                   |                      |                          |                    |      |                |       |                                      |      |
| 44                        | Bundala              | S                 | 6216.0               | 6216.0                   | 1                  | (1)  | 5              | (6)   | 13.9                                 | 2.7  |
| 523                       | Kahanda Kalapuwa'    | OSF               | 200.0                | 200.0                    | 1                  | (0)  | 3              | (0)   | 0.0                                  | 0.0  |
| 164                       | Kalamitiya Kalapuwa' | S                 | 712.0                | 712.0                    | 1                  | (0)  | 5              | (0)   | 80.0                                 | 16.7 |
| 186                       | Katagamuwa           | S                 | 1003.6               | 1003.6                   | 1                  | (1)  | 6              | (6)   | 2.4                                  | 12.5 |
| 237                       | Madunagala           | FR                | 975.2                | 975.2                    | 1                  | (1)  | 3              | (6)   | 20.8                                 | 17.2 |
| 525                       | Miyandagala          | OSF               | 300.0                | 300.0                    | 1                  | (1)  | 2              | (6)   | 100                                  | 21.6 |
| 524                       | Rekawa Kalapuwa'     | OSF               | 50.0                 | 50.0                     | 1                  | (0)  | 3              | (0)   | 20.0                                 | 0.0  |
| 398                       | Ruhunu Block 1       | NP                | 13679.2              | 13679.2                  | 2                  | (-)  | 24             | (-)   | 1.4                                  | 4.1  |
| 464                       | Wedasitikanda        | FR                | 1343.4               | 1343.4                   | 1                  | (2)  | 5              | (12)  | 0.0                                  | 14.6 |
| ADJOINING DISTRICTS (N=4) |                      |                   |                      |                          |                    |      |                |       |                                      |      |
| 187                       | Kataragama           | S                 | 837.7                | 837.7                    | 1                  | (-)  | 5              | (-)   | 4.5                                  | 8.3  |
| 399                       | Ruhuna Block 2       | NP                | 9931.0               | 9931.0                   | 2                  | (-)  | 13             | (-)   | 3.5                                  | 5.0  |
| 400                       | Ruhuna Block 3       | NP                | 40775.4              | 40775.4                  | 4                  | (-)  | 28             | (-)   | 2.9                                  | 0.9  |
| 401                       | Ruhuna Block 4       | NP                | 26417.7              | 26417.7                  | 1                  | (1)  | 5              | (12)  | 7.1                                  | 16.0 |
| TOTAL (DRY ZONE) :        |                      |                   | 102,441.2            | 102,149.8                | 18                 | (7)  | 107            | (48)  |                                      |      |

\* Accounts for land released subsequently to notification.

- Lies in one or more adjacent districts.

, Mangrove.

The analysis is based on a total of 21,841 records of 657 species of woody plants. Over 1,300 plant specimens were collected from the field, most of which have since been identified. Not included in the present analysis are 105 unidentified plant records (representing 13 genera and 27 species).

### SPECIES DIVERSITY WITHIN INDIVIDUAL FORESTS

Woody plant species recorded within individual forests are listed in IUCN (1993) (for woody plants). Many species of plants have been recorded in new localities, extending their known distributions. Some rare species have been found to be more common than previously thought and a number of woody species believed to have become extinct or not collected for a very long time have been recorded and collected for the first time in this century (Jayasuriya, 1995, Jayasuriya & Green, 1996).

The total number of species recorded within each forest is summarized in Table 2. Sinharaja, Nakiyadeniya, Kanneliya, Mulatiyana, Dellawa, Rammalakanda and Diyadawa are the most diverse forests for woody plants, with some 200 or more species recorded in each. All of these lie in the wet zone. The most diverse forest for woody plants in the dry zone is Ruhuna Block 3 with over 100 species (Table 2). These forests are among the largest and, with the exception to Bundala, are considered to have been adequately sampled (Table 1).

Sinharaja contains both the greatest number of woody species (277) and endemic woody species (150). Together with Rammalakanda and Ruhuna Block 3, it has the most unique species (i.e. species not represented in any other site). Kanneliya is notable, having one of the highest percentages of endemic woody species (60%) of any forest, as well as the most nationally and globally threatened woody species. Haycock, Oliyagankele and Welihena (all insufficiently sampled), with half the number of species, are also notable with respect to their high proportions of endemic and threatened woody species. In the dry zone, Ruhuna Blocks 3-4 have the most endemic woody species (Table 2).

**Table 2: Summary of woody plant diversity recorded within natural forests in Southern Province. Forests are listed in descending order for species diversity, those in upper case having been adequately sampled. Species recorded within individual forests are listed in IUCN (1993).**

| No  | Forest Name  | Families | Genera | Species | S p e c i e s |         |            |        |
|-----|--------------|----------|--------|---------|---------------|---------|------------|--------|
|     |              |          |        |         | Unique        | Endemic | Threatened |        |
|     |              |          |        |         |               |         | National   | Global |
| 414 | SINHARAJA    | 166      | 170    | 277     | 11            | 150     | 24         | 7      |
| 303 | NAKIYADENIYA | 161      | 164    | 237     | 5             | 117     | 24         | 11     |
| 175 | KANNELIYA    | 147      | 149    | 233     | 2             | 140     | 26         | 16     |
| 293 | MULATIYANA   | 149      | 151    | 205     | 8             | 97      | 18         | 6      |
| 69  | DELLAWA      | 144      | 147    | 203     | 0             | 101     | 9          | 6      |
| 388 | RANMALKANDA  | 141      | 148    | 199     | 11            | 89      | 12         | 6      |

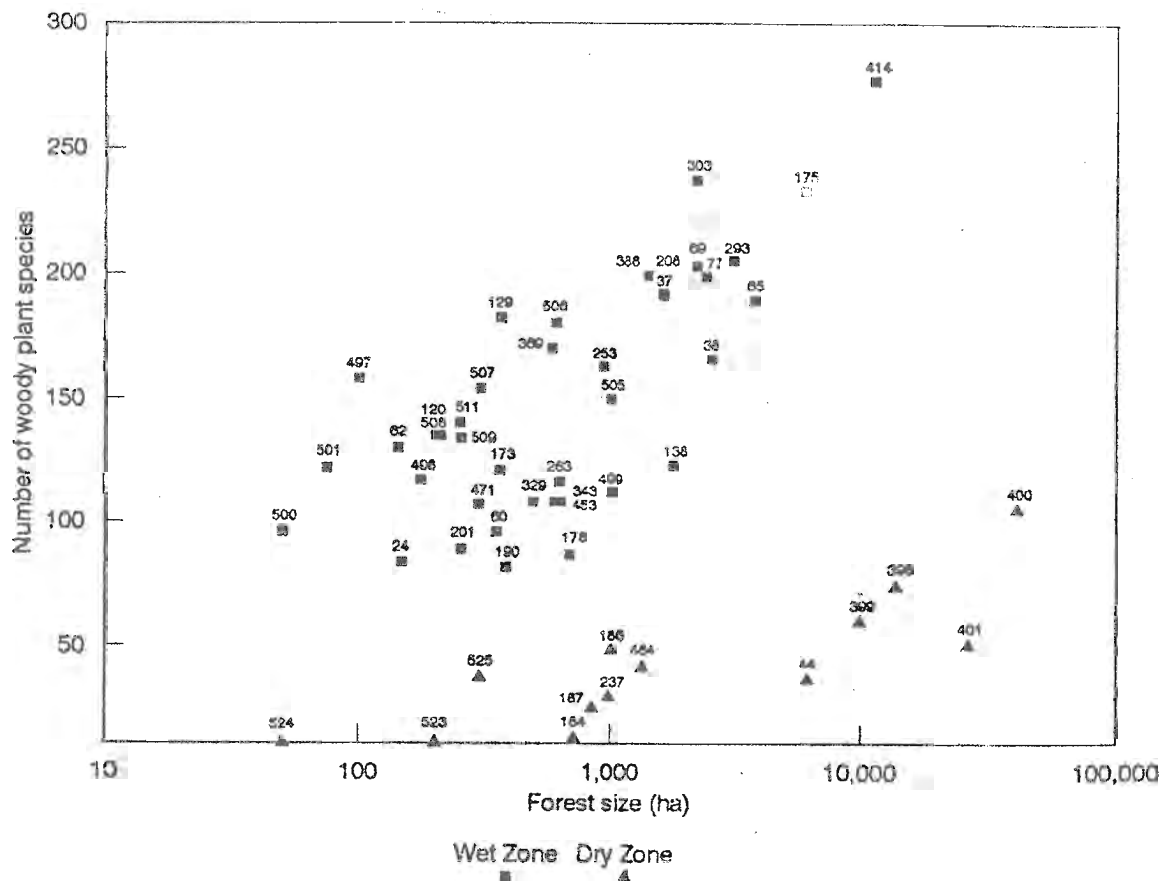
Table 2: Contd...

| No. | Forest Name          | Families | Genera | Species | S p e c i e s |         |                        |        |
|-----|----------------------|----------|--------|---------|---------------|---------|------------------------|--------|
|     |                      |          |        |         | Unique        | Endemic | Threatened<br>National | Global |
| 77  | DIYADAWA             | 138      | 142    | 199     | 1             | 106     | 16                     | 6      |
| 208 | KOMBALA-KOTTAWA      | 131      | 132    | 192     | 0             | 108     | 17                     | 11     |
| 37  | BERALIYA (AKURESSA)  | 136      | 137    | 191     | 2             | 102     | 15                     | 6      |
| 65  | DEDIYAGALA           | 126      | 126    | 189     | 1             | 112     | 18                     | 10     |
| 129 | Haycock              | 124      | 125    | 182     | 2             | 105     | 16                     | 12     |
| 506 | Tiboruwakota         | 129      | 130    | 180     | 1             | 93      | 16                     | 6      |
| 369 | POLGAHAKANDA         | 124      | 126    | 170     | 0             | 90      | 10                     | 7      |
| 38  | BERALIYA (KUDAGALA)  | 123      | 125    | 166     | 6             | 90      | 12                     | 5      |
| 253 | Malambure            | 125      | 128    | 163     | 1             | 89      | 13                     | 7      |
| 497 | Kalubowitiyana       | 126      | 129    | 158     | 4             | 59      | 10                     | 4      |
| 507 | Homadola             | 107      | 110    | 154     | 0             | 83      | 12                     | 6      |
| 505 | Tawalama             | 108      | 111    | 150     | 0             | 90      | 16                     | 8      |
| 511 | Bambarawana          | 114      | 117    | 140     | 1             | 58      | 8                      | 6      |
| 120 | Hebarakada           | 101      | 104    | 135     | 0             | 71      | 9                      | 2      |
| 508 | Hindeinattu          | 114      | 117    | 135     | 0             | 59      | 11                     | 6      |
| 509 | Auwegalakanda        | 104      | 105    | 134     | 0             | 74      | 12                     | 7      |
| 62  | Darakulakanda        | 108      | 111    | 130     | 1             | 58      | 9                      | 5      |
| 138 | Horagala-Paragala    | 102      | 104    | 123     | 0             | 56      | 9                      | 2      |
| 501 | Aninkanda            | 99       | 101    | 122     | 2             | 57      | 6                      | 3      |
| 173 | Kandawattegoda       | 96       | 99     | 121     | 0             | 58      | 7                      | 4      |
| 498 | Kurulugala           | 89       | 90     | 117     | 5             | 55      | 6                      | 3      |
| 263 | Masmullekele         | 97       | 99     | 116     | 0             | 55      | 9                      | 4      |
| 499 | Silverkanda          | 86       | 86     | 112     | 4             | 54      | 6                      | 3      |
| 329 | Oliyagankale         | 82       | 85     | 108     | 2             | 63      | 10                     | 6      |
| 453 | Viharakele           | 87       | 90     | 108     | 0             | 58      | 9                      | 2      |
| 343 | Panilkanda           | 95       | 96     | 108     | 1             | 43      | 3                      | 2      |
| 471 | Welihena             | 78       | 81     | 107     | 0             | 68      | 13                     | 5      |
| 400 | DRUHUNA BLOCK 3      | 75       | 77     | 105     | 11            | 8       | 2                      | 1      |
| 60  | Dandeniya Aprekele   | 81       | 83     | 96      | 2             | 47      | 7                      | 2      |
| 500 | Deranagala           | 84       | 87     | 96      | 2             | 36      | 4                      | 1      |
| 201 | Kirinda Mayakele     | 72       | 74     | 89      | 0             | 44      | 6                      | 2      |
| 178 | Kanumuldeniya        | 77       | 79     | 87      | 0             | 38      | 4                      | 2      |
| 24  | Badullakele          | 72       | 73     | 84      | 0             | 39      | 7                      | 3      |
| 190 | Kekanadura           | 76       | 76     | 82      | 0             | 36      | 6                      | 4      |
| 398 | DRUHUNA BLOCK 1      | 58       | 59     | 74      | 8             | 3       | 1                      | 1      |
| 399 | DRUHUNA BLOCK 2      | 49       | 49     | 80      | 5             | 4       | 2                      | 2      |
| 401 | DRUHUNA BLOCK 4      | 42       | 42     | 50      | 1             | 8       | 2                      | 1      |
| 186 | DKatagamuwa          | 41       | 41     | 48      | 2             | 5       | 0                      | 1      |
| 464 | DWedasitikanda       | 32       | 34     | 41      | 4             | 4       | 1                      | 1      |
| 525 | DMiyandagala         | 29       | 29     | 37      | 4             | 2       | 1                      | 1      |
| 44  | DBundala             | 34       | 35     | 36      | 5             | 3       | 0                      | 0      |
| 237 | DMadunagala          | 25       | 26     | 29      | 1             | 2       | 1                      | 0      |
| 187 | DKataragama          | 20       | 21     | 24      | 1             | 0       | 0                      | 0      |
| 164 | DKalamitiya Kalpuwa' | 12       | 12     | 12      | 0             | 0       | 0                      | 0      |
| 524 | DRekawa Kalpuwa'     | 9        | 9      | 10      | 4             | 1       | 0                      | 0      |
| 523 | DKAHANDA KALAPUWA'   | 10       | 10     | 10      | 5             | 0       | 1                      | 0      |

D Dry Zone (the rest are in the Wet Zone)  
, Mangrove

### Influence of forest size

In general, the larger the size of a forest, the greater the number of species contained within it up to a threshold which is a function of its complexity of heterogeneity. Such a trend is evident for woody plants (Fig. 2), despite the limitation that many forests have not been adequately sampled. As discussed previously, the distinction between wet and dry zone forests is marked for woody plants. These data endorse the maxim that conservation areas should be as large as possible to maximise representation of species.

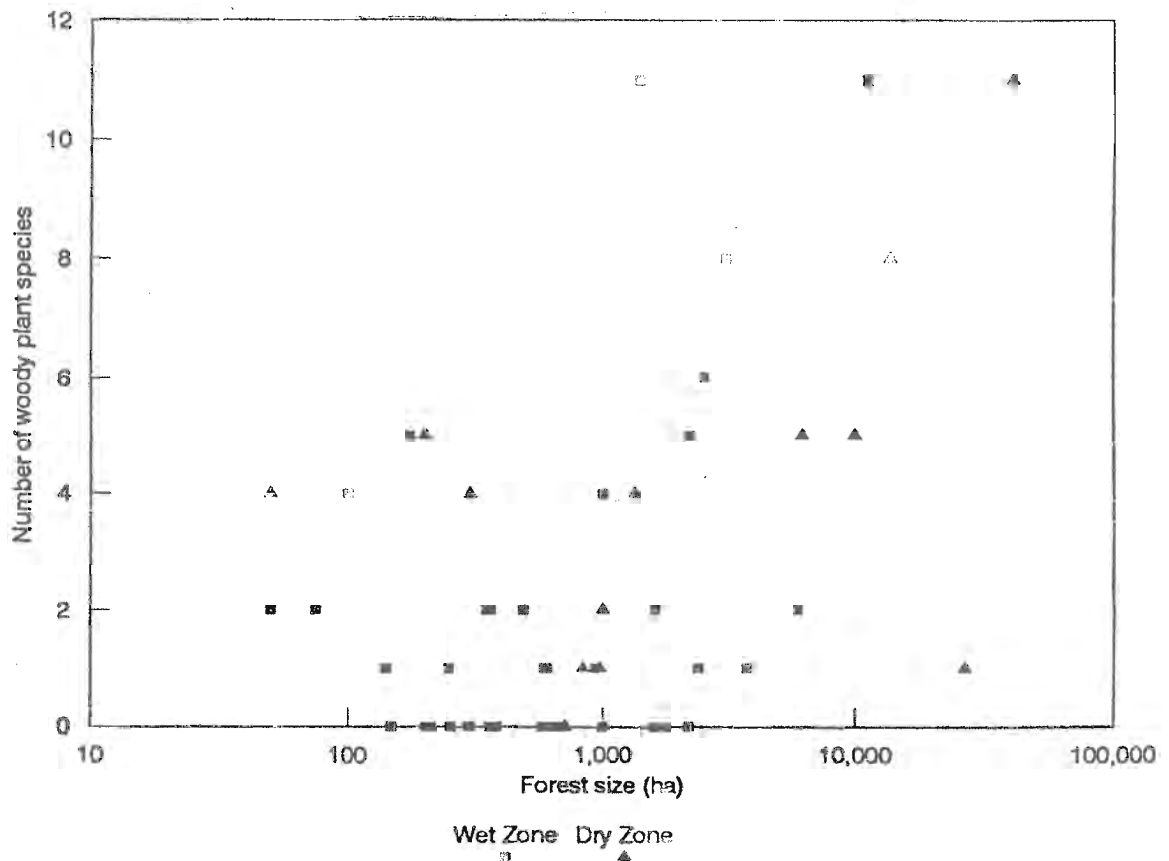


Note : Data points are labelled by forest number

Figure 2 : Relationship between species diversity and forest size for woody plants

### Rare and endemic species

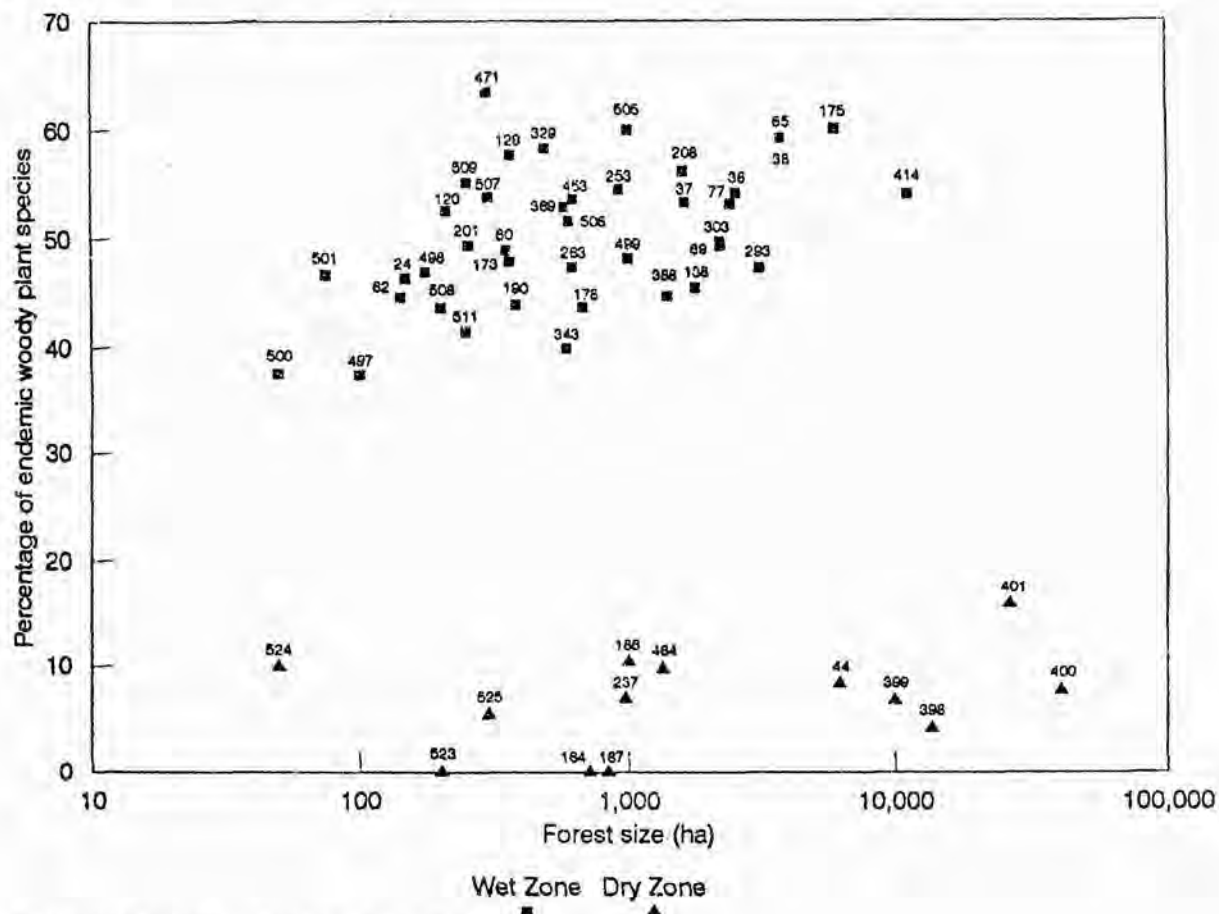
Many forests contain one or more rare species that are uniquely restricted in their distribution to that particular site (Table 2). There is no clear relationship between the number of species unique to a particular forest and its size (Fig. 3). This emphasizes the importance of protecting small as well as large forests in order to conserve the entire spectrum of species. Kalubowitiyana [497] and the mangrove of Rekawa [524] are prime examples of small forests (< 100 ha) with as many unique species as many larger forests (> 1,000 ha) or more. Both are in the category of other state forests and, therefore, receive negligible legal protection.



**Figure 3 : Relationship between the number of unique species and forest size for woody plants**

Levels of endemism are high in wet zone forests, ranging from 37% to 64% for woody plants. They are much lower, usually below 10%, in dry zone forests with the notable exception of Ruhuna Block 4 (insufficiently sampled) at about 16%. While small forests tend to contain fewer endemic species than large forests, their proportion of endemics

may be as high or even higher (Fig. 4). The 297 ha forest of Welihena [471] (insufficiently sampled), for example, ranks 33rd for woody plant diversity (Table 2) but it has the highest proportion of endemics (64%), as shown in Figure 3. As in the case of unique species, there is no clear relationship between levels of endemism and forest size (Fig. 4), further emphasizing the relative importance of small forests for endemic species.



Note : Data points are labelled by forest number

**Figure 4 : Relationship between the percentage of endemic species and forest size for woody plants**

In defining an optimal conservation areas network, therefore, it is vital that small forests are not overlooked in deference to larger forests because they may be important for rare and endemic species.

#### Species diversity within forest complexes

In order to overcome problems of sample size, forests were amalgamated into 18 complexes. Each complex is numbered according to the number of one of its constituent forests. The plant diversity represented within each complex is summarized in Table 3.

**Table 3: Summary of woody plant diversity recorded within natural forest complexes in Southern Province. Forests complexes are listed in descending order for species diversity.**

| Forest complex |                         |                                | Species  |        |         |        |         |            |        |
|----------------|-------------------------|--------------------------------|----------|--------|---------|--------|---------|------------|--------|
| No.            | Subsidiary Nos.         | Name                           | Families | Genera | Species | Unique | Endemic | Threatened |        |
|                |                         |                                |          |        |         |        |         | National   | Global |
| 175            | 65,303,500, 505,507,508 | KDN et al.                     | 203      | 207    | 357     | 12     | 185     | 43         | 19     |
| 414            | 498,499,506             | Sinharaja et al.               | 194      | 198    | 337     | 28     | 173     | 31         | 11     |
| 138            | 293,388                 | Hora-para/Mula/Ram             | 191      | 196    | 293     | 21     | 131     | 22         | 8      |
| 69             | 77,497                  | Della/Diya/Kalu                | 190      | 194    | 290     | 6      | 133     | 21         | 8      |
| 120            | 129,509,511             | Haba/Hay/Auw/Bamb              | 177      | 179    | 263     | 3      | 131     | 23         | 13     |
| 253            | 369                     | Malam/Polga                    | 148      | 150    | 211     | 1      | 113     | 17         | 9      |
| 38             | 62                      | Berel/Daru                     | 147      | 149    | 211     | 7      | 104     | 16         | 7      |
| 173            | 208                     | Kanda/Komb-Kott                | 142      | 144    | 210     | 0      | 112     | 18         | 11     |
| 37             |                         | Bereliya (Akuressa)            | 136      | 137    | 191     | 2      | 102     | 15         | 6      |
| 343            | 501                     | Panil/Anin                     | 126      | 128    | 155     | 4      | 70      | 7          | 3      |
| 329            | 471                     | Oliy/Weli                      | 97       | 100    | 145     | 2      | 89      | 18         | 8      |
| 60             | 190,201                 | Dand/Keka/Kiri                 | 112      | 112    | 145     | 3      | 73      | 13         | 5      |
| 398            | 399,400,401             | D <sup>D</sup> Ruhuna NP       | 100      | 103    | 143     | 56     | 13      | 5          | 2      |
| 24             | 263                     | Badu/Masmu                     | 111      | 112    | 142     | 0      | 66      | 12         | 6      |
| 178            | 453                     | Kanu/Vihi                      | 103      | 106    | 128     | 0      | 65      | 10         | 3      |
| 186            | 187,464                 | D <sup>D</sup> Kata/Kata/Weda  | 59       | 61     | 75      | 10     | 7       | 1          | 2      |
| 237            | 525                     | D <sup>D</sup> Madu/Miya       | 45       | 45     | 55      | 5      | 3       | 1          | 1      |
| 44             | 164,523,524             | D <sup>D</sup> Bund/Man-groves | 49       | 49     | 53      | 21     | 4       | 1          | 0      |

<sup>D</sup> Dry Zone (the rest are in the Wet Zone)

The most diverse site for woody plants is KDN and others (Kanneliya, Dediyaigala, Nakiyadeniya and others), the largest of the complexes (13,400 ha). It also has the most endemic and threatened (nationally and globally) species. This is particularly remarkable since much of KDN has been logged for timber in the past. KDN is considered to be the most important lowland rain forest in the country, warranting strict protection. Although the KDN Reserves are considered separately for administrative purposes, they constitute a single physical area and therefore, a nomenclatural change, viz: KANDENIYA FOREST RESERVE (consisting of three contiguous forest units) is proposed. Sinharaja and others (12,962 ha), second most diverse complex, contains unique species among wet zone complexes. Also notable for its high complement of unique species is Horagala-Paragala/ Mulatiyana & Rammalakanda (6,356 ha). Other highly diverse complexes, with over 250 species of woody plants, are Dellawa/Diyadawa/Kalubowiyana (4,784 ha) and Habarakanda/Haycock/Aluwegalakanda/Bambarawana (1,070 ha) (Table 3).

Of the dry zone forests, Ruhuna National Park (i.e. Blocks 1-4) is outstandingly important, with nearly twice as many woody species as any other dry zone forest and double the number of unique species compared to any dry or wet zone forest. Doubtless, this reflects its very large size (90,803 ha). The complex comprising Bundala and the three mangroves (9,172 ha) also contains many unique species (Table 3).

#### **Defining an optimum conservation areas network**

The results of applying the two algorithms to the woody plant data are presented in Tables 4a, b. A total of 15 forest complexes covering 63,798 ha or 11.6% of the Southern Province are required in order that each species is represented at least once. The same network is selected irrespective of whether or not the iterative procedure is weighted for rarity (i.e. unique species), although the order in which complexes are selected differs. The three complexes which do not contribute any additional species to the network are Badullakele/Masimullekele [237], Kandawattegoda/Kobmala-Kottawa [1731 and Kanumuldeniya Viharekele [178].

Similarly, if the algorithms are constrained to endemic woody species, only 12 complexes are necessary irrespective of any weighting for rarity (Tables 5a, b). They cover a total area of 56,093 ha or 10.2% of the Province. The three additional redundant complexes are Beraliya (Akuressa) [371, Dellawa/Diyadawa/Kalubowitiyana [69] and Madunagala/Miyandagala [237].

While it is sound conservation practice to ensure that each species is represented in at least two forest complexes, this condition cannot be met for either all woody species (Tables 6a) or endemics (Table 6b). Even if all 18 complexes are protected only 73% of woody species or 82% of endemic woody species would be represented within at least two complexes. It may be unrealistic, however, to attempt to meet this criterion as certain species may prove to be extremely localized in their distribution. This will only become apparent as forests in adjacent districts are surveyed.



**Table 4 (a) :** Network of forest complexes required to conserve woody plant diversity in Southern Province. Forest complexes are ranked in descending order of their selection, based on their contribution of species to the network. Those below the dotted line do not contribute any additional species to the network.

| Forest complex |     |                         |                     | Protected Species |      |       |       | Unprotected Species |
|----------------|-----|-------------------------|---------------------|-------------------|------|-------|-------|---------------------|
| Rank           | No. | Subsidiary Nos.         | Name                | New               | %    | Total | %     | Total               |
| 1              | 175 | 65,303,500, 505,507,508 | KDN et al.          | 357               | 54.3 | 357   | 54.3  | 300                 |
| 2              | 398 | 399,400,401             | DRuhuna NP          | 118               | 18.0 | 475   | 72.3  | 182                 |
| 3              | 414 | 498,499,506             | Sinharaja et al.    | 60                | 9.1  | 535   | 81.4  | 122                 |
| 4              | 138 | 293,388                 | Hora-Para/Mula/Ram  | 35                | 5.3  | 570   | 86.8  | 87                  |
| 5              | 44  | 164,523,524             | DBund/Mangroves     | 23                | 3.5  | 593   | 90.3  | 64                  |
| 6              | 186 | 187,464                 | DKata/Kata/Weda     | 16                | 2.4  | 609   | 92.7  | 48                  |
| 7              | 69  | 77,497                  | Della/Diya/Kalu     | 12                | 1.8  | 621   | 94.5  | 36                  |
| 8              | 38  | 62                      | Berel/Daru          | 11                | 1.7  | 632   | 96.2  | 25                  |
| 9              | 60  | 190,201                 | Dand/Keka/Kiri      | 5                 | 0.8  | 637   | 97.0  | 20                  |
| 10             | 237 | 525                     | DMadu/Miya          | 5                 | 0.8  | 642   | 97.7  | 15                  |
| 11             | 120 | 129,509,511             | Haba/Hay/Auw/Bamb   | 4                 | 0.6  | 646   | 98.3  | 11                  |
| 12             | 329 | 471                     | Oliy/Weli           | 4                 | 0.6  | 650   | 98.9  | 7                   |
| 13             | 343 | 501                     | Panil/Anin          | 4                 | 0.6  | 654   | 99.5  | 3                   |
| 14             | 37  |                         | Beraliya (Akuressa) | 2                 | 0.3  | 656   | 99.8  | 1                   |
| 15             | 253 | 369                     | Malam/Polga         | 1                 | 0.2  | 657   | 100.0 | 0                   |
| 16             | 178 | 453                     | Kanu/Vihi           | 0                 | 0.0  | 657   | 100.0 | 0                   |
| 17             | 173 | 208                     | Kanda/Komb-Kott     | 0                 | 0.0  | 657   | 100.0 | 0                   |
| 18             | 24  | 263                     | Badu/Masmu          | 0                 | 0.0  | 657   | 100.0 | 0                   |

D Dry Zone (the rest are in the wet zone)

**Table 4 (b) :** Network of forest complexes required to conserve woody plant diversity in Southern Province. Forest complexes are ranked in descending order of their selection, based on their contribution of unique species to the new work. Those below the dotted line do not contribute any additional unique species to the network.

| Forest complex |     |                           |                              | Protected Species    |     |      |       | Unprotected Species |       |
|----------------|-----|---------------------------|------------------------------|----------------------|-----|------|-------|---------------------|-------|
| Rank           | No. | Subsidiary Nos.           | Name                         | Unique Species Total | New | %    | Total | %                   | Total |
| 1.             | 398 | 399,400,401               | D <sup>R</sup> uhuna NP      | 56                   | 143 | 21.8 | 143   | 21.8                | 514   |
| 2.             | 414 | 498,499,506               | Sinharaja et al.             | 28                   | 319 | 48.6 | 462   | 70.3                | 195   |
| 3.             | 44  | 164,523,524               | D <sup>B</sup> und/Mangroves | 21                   | 25  | 3.8  | 487   | 74.1                | 170   |
| 4.             | 138 | 293,388                   | Hora-Para/Mula/Ram           | 21                   | 55  | 8.4  | 542   | 82.5                | 115   |
| 5.             | 175 | 65,303,500<br>505,507,508 | KDN et al.                   | 12                   | 51  | 7.8  | 593   | 90.3                | 64    |
| 6.             | 186 | 187,464                   | D <sup>K</sup> ata/Kata/Weda | 10                   | 16  | 2.4  | 609   | 92.7                | 48    |

Table 4 (b): contd..

| Forest complex |     |                 |                     | Protected Species    |     |     |       |       | Unprotected Species |
|----------------|-----|-----------------|---------------------|----------------------|-----|-----|-------|-------|---------------------|
| Rank           | No. | Subsidiary Nos. | Name                | Unique Species Total | New | %   | Total | %     | Total               |
| 7.             | 38  | 62              | Berel/Daru          | 7                    | 11  | 1.7 | 620   | 94.4  | 37                  |
| 8.             | 69  | 77,497          | Delle/Diya/Kalu     | 6                    | 12  | 1.8 | 632   | 96.2  | 25                  |
| 9.             | 237 | 525             | DMadu/Miya          | 5                    | 5   | 0.8 | 637   | 97.0  | 20                  |
| 10.            | 343 | 501             | Panil/Anin          | 4                    | 4   | 0.6 | 641   | 97.6  | 16                  |
| 11.            | 60  | 190,201         | Dand/Keka/Kiri      | 3                    | 5   | 0.8 | 646   | 98.3  | 11                  |
| 12.            | 120 | 129,509,511     | Haba/Hay/Auw/Bamb   | 3                    | 4   | 0.6 | 650   | 98.9  | 7                   |
| 13.            | 37  |                 | Beraliya (Akuressa) | 2                    | 3   | 0.5 | 653   | 99.4  | 4                   |
| 14.            | 329 | 471             | Oliy/Weli           | 2                    | 3   | 0.5 | 656   | 99.8  | 1                   |
| 15.            | 253 | 369             | Malam/Polga         | 1                    | 1   | 0.2 | 657   | 100.0 | 0                   |
| 16.            | 178 | 453             | Kanu/Vihi           | 0                    | 0   | 0.0 | 657   | 100.0 | 0                   |
| 17.            | 173 | 208             | Kanda/Komb-Kott     | 0                    | 0   | 0.0 | 657   | 100.0 | 0                   |
| 18.            | 24  | 263             | Badu/Masmu          | 0                    | 0   | 0.0 | 657   | 100.0 | 0                   |

D Dry Zone (the rest are in the wet zone)

**Table 5 (a) : Network of forest complexes required to conserve woody plant diversity in Southern Province. Forest complexes are ranked in descending order of their selection, based on their contribution of endemic species to the network. Those below the dotted line do not contribute any additional species to the network.**

| Forest complex |     |                         |                     | Protected Species |      |       |       | Unprotected Species |
|----------------|-----|-------------------------|---------------------|-------------------|------|-------|-------|---------------------|
| Rank           | No. | Subsidiary Nos.         | Name                | New               | %    | Total | %     | Total               |
| 1.             | 175 | 65,303,500,505,507, 508 | KDN et al.          | 185               | 73.7 | 185   | 73.7  | 66                  |
| 2.             | 414 | 498,499,506             | Sinharaja et al.    | 26                | 10.4 | 211   | 84.1  | 40                  |
| 3.             | 138 | 293,388                 | Hora-Para/Mula/Ram  | 12                | 4.8  | 223   | 88.8  | 28                  |
| 4.             | 38  | 62                      | Berel/Daru          | 6                 | 2.4  | 229   | 91.2  | 22                  |
| 5.             | 398 | 399,400,401             | DRuhuna NP          | 6                 | 2.4  | 235   | 93.6  | 16                  |
| 6.             | 60  | 190,201                 | Dand/Keka/Kiri      | 5                 | 2.0  | 240   | 95.6  | 11                  |
| 7.             | 329 | 471                     | Oliy/Weli           | 4                 | 1.6  | 244   | 97.2  | 7                   |
| 8.             | 253 | 369                     | Malam/Polga         | 2                 | 0.8  | 246   | 98.0  | 5                   |
| 9.             | 343 | 501                     | Panil/Anin          | 2                 | 0.8  | 248   | 98.8  | 3                   |
| 10.            | 44  | 164,523,524             | DBund/Mangroves     | 1                 | 0.4  | 249   | 99.2  | 2                   |
| 11.            | 120 | 129,509,511             | Haba/Hay/Auw/Bamb   | 1                 | 0.4  | 250   | 99.6  | 1                   |
| 12.            | 186 | 187,464                 | DKata/Kata/Weda     | 1                 | 0.4  | 251   | 100.0 | 0                   |
| 13.            | 237 | 525                     | DMadu/Miya          | 0                 | 0.0  | 251   | 100.0 | 0                   |
| 14.            | 178 | 453                     | Kanu/Vihi           | 0                 | 0.0  | 251   | 100.0 | 0                   |
| 15.            | 173 | 208                     | Kanda/Komb-Kott     | 0                 | 0.0  | 251   | 100.0 | 0                   |
| 16.            | 69  | 77,497                  | Delle/Diya/Kalu     | 0                 | 0.0  | 251   | 100.0 | 0                   |
| 17.            | 24  | 263                     | Badu/Masmu          | 0                 | 0.0  | 251   | 100.0 | 0                   |
| 18.            | 37  |                         | Beraliya (Akuressa) | 0                 | 0.0  | 251   | 100.0 | 0                   |

D Dry Zone (the rest are in the wet zone)

**Table 5 (b) : Network of forest complexes required to conserve woody plant diversity in Southern Province. Forest complexes are ranked in descending order of their selection, based on their contribution of unique endemic species to the network. Those below the dotted line do not contribute any additional unique species to the network.**

| Forest complex |     |                         |                     | Protected Species    |     |      |       | Unprotected Species |
|----------------|-----|-------------------------|---------------------|----------------------|-----|------|-------|---------------------|
| Rank           | No. | Subsidiary Nos.         | Name                | Unique Species Total | New | %    | Total | % Total             |
| 1.             | 414 | 498,499,506             | Sinharaja et al.    | 15                   | 173 | 68.9 | 173   | 68.9                |
| 2.             | 138 | 293,388                 | Hora-Para/Mula/Ram  | 8                    | 18  | 7.2  | 191   | 76.1                |
| 3.             | 175 | 65,303,500, 505,507,508 | KDN et al.          | 5                    | 32  | 12.7 | 223   | 88.8                |
| 4.             | 398 | 399,400,401             | DRuhuna NP          | 5                    | 6   | 2.4  | 229   | 91.2                |
| 5.             | 38  | 62                      | Berel/Daru          | 2                    | 6   | 2.4  | 235   | 93.6                |
| 6.             | 60  | 190,201                 | Dand/Keka/Kiri      | 2                    | 5   | 2.0  | 240   | 95.6                |
| 7.             | 329 | 471                     | Oliy/Weli           | 2                    | 4   | 1.6  | 244   | 97.2                |
| 8.             | 343 | 501                     | Panil/Anin          | 2                    | 2   | 0.8  | 246   | 98.0                |
| 9.             | 44  | 164,523,524             | DBund/Mangroves     | 1                    | 1   | 0.4  | 247   | 98.4                |
| 10.            | 120 | 129,509,511             | Haba/Hay/Auw/Bamb   | 1                    | 1   | 0.4  | 248   | 98.8                |
| 11.            | 186 | 187,464                 | DKata/Kata/Weda     | 1                    | 1   | 0.4  | 249   | 99.2                |
| 12.            | 253 | 369                     | Malam/Polga         | 1                    | 2   | 0.8  | 251   | 100.0               |
| 13.            | 237 | 525                     | DMadu/Miya          | 0                    | 0   | 0.0  | 251   | 100.0               |
| 14.            | 178 | 453                     | Kanu/Vihi           | 0                    | 0   | 0.0  | 251   | 100.0               |
| 15.            | 173 | 208                     | Kanda/Komb-Kott     | 0                    | 0   | 0.0  | 251   | 100.0               |
| 16.            | 69  | 77,497                  | Delle/Diya/Kalu     | 0                    | 0   | 0.0  | 251   | 100.0               |
| 17.            | 24  | 263                     | Badu/Masmu          | 0                    | 0   | 0.0  | 251   | 100.0               |
| 18.            | 37  |                         | Beraliya (Akuressa) |                      |     |      |       |                     |

D Dry Zone (the rest are in the wet zone)

**Table 6 (a) : Network of forest complexes required to conserve woody plant diversity in Southern Province, with species represented in at least two complexes. Forest complexes are ranked in descending order of their selection, based on their contribution of endemic species to the network.**

| Forest complex |     |                         |                     | Protected Species |      |       |      | Unprotected Species |
|----------------|-----|-------------------------|---------------------|-------------------|------|-------|------|---------------------|
| Rank           | No. | Subsidiary Nos.         | Name                | New               | %    | Total | %    | Total               |
| 1.             | 175 | 65,303,500,505,507, 508 | KDN et al.          | 0                 | 0.0  | 0     | 0.0  | 657                 |
| 2.             | 414 | 498,499,506             | Sinharaja et al.    | 274               | 41.7 | 274   | 41.7 | 383                 |
| 3.             | 398 | 399,400,401             | DRuhuna NP          | 13                | 2.0  | 287   | 43.7 | 370                 |
| 4.             | 138 | 293,388                 | Hora-Para/Mula/Ram  | 42                | 6.4  | 329   | 50.1 | 328                 |
| 5.             | 186 | 187,464                 | DKata/Kata/Weda     | 40                | 6.1  | 369   | 56.2 | 288                 |
| 6.             | 69  | 77,497                  | Delle/Diya/Kalow    | 26                | 4.0  | 395   | 60.1 | 262                 |
| 7.             | 44  | 164,523,524             | DBund/Mangroves     | 9                 | 1.4  | 404   | 61.5 | 253                 |
| 8.             | 38  | 62                      | Berel/Daru          | 14                | 2.1  | 418   | 63.6 | 239                 |
| 9.             | 237 | 525                     | DMadu/Miya          | 14                | 2.1  | 432   | 65.8 | 225                 |
| 10.            | 120 | 129,509,511             | Haba/Hay/Auw/Bamb   | 13                | 2.0  | 445   | 67.7 | 212                 |
| 11.            | 60  | 190,201                 | Dand/Keka/Kiri      | 6                 | 0.9  | 451   | 68.6 | 206                 |
| 12.            | 37  |                         | Beraliya (Akuressa) | 5                 | 0.8  | 456   | 69.4 | 201                 |
| 13.            | 173 | 208                     | Kande/Komb-Kott     | 7                 | 1.1  | 463   | 70.5 | 194                 |
| 14.            | 329 | 471                     | Oliy/Weli           | 5                 | 0.8  | 468   | 71.2 | 189                 |

**Table 7 : Minimum network of forest complexes required for conservation, based on various criteria with respect to biological diversity and soil conservation/hydrology.**

| Criteria                                   | Minimum network of complexes |                 | Redundant complexes                   |
|--------------------------------------------|------------------------------|-----------------|---------------------------------------|
|                                            | No. #                        | Area (% prov.)* |                                       |
| <b>Woody plants</b>                        |                              |                 |                                       |
| 1 Species                                  | 15                           | 63,798 (11.6%)  | [24], [173], [178]                    |
| 2 Endemic Species                          | 12                           | 56,093 (10.2%)  | [24], [37], [69], [173], [178], [237] |
| <b>Woody plants + Animals</b>              |                              |                 |                                       |
| 3 Species                                  | 17                           | 66,547 (12.1%)  | [178]                                 |
| 4 Endemic species                          | 15                           | 64,206 (11.7%)  | [24], [178], [237]                    |
| <b>Soil/Water</b>                          |                              |                 |                                       |
| 5                                          | 12                           | 60,562 (11.0%)  | [24], [44], [60], [186], [237] [329]  |
| <b>Woody plants + Soil/Water</b>           |                              |                 |                                       |
| 6 Species                                  | 17                           | 67,085 (12.2%)  | [24]                                  |
| 7 Endemic species                          | 16                           | 65,510 (11.9%)  | [24], [237]                           |
| <b>Woody plants + Animals + Soil/Water</b> |                              |                 |                                       |
| 8 Species                                  | 18                           | 67,851 (12.3%)  | None                                  |
| 9 Endemic species                          | 16                           | 65,510 (11.9%)  | [24], [237]                           |

# Where appropriate, minimum networks include Bund/Mangroves [44], Ruhuna NP [398] and Sinharaja et. al. [414], none of which has yet been assessed for soil conservation/hydrology, on the basis that [398] and [414] are of importance and [44] is of negligible value for soil conservation and hydrology.

\* Area of Southern Province is 550,096 ha (Galle = 160,733 ha, Matara = 129,931 ha, Hambantota = 259,432 ha). The adjacent forests of Haycock (362 ha), Kataragama (838 ha), Ruhuna Blocks 2-4 (77,124 ha) and approximately two-thirds of Sinharaja (7,383 ha), which lie outside the Province, are excluded from the total area of the network in order to calculate its percentage of the Province.

## DISCUSSION AND CONCLUSIONS

The NCR is the first ever systematic and relatively comprehensive evaluation of the importance of Sri Lanka's natural forests for biological diversity. It is also a unique project unparalleled elsewhere in the tropics, and may provide a useful model for possible application in other tropical countries.

Considerable progress has already been achieved, with about 10% of the country surveyed and results analysed for the Southern Province. Apart from the institutional aspects, immediate technical benefits are already apparent in the detailed knowledge of species distributions obtained from the thousands of records of plants collected in the field. Many species, including endemics and rarities, have been recorded in new localities, and several species new to Sri Lanka have been discovered.

### **Costs of optimal network**

The NCR survey of the island includes not only the plant diversity, but also the animal diversity, soil conservation and hydrology (IUCN 1993). The various conservation options and their associated costs in terms of land requirements are summarized in Table 7. This preliminary analysis shows that all 18 forest complexes, representing 12.3% of the total area of the Southern Province, should be protected if maximum conservation criteria are to be applied (Option 8), namely 100% representation of woody plant species and certain groups of animal species and protection of all forests that are important or may be important for soil conservation and hydrology. Even within this network, only 73% of the woody species, or 82% of the endemic woody species, would be represented in at least two complexes. Representation of species in two or more sites may be an unrealistic goal, however, given the very localised distributions of some species, compounded by the way in which the remaining natural forests have become increasingly fragmented and isolated. Each forest is uniquely important, contributing species not found in other forests of the same complex.

Of the various other options, all of which are less costly in terms of the amount of land required for conservation, Option 9 should be considered as a minimum policy in order to safeguard endemic species of plants and animals, as well as to protect complexes important for soil conservation and hydrology (Table 7). Any network comprising fewer than these 16 complexes could jeopardise the future security of some species endemic to Sri Lanka. Such a network is only marginally smaller than that representative of all species, and comprises 11.9% of the total area of the Province.

Optimal networks of forest complexes defined by Option 8 are shown in Figure 5 for 100% representation of species. The importance of each forest for woody plants, animals, and soil conservation and hydrology is shown as a series of overlays using a geographic information system.

These networks, like others defined in Table 7, are conservative and will need to be reviewed within the national context once the NCR is completed. The distributions of many species are not confined to the Southern Province and, therefore a network representative of 100% of the Province's biological diversity is likely to comprise fewer complexes as more species are recorded in forests outside the Province. There is an absolute minimum requirement of 8-12 complexes, however, if soil conservation and hydrological criteria are to be met.

### **Applications and limitations of the NCR**

Survey of the Southern Province (and the preliminary results of the wet zone) indicate that future conservation efforts will need to give highest priority to protecting the largest contiguous forests both to conserve biodiversity and to protect the headwaters of all of the

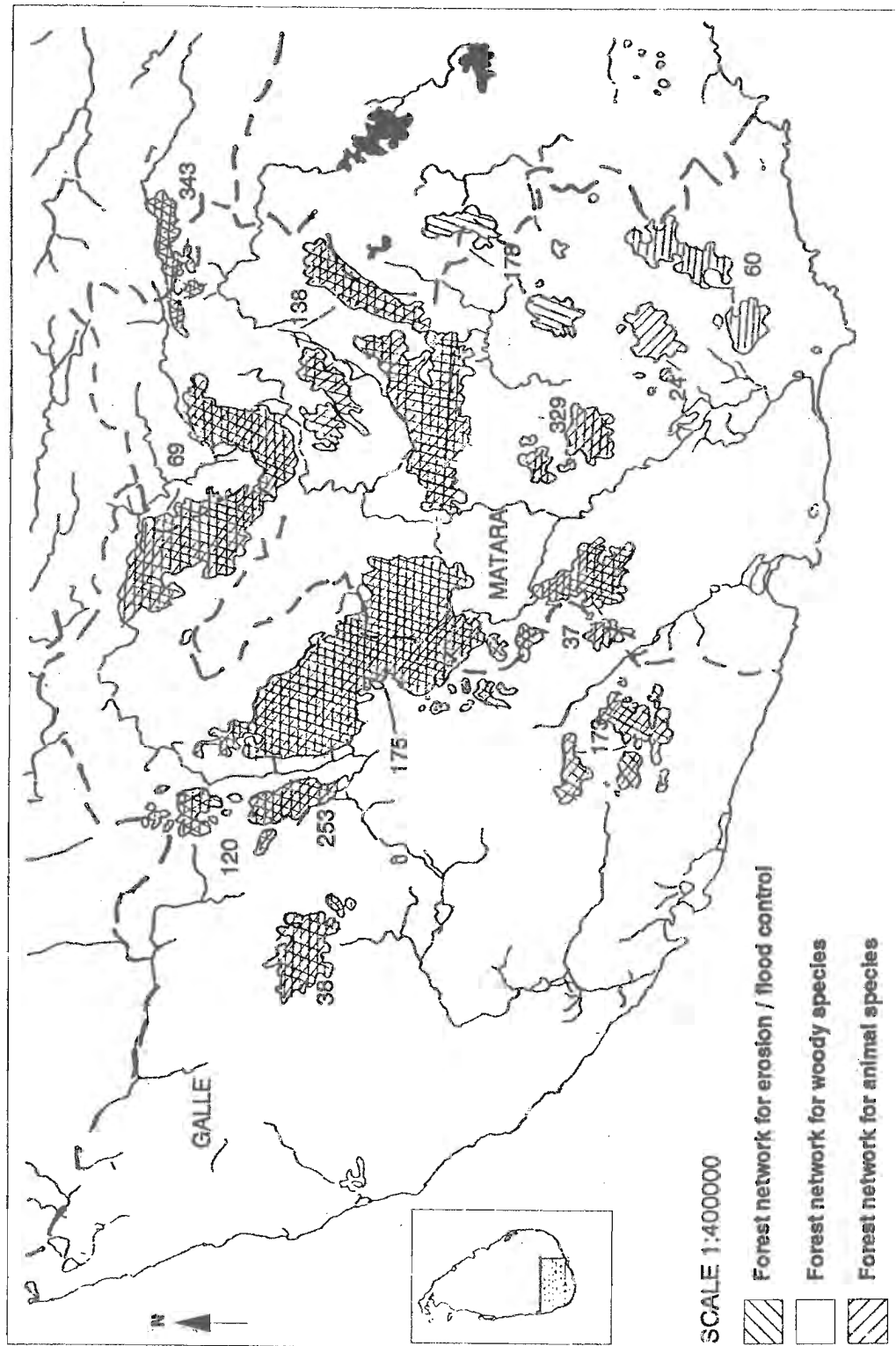


Figure 5 : Optimal network of closed canopy natural forests in Galle and Matara districts, with 100% representation of species of woody plants and animals (selected groups) and including forests vital for soil conservation and hydrology.

country's major rivers, and many relatively small forest areas mainly to conserve several rare and endemic plant and animal species. Yet this only represents a minimal allocation of land for conservation in the face of ever increasing socio-economic pressures. Therefore, in planning a network of conservation forests, biodiversity, hydrological and socio-economic needs must be addressed holistically and strictly on a sustainable basis.

It should also be noted that the NCR biodiversity survey was limited to woody flowering plants and vertebrates and selected invertebrate animals due to time and resource constraints. Furthermore, sampling adequacy has not been achieved for a number of forest sites while some large and complex areas warrant more extensive sampling due to high diversity.

Relative conservation values for various forest sites and the conservation areas network generated by the NCR database will necessarily influence a variety of conservation planning issues such as identification of core areas, buffer zones and transition areas, revision of boundaries, reforestation of degraded areas, controlled harvesting of non-timber forest products, enhancement of research education and tourism and legislative revision. The legal status of many of these forests will need to be upgraded, particularly those currently designated as other state forests (including proposed reserves). Conservation requirements need not preclude sustainable use of forest resources provided that it is properly managed and controlled. Forests providing a multiplicity of services will need to be zoned with core zones for strict protection of biologically important biota, resource use zones for harvesting forest products, and buffer zones for absorbing the impact of peripheral human activities. However, it is strongly emphasized that timber extraction in any degree, and any other development activities leading to species and habitat degradation in natural areas, should not be planned as the NCR data, at present, are not sufficient to support such activities. This is furthermore important as the threat of extinction to species is evidently proportional to the rate of decline in population and fragmentation or diminution rates for natural areas occupied due to excessive human activity. While the immediate application of this information is to design an optimal national network of conservation areas with respect to natural forests, in the longer term it represents an extremely powerful tool for evaluating the potential impact of proposed development projects on forests, for monitoring changes in the composition of flora and for management planning, particularly with respect to zonation, including buffer zone development. The ultimate value of having undertaken a nationwide survey will be realized when the impact of any proposed development can be assessed in terms of which species are likely to be threatened or to disappear. Only then can the real costs of such developments be balanced against the benefits.

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# ECOLOGICAL CHARACTERISTICS AND ENVIRONMENTAL FUNCTIONS OF TROPICAL RAIN FORESTS

T.C. Whitmore

## ABSTRACT

*A distinctive ecological characteristic of tropical rain forests that continues to excite biological interest is their extremely high species richness and diversity. It has many causes, one of which is structural complexity of the forest canopy which is also in a continuous state of change by the development of canopy gaps and subsequent regrowth. Aspects of this dynamism also contribute to diversity. Small gaps are filled by climax species and create a shifting mosaic steady state that has been subject to much recent research. Large community-scale disturbance due to rare catastrophic destruction creates big gaps which become filled by pioneers and its signs persist for their lifetime. Other signs, e.g. charcoal and human artefacts, are long persistent. Increasingly more rain forests are being found with signs of large scale disturbance. Tropical rain forests impact hydrology and climate, and through the release of greenhouse gases, their destruction contributes to current climatic change.*

## ECOLOGICAL CHARACTERISATION OF TROPICAL RAIN FORESTS

Three groups of ecological characteristics will be considered. The first is species richness, unequalled in any other land ecosystem, though believed to be similarly high in coral reefs. The phenomenal current general interest in tropical rain forests (trf)<sup>1</sup> today is largely due to a perception that they contain a high fraction of all life on earth, and that their rapid attrition is leading to extinction on a scale similar to the five natural mass extinction events during the Phanerozoic, most recently at the Cretaceous/Tertiary boundary 65M years ago.

One of the perennial driving forces for scientific interest in trf is the search for mechanisms leading so many species to co-exist. There are in fact many reasons (e.g. Whitmore 1984 section 17.6). One is the structure of trf. This is the second ecological characteristic to be considered. Thirdly, rain forest canopy dynamics and the role of disturbance in maintaining species richness are addressed.

### Species richness

In the sense in which species richness is discussed it usually also includes diversity, for trf are both very rich in numbers of species and also diverse in the occurrence of numerous unrelated taxa of both plants and animals, from many orders and families.

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<sup>1</sup>trf = tropical rain forests

Diversity can usefully be divided into three scales : gamma, beta and alpha diversity (Whittaker 1972). Gamma diversity is the large-scale landscape diversity. In trf a large area is likely to have different rain forest formations (Whitmore 1975) on different rock types or physiographic settings and these are mostly sharply bounded. They differ in structure and physiognomy. For example, so-called heath forests are found on white, siliceous, podsolised sands in all three tropical continents and everywhere have the same distinctive rather open canopy with numerous pole size trees that have small leathery leaves. Many plant species are confined to the heath forest formation, though these differ between regions and continents. Another facet of gamma diversity is that part of a landscape recovering from a windstorm, drought, drought-induced fire, or, increasingly today, from human disturbance. This regrowth forest will have different species composition.

Beta diversity is the variation from place to place within the same forest formation, for example the catenary sequence of species from ridge crest to hillside to valley of which a good example is the *Shorea* section *Doona* species of Sinharaja forest in Sri Lanka.

Alpha diversity is the richness in one place, i.e. on a single small plot. Tropical rain forests are famous for this. Most rain forests have over 100 tree species, (10cm diameter or more) per hectare and due to beta diversity adjacent hectares differ. By contrast, all Europe north of the Alps and west of Russia has only 50 native tree species, and eastern north America only 171 species. The richest trf so far discovered all lie in the western Amazon close to the Andes in Peru, Ecuador and Colombia. The most species-rich are at Cuyabeno in Ecuador which reach 307 species per hectare (Valencia *et al.* 1994). Second most rich are several plots in Kalimantan with up to about 260 species per hectare. The global pattern (Fig. 1) is that Africa is least rich, with only 20-30 species per hectare, except near Mt Cameroon, and in Gabon (Gentry 1988). Much of South America is relatively poor, though plots are few. Asia is consistently very rich.

There are very few complete species counts. One in Costa Rica found 233 vascular plant species on 100m<sup>2</sup>, of which only 4 were trees but 71 were tree seedlings  $\leq 3$  m tall. (Table 1) That is 20 percent of the flora of the British Isles on half the area of a tennis court (Whitmore *et al.* 1986).

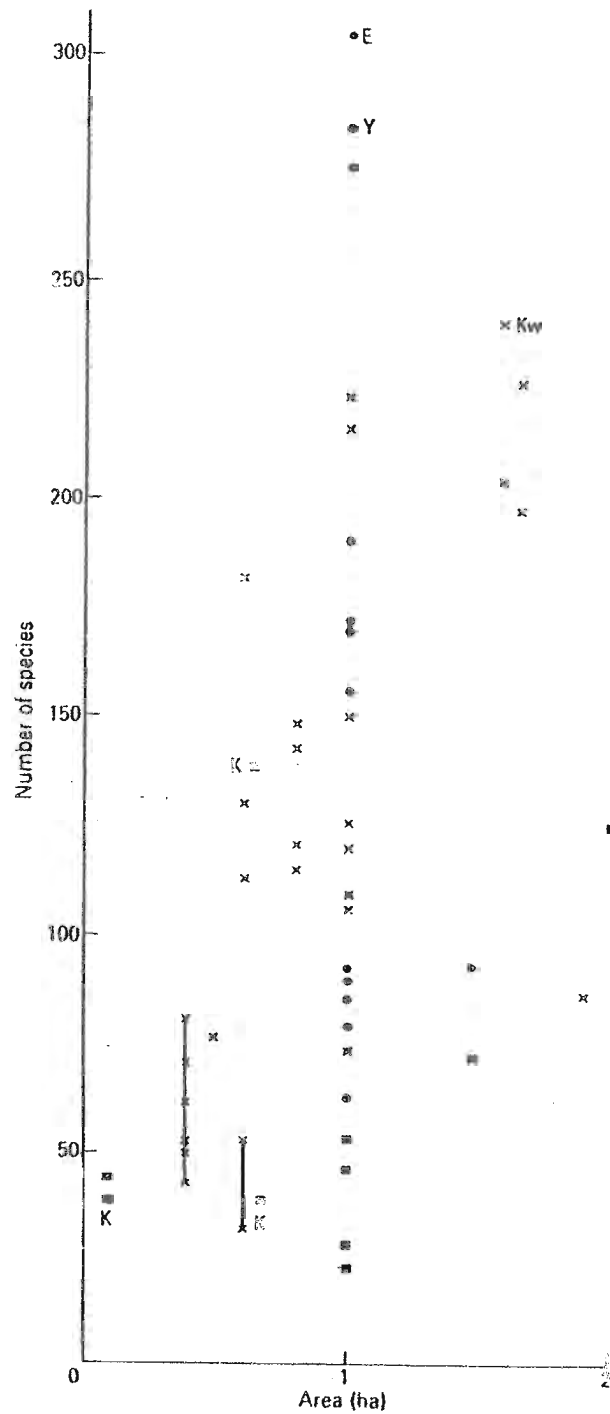


Figure 1 : Species numbers among trees over 0.1 m diameter on small plots in tropical lowland rain forest • America (Y Yanamono, E Ecuador), x Eastern tropics (Kw Kalimantan-Wanariset); ■ Africa (K Korup, Cameroon). (Whitmore 1990, Fig. 2.27).

**Table 1: Numbers of species and individuals in the different synusia on a 100 m<sup>2</sup> plot in evergreen rain forest near Horquetas, Costa Rica (Whitmore *et al.* 1986, Table 1)**

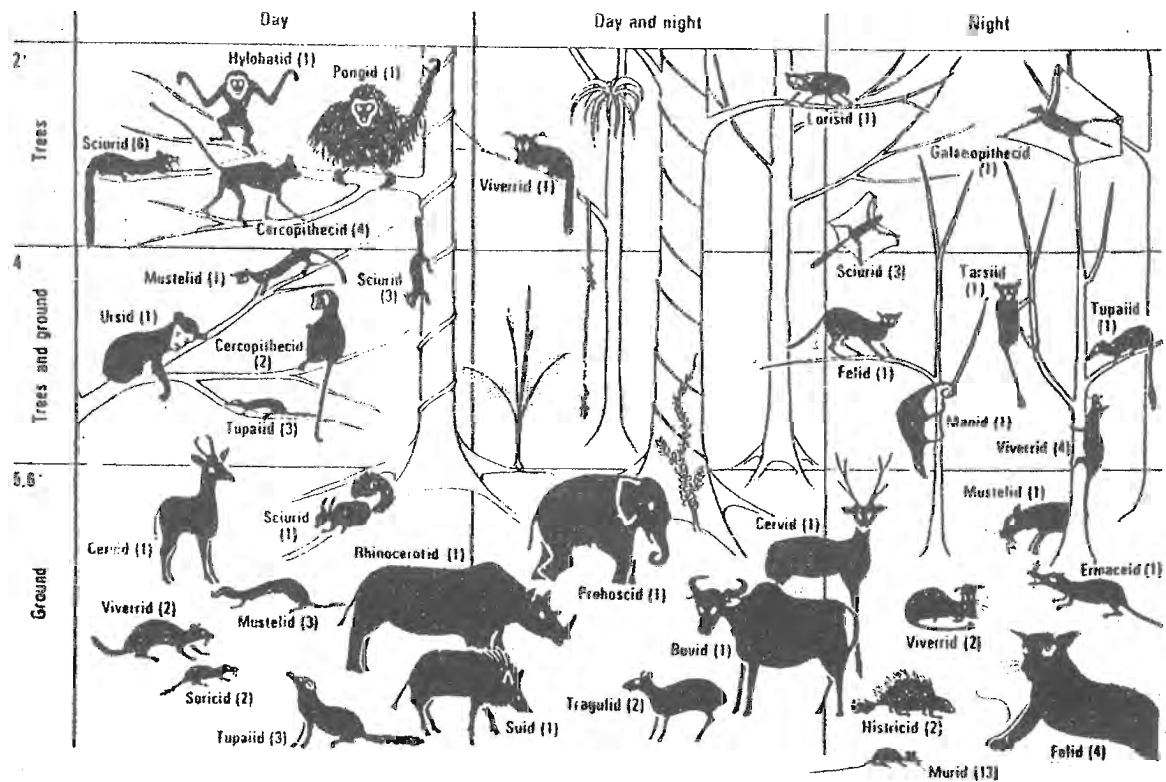
|                                  |                                    | Individuals | Species |                  |
|----------------------------------|------------------------------------|-------------|---------|------------------|
|                                  |                                    |             | Total   | Cumulative total |
| Vascular Plants:                 |                                    |             |         |                  |
| (a)                              | Independent (free-standing) plants |             |         |                  |
|                                  | plants < 1m tall                   | 1349        | 132     | 132              |
|                                  | (of which tree seedlings)          | (566)       | (64)    |                  |
|                                  | plants 1-3m tall                   | 144         | 36      | 140              |
|                                  | (of which trees)                   | (134)       | (5)     |                  |
|                                  | plants > 3m tall                   | 38          | 18      | 144              |
|                                  | (of which trees)                   | (35)        | (4)     |                  |
| (b)                              | Dependent Plants                   |             |         |                  |
|                                  | Climbers                           |             |         |                  |
|                                  | bole                               | 233         |         |                  |
|                                  | woody (free-hanging)               | 68          | 21      | 165              |
|                                  |                                    |             | 20      | 174              |
|                                  | Epiphytes                          | 339         | 61      | 233              |
|                                  | (of which aroids)                  | (90)        | (17)    |                  |
|                                  | (of which bromeliads)              | (49)        | (8)     |                  |
|                                  | (of which ferns)                   | (87)        | (9)     |                  |
| <b>Total all vascular plants</b> |                                    | <b>2171</b> |         | <b>233</b>       |
| Bryophyta                        |                                    |             |         |                  |
|                                  | liverworts                         | ?           | 25      |                  |
|                                  | mosses                             | ?           | 7       |                  |
| <b>Total all Bryophyta</b>       |                                    |             |         | <b>32</b>        |

The count was made by a team of 11 people, removing one synusia at a time, and took a total of 192 man-hours. At this rate it would take ten man-years to extend the plot to a full hectare.

Species counts in Malaysia have revealed that relatively small areas have a considerable fraction of the regional flora. This was first shown by Ashton in Sarawak where 6.6 ha spread across 13 km<sup>2</sup> had about half of the total Sarawak complement of trees over 10 cm diameter (Ashton 1964). It has been shown again in Peninsular Malaysia, where trees of 1 cm diameter and over on a 50 ha plot at Pasoh comprise about one third (820 species) of the Malayan tree flora. This finding is contrary to the supposition that high species numbers in trf are due to the presence of numerous very local endemics. It is a valuable finding for today as efforts develop to conserve the total biological heritage of the trf on small relict fragments set in an anthropogenic landscape.

The forest canopy is habitat for numerous animals, and trf are extremely rich. There is strong niche partitioning (Fig. 2), and strong specialization, of which the feeding guilds of bats (especially in South America) and of birds are just two examples.

Interactions between different species continue to be discovered. A feature of trf is the importance of vertebrates as pollinators and dispersers. Some close one-to-one relationships exist, though it is now increasingly being discovered that trf do not function like finely-tuned machines with each species a unique cog. For example, species of *Meliaceae* in Malaysia have different dispersers in different parts of their range (Mabberley *et al.* 1995).



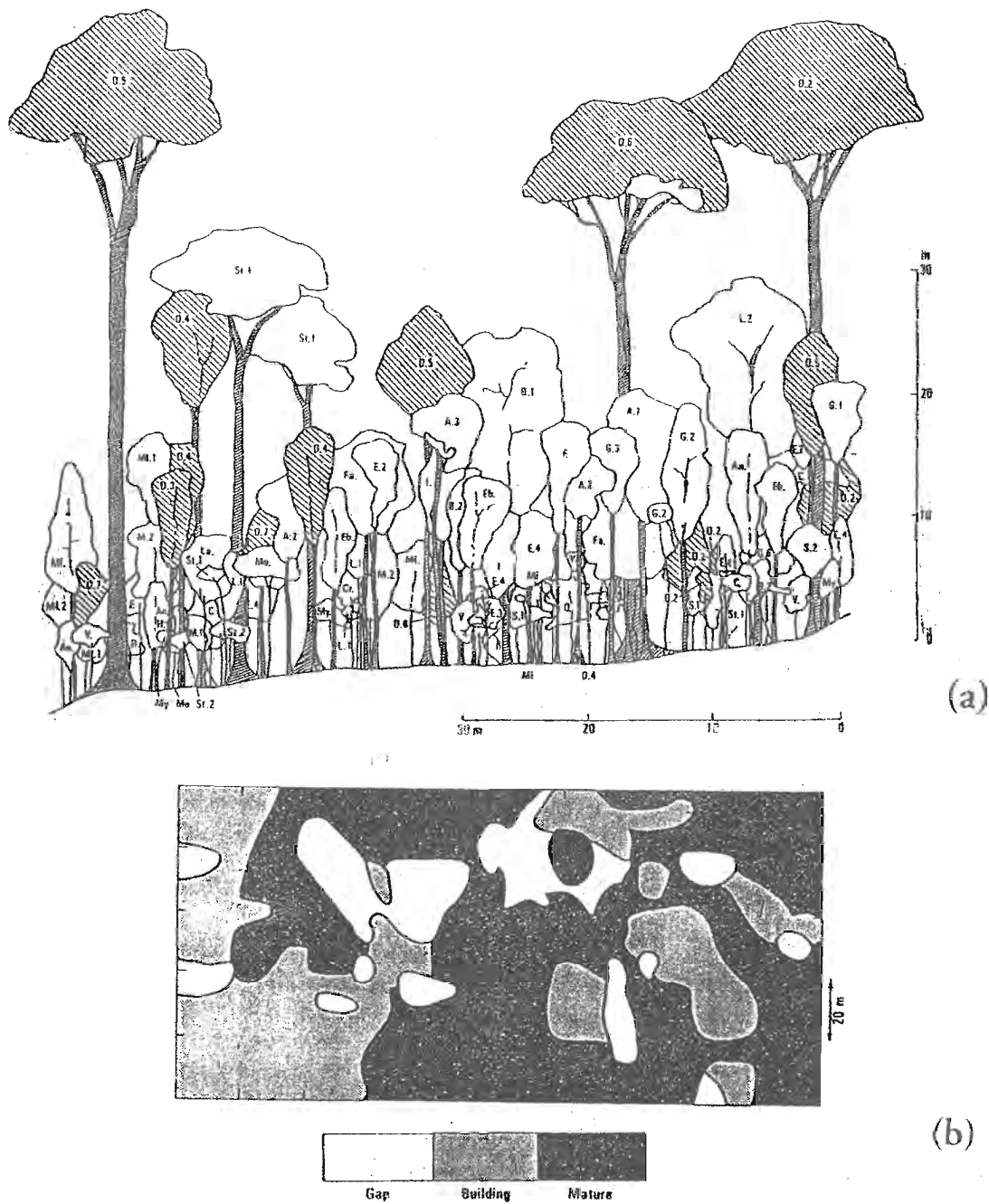
**Figure 2 :** Stratification in space and time of non-flying mammals in the lowland rain forest of Sabah (Whitmore 1995, Fig. 2.26).

## Forest structure

Tropical rain forest structure is one of its distinctive ecological characteristics. Trees of many shapes and sizes are the main life form in trf, from tiny undergrowth Schopfbäumchen (monopodial treelets) to 60-80 m tall giants, crown emergent above the canopy. Buttresses, cauliflory and ramiflory are other distinctive features. By convention, and useful for pedagogic purposes, the canopy is sometimes considered to be layered or stratified. This is a simplified abstraction of the reality that trees of many different heights occur. The tree framework supports climbers and epiphytes, and these life forms can themselves be subgrouped. For example, there are big free-hanging woody climbers (a distinctive feature of lowland rain forest) and bole-adherent, mainly herbaceous, ones. This canopy complexity is one contributing factor to the hyper-richness of the trf. The temperate rain forests of Pacific northwest America are just as tall, but much poorer in species, so canopy height by itself is not always concomitant with richness.

## Canopy dynamics

The widespread realization that trf canopies are dynamic, in a continuous state of flux, was the death knell of canopy stratification as a defining feature, for trees and layers of trees are forever changing. Canopy gaps are created by death, and the forest growth cycle of gap, building and mature stages (Watt 1947) results in a mosaic of patches of different canopy height, (Fig.3). In this respect trf are like most of the world's forests. Indeed, one important realization, as our knowledge of trf continually increases, is that in many respects, including their 'gap phase dynamics', trf are not unique. A distinction can be made between the nature of forest regrowth between small and large gaps, with the change in lowland trf at a gap size of c. 0.1 ha or less. A general pattern has been discovered, though with local variants and embellishments, that in small gaps shade-tolerant seedlings present on the forest floor before gap creation are released and form the new forest growth cycle, whereas in big gaps light demanding species that germinate from seed after gap creation form the new forest. A paper at the previous Kandy Symposium (van Steenis 1958) drew attention to these two strongly contrasting ecological groups of species and named them dryads and nomads respectively. The latter group are so-named because they cannot regenerate *in situ* but are fated to move at each generation across the forest to a new big gap. These two guilds are now commonly called climax and pioneer species. Much research and numerous papers have now been devoted to characterizing them, attempting to subdivide them, and, more recently, to elucidating the ecophysiology of shade tolerance and rapid growth respectively.



**Figure 3 :** The forest growth cycle displayed. Lowland evergreen dipterocarp rain forest

- (a) in profile showing mature and (in middle) building phase, Belalong, Brunei (Ashton 1964).
- (b) in plan showing the mosaic of gap, building and mature phases, Sg. Menyala, Peninsular Malaysia (Whitmore 1975, Fig. 2.3).

There has been a vast effort put into the many facets of forest regrowth in small gaps: phenology of seed production, seed characteristics, seed dormancy, triggers for germination, seedling establishment, survival, site specificity, demography and release. There has been little work in trf on sapling and pole demography, but a realization is growing that multiple release in successive canopy gaps is probably important, as it is in temperate forests (Clark & Clark 1992). The driving force behind much of this work has been to elucidate species packing. Can richness be explained in terms of niche-specialisation or is chance important? Overall (i.e. at gamma and beta scale), species composition remains steady though varying on any given spot (i.e. at alpha scale), the so-called shifting-mosaic steady-state.

Less research has been devoted to big canopy gaps. They need only occur about once a century to have a persisting influence (Whitmore 1989). Thus, in the scale of a human life or certainly of a research grant, they are rare events. The direct signs of a large gap are the species composition of the forest, and to some extent its canopy structure. But unless another big gap occurs these signs will disappear after a single tree generation, about a century. As observations increase in formerly inaccessible parts of the world's rain forests the ubiquity of former past large scale disturbance is being increasingly realized, from indirect signs (Whitmore & Burslem in press). Since the great 1982/3 El Nino drought in Borneo and subsequent Great Fire, the flammability of even perhumid trf has been realized. Fossil charcoal has been dated from parts of Amazonia and the indication is of repeated fires during the Holocene, perhaps set by Man, probably associated with El Nino caused droughts. In many places in Amazonia potsherds indicate former habitation in now empty forest. The same applies to Nigeria and Zaire in the African trf. In central America trf occurs in places known to have been open country at the time of the Spanish Conquest 400 years ago. There, as also in parts of Amazonia, concentrations of useful plants, some occurring outside their natural range, are additional signs of past human occupancy. So, one of the great discoveries of the past few years has been that much trf is not the pristine ecosystem, untouched since the flowering plants evolved, that we once believed (Richards 1952). This reality adds colour to the current heated debate on human impact on trf.

## ENVIRONMENTAL FUNCTIONS OF TROPICAL RAIN FORESTS

Present day concern about the loss of trf is also partly driven by claims that its environmental functions may disappear, and that this will contribute to climatic change.

Two environmental functions can be perceived, the hydrological role of trf and their place in the global carbon cycle.

### Hydrology

Climate is partly determined by the interchange of energy at the earth's surface, and the nature of surface cover is important. The three facets of surface cover used in climatic models are: surface albedo (viz the fraction of incident energy that is radiated back into the



atmosphere), evapotranspiration, and surface roughness. Table 2 shows the first two for forest, grassland and bare ground. It can be seen that a forest is highly absorptive of radiation, and has high evapotranspiration. Change away from continuous tree cover will therefore be likely to affect climate. However, there is no substantial difference between a natural forest and a tree plantation, of e.g. rubber or oil palm. Concerning the third parameter, many primary trfs have a rough canopy due to emergent trees, secondary forests are less rough, and plantations and arable and pastoral land use are rather smooth. In a comprehensive review Bruijnzeel (1990) was unable to find any place where it can be rigorously proven that removal of trf had led to a change in rainfall. This is partly because there is high inherent natural interannual variability and climate is commonly synoptic, not generated locally. However, there is evidence that substantial deforestation of the Amazon basin and replacement by pasture of arable agriculture would probably reduce rainfall (Salati & Vose 1984). The same might apply to the other great continental trf, the forests of the Zaire basin.

**Table 2: Some climatic properties of different surface covers (Whitmore 1990, Table 10.12)**

|                                      | Forest | Grass    | Herbaceous Crops | Bare    |
|--------------------------------------|--------|----------|------------------|---------|
| Potential evapotranspiration mm/year | 850    | 550-750  | 550-750          | 400-500 |
| Surface albedo                       | 0.12   | 0.16-0.2 | 0.2              | 0.35    |

It is sometimes believed that a forested catchment ensures an even flow of water. Numerous watershed experiments have now shown that continuous vegetation cover is needed to maintain soil permeability and water holding capacity, and this can be grassland. Tropical trees, like temperate ones, have high evapotranspiration, and water yield of a catchment may indeed decrease if the landcover is changed. Bruijnzeel (1990) reviewed the evidence.

### **Carbon cycle and greenhouse gases**

Lowland trf commonly has above ground biomass of c. 400t/ha, a carbon content of c. 200t/ha, plus a further 5-20 percent below ground, and yet more in soil organic matter. Natural climax trf is *ipso facto* in equilibrium and every patch of building forest is balanced by an equal patch in decay, so the carbon balance is neutral. Replacement of trf by fast growing trees, whose timber is then used for pulp or construction, will increase carbon sequestration. Replacement by a vegetation of lower biomass will usually mean an addition of carbon dioxide to the atmosphere.

Forest clearance and cultivation leads to reduction of soil carbon by oxidation, commonly by about a quarter in the first five years (Houghton 1995). This releases CO<sub>2</sub> as well as nitrous oxide (N<sub>2</sub>O) which is a powerful greenhouse gas. Where pasture replaces forest, cattle produce 170 litres per head per day of methane, another greenhouse gas.

During the 1980s tropical deforestation added  $2 \times 10^9$  tons/year of carbon (Houghton 1995, Table 15.4). Although thrice that amount came from burning fossil fuels ( $5.6 \times 10^9$ t) efforts to reduce atmospheric  $\text{CO}_2$  increase will be best achieved by reducing all sources. Already the 1980s policy of Brazil to create huge pastures in southeast Amazonia from trf has been abandoned, partly as a consequence of widely voiced concern about climate.

The annual global increase in atmospheric carbon dioxide is equivalent to  $3.5 \times 10^9$  tons of carbon, much less than the amount added annually from deforestation and burning forest fuel,  $7.6 \times 10^9$ t. The difference,  $4.2 \times 10^9$ t of carbon, is presumed to be taken up by the oceans and terrestrial vegetation, the so-called 'carbon sink'. On land, carbon is absorbed by secondary forests and tree plantations (i.e. forests in which biomass is increasing). There is also some evidence that primary tropical forests may be a net carbon sink and absorbing  $1-2 \times 10^9$ t/year, though this claim is a result of truly heroic extrapolations from two stations in the Brazilian Amazon measured for 44 and 11 days respectively (Grace *et al.* 1995) during a year of lower than usual temperature (consequent to the eruption of Mt. Pinatubo) and hence low respiration. Even if carbon uptake by primary forest is shown to occur its ability to help offset atmospheric  $\text{CO}_2$  increase is limited for, as Danny Harvey (1991) has pointed out, any 'carbon fertilisation' effect will saturate and diminish as global temperature rises, whereas the concomitant increase in respiration will continue to increase.

## CONCLUSION

The UNESCO Humid Tropics Programme began with the Kandy Symposium in 1956 and continued for nearly twenty years. To start with it was still possible to encapsulate the areas of active rain forest research in a single meeting and symposium publication. But growth has been exponential, and rain forest science has become multifaceted and highly fragmented. We now need occasional symposia such as the present one to attempt to distil the essence of current knowledge from its multifarious growth points. The urgent task for today is then to use our much better understanding of rain forest science to steer and to mitigate human impact on tropical forests, for that too has increased dramatically since 1956.

## ACKNOWLEDGEMENT

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## THE DECIDUOUS FOREST OF THAILAND

Utis Kutintara

### ABSTRACT

The deciduous or seasonal forests of Thailand are characterized by their physiognomic function of the community by which nearly all trees shed their leaves during the dry period and most species have some adaptive characteristics to survive under forest fire pressure. The vegetation type covers more than 40 percent of the total forest land of the country especially in the northern half where the seasons are distinctively pronounced. This plant formation is subdivided into 4 vegetation types, namely: mixed deciduous forest, deciduous dipterocarp forest, savanna and tropical grassland.

The mixed deciduous forest occurs along the dry belt of the country where precipitation is less than 1,600 mm/yr, on deep soils and long dry season (more than 4 months). The dominant tree species is teak (*Tectona grandis*) intermixing with *Xylia xylocarpa*, *Terminalia alata*, *Pterocarpus macrocarpus* etc. but teak may be absent in some places and bamboos are present in the middle layer. The deciduous dipterocarp forest occupies rather more dry sites and shallow soils. This forest is characterized by having the deciduous dipterocarp species in the top layer such as *Dipterocarpus tuberculatus*, *D. obtusifolius*, *D. intricatus*, *Shorea siamensis*, and *S. obtusa*. The savanna is associated with very dry sites which have grasses as the dominant plants and trees or shrubs are sparsely distributed. *Imperata cylindrica*, *Vetiveria zizanioides*, *Panicum notatum* and *Themeda triandra* are the dominant grass species while the common trees and shrubs are *Acacia harmandiana*, *A. catechu*, *A. tomentosa*, *Careya herbacea* and *Antidesma montanum*. The tropical grassland usually occurs on saline soils or very dry sites or strongly sandy soils. Annual fire is an important limiting factor preventing invasion of tree or shrub species into this type.

The deciduous forest communities usually have a unique ecosystem. A large amount of annual fresh biomass produced close to the ground provides high possible energy transferred to herbivores which in turn supply food for carnivores. Decomposition rate is not so rapid as in the evergreen forests, but annual forest fire destroys all debris and dead materials on forest floor.

### INTRODUCTION

Thailand is one of the richest centres in biological diversity, especially at the community and species levels. It has more advantages than many other countries of the same size in many categories, especially climatic, geographic and topographic factors. In fact, Thailand has two climatic zones: the true tropical climate in the far south from Kra Isthmus which is characterized by a long rainy season and a short dry season with high

annual precipitation. This climatic type supports the tropical evergreen forest biome, while the central, northern and northeastern regions are under monsoons and have a long dry season with a short cool period. It is the characteristic sub-tropical climate which supports various forest types under the tropical deciduous biome. (Lekagul & McNeeley 1977).

Geographically, the southern part is in the Malaysian Peninsula and the northern and eastern parts are deep in continental Asia; thus Thailand has both coastal and inland vegetation types. Topographically, the country has lowland areas at sea level both in the coastal zone and swampy land in the South and Central Portions while the northern region consists of hilly areas with many high peaks. The highest altitude in Doi Inthanon National Park is about 2,500 metres above sea level. Thus, Thailand has both lowland vegetation types such as mangrove, peat swamp and montane forests (called hill evergreen by Smitinand 1977 a).

Forest types and their distribution in Thailand are primarily influenced by climatic, geographic and topographic factors. Under these three factors, soil types play an important role in local variations. Altitude can roughly indicate climate and some other factors of the habitats; thus the vegetative cover types show some correlation with elevation (Smitinand 1977 a,b, Kutintara 1993 a). In general, plant communities in Thailand can be broadly classified by their physiognomic function of the dominant life forms into two main groups; the evergreen forests and, the deciduous forests. Each group can be further classified based on species composition especially in the canopy layer into various forest types (associations) as shown in Table 1 (Kutintara 1993 a).

The evergreen forests are found in the areas of high rainfall in the true tropical climate; thus their main distribution area is in the southern and southeastern provinces with some spots of high moisture in the north and northeastern regions especially at high elevation. The deciduous types occur in relatively low annual rainfall (lower than 1,600 mm per year) with a long dry season (Smitinand 1977a).

There are in addition, other communities that are rare and cover small areas of special condition and not normally categorized separately, such as cliff community, limestone forest, riverine forest and subalpine forest (Santisuk 1985, Kutintara 1993a).

## **DECIDUOUS FORESTS AND THEIR SUBDIVISION**

### **General Characteristics of the Communities**

The tropical deciduous biome is characterized by all trees and shrubs which shed their leaves during the dry season. Naturally, it is associated with the subtropical climate or monsoonal climate which has a long dry season alternating with the rainy season. This biome is in between the tropical moist evergreen forest (tropical rain forest) and the warm temperate biome. As mentioned in table 1, Thailand has 4 sub-community types

**Table 1 : The vegetative cover types (forest types) in Thailand (adopted from Kutintara 1993a and Smitinand 1977a)**

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**I. EVERGREEN FOREST**

- ◆ Mangrove Forests
- ◆ Swamp Forests
  - Fresh water swamp forest
  - Peat swamp forest
- ◆ Beach Forest
- ◆ Tropical Moist Evergreen Forests
  - Lower tropical moist evergreen forest
  - Upper tropical moist evergreen forest
- ◆ Dry Evergreen Forest (or Semi-Evergreen forest)
- ◆ Pine forests
  - Pine - oak forest
  - Pine - dipterocarp forest
- ◆ Montane Forests
  - Lower montane forest
  - Upper montane forest (or moss forest)

**II. DECIDUOUS FORESTS**

- ◆ Mixed Deciduous forests
    - Moist upper mixed deciduous forest
    - Dry upper mixed deciduous forest
    - Lower mixed deciduous forest
  - ◆ Deciduous Dipterocarp Forest
  - ◆ Savanna
  - ◆ Tropical grassland
-



(associations) in this category: the mixed deciduous, the deciduous dipterocarp, the savanna and the tropical grassland. According to Tho (1991), some sub-associations under this group should be categorized under the tropical moist forest, while the others should be classified as the tropical dry forest (Shepherd *et al.* 1991). Nearly all plant species existing in these communities show some ecological characteristics to survive and maintain the species in dry habitat and under forest fire problems. Although most of the deciduous communities shed all their leaves during the dry period, some transitional sub-associations have a number of evergreen trees, and some may have new leaves as soon as possible without depending on the first rain of the wet season.

Deciduous forests are sometimes called monsoon forests because they are influenced by the shift of prevailing monsoon winds which control the periodic entry of dry and rainy seasons. According to the distinct seasonal changes in their phenological characteristics, they are also called "seasonal forest".

### **Distribution of the Deciduous Forest**

In Thailand, the deciduous forests are found as far south as Prachaubkirikan, the southern province of the middle region. They occur up north to Chiang Rai, the northernmost province of the country. They cover nearly all the middle and lower elevations in the northeastern region except very high mountains and the very moist riverine area. Since they occur on a wide range of environmental factors, their structure and species composition varies considerably according to local climate, soil type and topography.

### **Sub - Communities and Associations**

Based on dominant life forms and dominant groups of tree species, the deciduous forests can be broadly classified into 4 associations as mentioned above. The mixed deciduous and the deciduous dipterocarp forests are similar in life-form composition, but they are separated by a dominant taxonomic group where the deciduous dipterocarp is dominated by deciduous dipterocarp species, while the mixed deciduous is predominated by teak or other species. The savanna is characterized by intermixing of trees or shrubs with grass life forms in equal proportion of crown cover, while the tropical grassland must have grass and herb covering more than 70 percent.

Smitinand (1977a) sub-divided the mixed deciduous forest association into three sub-types: the moist upper mixed deciduous forest, the dry upper mixed deciduous forest, and the lower mixed deciduous forest. Although, the names of the sub-types reflect the moisture gradient, they also reflect the species composition. The other system of sub-division at this level is recommended by Kutintara (1975) which is based on species composition especially the dominant plants at the top and the middle layers. The mixed deciduous forest is sub-divided into four sub-associations: the mixed deciduous with teak and bamboos, the mixed deciduous with teak without bamboos, the mixed deciduous



without teak with bamboos, and the mixed deciduous without teak and bamboos. Some sub-associations can be further sub-divided into tall or scrub community.

The deciduous dipterocarp forest association is characterized by the presentation of deciduous dipterocarp species in at least two of the indicator plants which are composed of *Dipterocarpus tuberculatus*, *D. obtusifolius*, *D. intricatus*, *Shorea siamensis* and *S. obtusa*. This association is usually identified as savanna forest by Ogawa *et al.* (1961) following the original sense of Schimper because its general appearance is of open nature with prevailing grass undergrowth. However, due to its continuous crown and large size trees in the top layer of many sub-associations, Thai foresters usually identify it as one of the high forests as well. Ogawa *et al.* (1961) divided this forest type into three sub-types (sub-associations) *Shorea* - *Pentacme* forest, *Dipterocarpus tuberculatus* - *D. obtusifolius* forest and mixed dry dipterocarp forest. Later on, Cooling (1968) added one more sub type, the Pine - Dipterocarp forest into this classification level. Each sub-association may be characterized into tall and scrub types.

The savanna of Thailand has not been subdivided by any ecologists, but based on general appearance, it can be broadly classified into two sub-associations: the mixed savanna and the deciduous dipterocarp savanna. The first sub-association is common in very dry sites especially on problem soils such as those having clay pan or high concentration of some elements, while the second sub-association usually occurs on shallow sandy or rocky soil in very dry sites of the deciduous dipterocarp range.

The tropical grassland has not yet been intensively studied but for preliminary observation, three dominant sub-types should be mentioned: the *Imperata cylindrica* sub-association which is dominated by *Imperata* grass with few other species, the mixed grasses sub-association which has various grasses, herbs and ferns intermixed in some ratio, and ferns sub-association which occurs mostly on high mountains at some altitudinal elevations. According to this classification system, all sub-association types can be further sub-divided into tall or scrub communities.

## **HABITAT TYPE OF DECIDUOUS FORESTS**

### **Mixed Deciduous Forest**

Generally, the mixed deciduous forest is found throughout the range of deciduous forest of the country from northern Prachuab Kirikhan province to the northern border and in the northeastern part of the country alternating with other forests. However, the sub-associations with teak confine only in the northern region from Nakhon Sawan upto Chiang Rai provinces, while the other two sub-associations dominate in northeastern and central regions; they are also found in some areas in the teak zone.

**Table 2 : The proposed classification of the deciduous forest in Thailand**

- 
- 1. Mixed Deciduous Forest Association
    - Sub - associations
      - 1. Mixed deciduous forest with teak and bamboos
      - 2. Mixed deciduous forest with teak without bamboos
      - 3. Mixed deciduous forest without teak and bamboos
      - 4. Mixed deciduous forest without teak with bamboos
  
  - 11 Deciduous Dipterocarp Forest Association
    - Sub - associations
      - 1. *Shorea siamensis* - *S. obtusa* forest
      - 2. *Dipterocarpus obtusifolius* - *D. tuberculatus* forest
      - 3. Mixed deciduous dipterocarp forest
      - 4. Pine - Dipterocarp forest
  
  - 111 Savanna
    - Sub - associations
      - 1. Deciduous dipterocarp savanna
      - 2. Mixed deciduous savanna
  
  - IV Tropical Grassland
    - Sub-associations
      - 1. *Imperata cylindrica* grassland
      - 2. Mixed grassland
      - 3. Fernland
- 

The mixed deciduous forest with teak and bamboos usually covers well watered areas at an elevation range of 300-800 metres, loamy soils either calcareous or granitic. In some areas, teak may be absent, and then, other common associated species become predominant in the community which is classified as the sub-association without teak. This sub type is very common on steep slopes, shallow soil and relatively dry sites which Smitinand (1977a) classified as the dry upper mixed deciduous forest. In general, the good teak forests usually have bamboos as the dominant species in the middle layer and they attain large dimensions in good quality sites. However, in many places the bamboos are absent especially in rather dry sites and at high elevation. Thus, the mixed deciduous without teak and bamboos sub-association in teak range is usually a scrub community.

Outside the teak zone is the area of the mixed deciduous without teak sub-associations, but they will have bamboos or not depending on many factors. In general, the mixed deciduous forest without teak with bamboos sub-association is more common in the western part of the country while the non bamboos sub-association is more common in the northeastern part.

### **Deciduous Dipterocarp Forest**

This association occurs only in Southeast Asian countries including Cambodia, Lao PDR, Thailand and Myanmar. The forest type can be found in association with the mixed deciduous forest which occurs at elevations between 100 to 1,000 metres above mean sea level. Its distribution ranges from Petchaburi province and west along the Thanon Thong Chai mountain range to Chiang Rai and also in the northeast on the Korat Plateau.

The *Shorea siamensis* - *S. obtusa* sub-association occurs in the most xeric habitat which is widespread on hillside slopes and usually where the ground is covered with rocks mainly of sandstones or granite-gneiss or basalt. Soils are mainly gravelly, sandy or lateritic.

*Dipterocarpus obtusifolius* - *D. tuberculatus* sub-association covers gently undulating ground at lower altitudes. The scrub type commonly occurs on rocky ridges which have high soil moisture but strong wind. Within this habitat, the top canopy is usually lower than 10 metres. At lower altitudes, especially on flat land of deeper sandy soils relatively free of rock and lateritic nodules, the stands may reach 35 metres high and the two dipterocarp species may equally mix or form nearly pure stand of one species.

The mixed deciduous dipterocarp sub-association is found where climatic or edaphic conditions are more mesic. Soils are commonly sandy clay loam but sometimes it is found in depressions and over eastern slopes (Ogawa *et al.* 1961). The scrub type occurs in poor condition for plant growth while the tall community is common on well drained deep soil.

The Pine-Dipterocarp sub-association occupies ridges at high elevations, especially more common at an altitude over 700 metres. It occurs extensively at elevation range of 800-1,100 metres which seems to be the upper limit of the deciduous dipterocarp range in Thailand (Cooling 1968, Kutintara 1975).

### **Savanna Forest**

Actually, this vegetation type should not occur naturally in a monsoonal climate but it does occur where the soil is very dry or has problems. It also exists in rain shadow with an annual rainfall of less than 800 mm. per year. Sometimes it exists as a result of

degradation of other forest types due to human activities and so is widely distributed in the country especially in the northeast and north of Thailand. Forest fire is a limiting factor of the type.

The dipterocarp savanna sub-association occurs on very dry sites of the deciduous dipterocarp association, on lateritic or sandy shallow soils. Fuelwood logging in the deciduous dipterocarp forest is the main cause of the expansion of this sub-association.

The mixed deciduous savanna sub-association is associated with the post dry sites or the problem soils in the mixed deciduous forest. This sub-association is also found on high altitude over the deciduous dipterocarp range where the soils are very shallow and have a high percentage of rock on the surface. Its distribution ranges are confined to the western part of the country from Kanchanaburi upto Mae Hongson provinces and many areas in the northeastern region.

## FOREST STRUCTURE AND SPECIES DIVERSITY

Naturally, the complexity of forest structure and species diversity of the vegetative cover types in Thailand tend to follow soil moisture gradients during the dry season, except for the wetland forests such as mangrove and peat swamp forests.

Thus, the deciduous forests have a less complex and lower number of species and density than that of the evergreen types. However, they are more complex and luxuriant species than those of the temperate and cold zone vegetation types.

### Mixed Deciduous Forest

In general, the tall mixed deciduous forests both with and without teak and both with and without bamboos have three vertical layers. The top canopy is about 20-35 metres high with teak as the leading dominant species in teak bearing zones. Undisturbed stands usually have continuous crown cover with some other associated species, especially, *Terminalia alata*, *T. tripteroides*, *T. bellerica*, *Lagerstroemia tomentosa*, *Azelia xylocarpa*, *Xylia xylocarpa* var. *kerrii*, *Pterocarpus macrocarpus*, *Dalbergia cultrata*, *D. oliveri*, *Haldina cordifolia*, *Gmelina arborea*, *Anogeissus acuminata*, *Millettia leucantha*, *Albizzia lebeck*, *A. procera*, *Acacia leucophloea*, *Adenathera pavonina*, *Dillenia pentagyna* and some others.

The middle canopy comprises medium size trees, 7-20 metres high which include *Terminalia calamansanai*, *Combretum quadrangulare*, *Careya arborea*, *Millettia brandisiana*, *Albizzia lucida*, *Dalbergia ovata*, *D. nigrescens*, *Pelthophorum dasyrachis*, *Homalia tomentosa*, *Lagerstroemia floribunda*, *L. speciosa*, *L. vilosa*, *L. macrocarpa*, *Casearia grewiaefolia*, *Diospyros mollis*, *D. montana*, *Eugenia cumini*, *Vitex peduncularis*, *V. canescens*, *V. pinnata* and *Dillenia aurea*. Many small trees are

commonly found at the lower part of this layer such as *Croton hutchinsonianus*, *C. oblongifolius*, *Cratoxylum formosum*, *Mallotus philippensis*, *Gardenia coronaria* and *G. obtusifolia*. Only a few palms occur in this forest type such as *Cycas pectinata* and *Calamus viminalis*. There are many shrubs of large and small sizes in this association which include *Bauhinia racemosa*, *Harrisonia perforata*, *Randia tomentosa*, *Croton* spp., *Mallotus* spp., *Premna* spp and *Aporosa* spp. (Smitinand 1977a)

At the middle layer under the teak and non-teak bearing areas, bamboos are quite common in many habitat types which form the sub-associations with and without bamboos. The species include *Dendrocalamus membranaceus*, *D. strictus*, *D. longispathus*, *Bambusa tulda*, *B. natanis*, *B. arundinacea*, *Gigantochloa albociliata*, *G. nigrociliata*, *G. hasskaliana*, *Thyrsostachys siamensis* and *Cephalostachyum pergracile*. In good sites, they can reach a large height of 20 metres and grow in dense stand. The mixed deciduous forest without teak but bamboos sub-association is very common in the western forest of the country ranging from Tak to Petchaburi provinces (Kutintara 1993a) while the mixed deciduous forest with teak and bamboos sub-association is found in the northern part.

Many kinds of climbers are commonly seen in this forest type and many of them climb up high to the top canopy for light. The common species include *Hymenopyramis brachiata*, *Artabotrys siamensis*, *Butea superba*, *Desmos chinensis*, *Dalbergia volubilis* and *Bauhinia bracteata*. The undergrowths vary depending on intensity of light penetration through the top and middle canopies. Under very dense crown cover, the forest floor has less undergrowths, while in forest gaps with high light intensity, grasses, herbs and small pioneer seedlings are commonly dominated over the natural undergrowth species of the type. Most of them belong to the genera *Themeda*, *Andropogon*, *Saccharum*, *Eragrostis*, *Oryza*, *Reynaudia*, *Carax*, *Hyparrhenia*, *Cyperus* and many genera in the *Zingiberaceae* family especially *Kaempferia*, *Curcuma*, *Achasma*, *Amomum* and *Ctenolophon* intermixing with *Hibiscus* spp., *Habenaria* spp., *Ceropegia* spp. and *Lygodium* spp.

Orchids are abundant in this forest type, including the genera *Dendrobium*, *Rhynchostylis*, *Aerides*, *Ascocentrum*, *Vanda*, *Bulbophyllum*, *Cymbidium*, *Coelogyne* and *Sarcanthus*. Epiphytes include genera such as *Hoya*, *Dischidia* and *Drynaria*. There are many species of ground orchids on the forest floor in which the most common one is *Peristylus goodyeroides*.

The mixed deciduous forest scrub type is rather open community and usually has no teak in its composition. The stands usually have only two layers with the top canopy about 15 metres high. Trees are rather stunted, deformed and twisted due to poor soil condition and high wind velocity on ridges. The dominant species resemble the mixed deciduous forest without teak sub-association, but the common leading dominants are *Terminalia alata*, *T. tripteroides*, *Xylia xylocarpa* var. *kerrii*, and *Vitex* spp. while *Croton* spp., *Gardenia obtusifolia*, *Randia tomentosa* and many other small xeric trees and shrubs

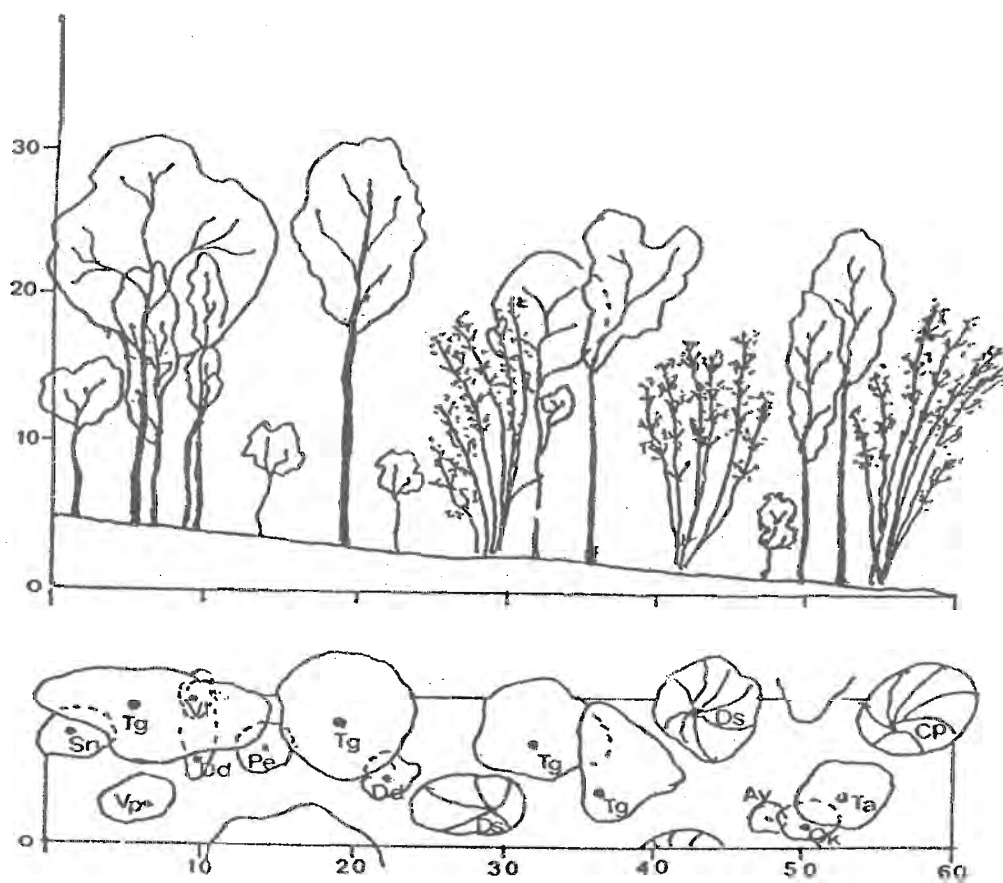


provide a continuous crown from the top to the undergrowth layers. In many places a bamboo, *Thyrsostachys siamensis* occurs with high density to form the mixed deciduous forest without teak with bamboo sub-association scrub community. Grasses and herbs are very common on the forest floor, but most of them have a growing period before flushing of the top canopy. Orchids and epiphytic plants are usually confined only on high branches to keep away from annual forest fire. According to the dryness of the site, some deciduous dipterocarp species may invade, especially *Shorea siamensis* or *S. obtusa*. The common leading dominant of the mixed deciduous forest without teak both with and without bamboos sub-associations species are : *Xylia xylocarpa* var. *kerrii*, *Lagerstroemia venusta*, *Terminalia alata*, *T. bellerrica* and *Pterocarpus macrocarpus*.

The example stand of the mixed deciduous forest with teak and bamboos sub-association as described by Forest Research Centre (1991) in Saiwin Wildlife Sanctuary, northern Thailand consists of teak and *Xylia xylocarpa* var. *kerrii* intermixed with *Terminalia bellerica*, *T. alata*, *Quercus kerrii*, *Bombax insularis*, *Pterocarpus macrocarpus*, *Gmelina arborea*, *Anogeissus acuminata*, *Albizzia lebbeck*, *Acacia leucophloea* and *Haldina cordifolia*. The second canopy includes *Dalbergia cultrata*, *D. oliveri*, *D. ovata*, *Mitragyna brunonis*, *Vitex peduncularis*, *V. pinnata*, *Dillenia aurea*, *Terminalia chebula*, *Spondias pinnata*, *Morinda coreia*, *Bridelia retusa*, *Lagerstroemia macrocarpa*, *Croton oblongifolius*, *Cratoxylum formosum*, *Mallotus philippensis* and *Gardenia coronaria*. The shrub species of lower than 5 metres high are *Strychnos nux-vomica*, *Phoenix humilis*, *P. acualis* and *Vaccinium sprengelii*. The common climbers are *Bauhinia glauca* and *Butea superba*.

The common bamboos in this sub-association are *Dendrocalamus strictus*, *D. membranaceus*, *Bambusa natans*, *B. tulda*, *B. arundinacea*, *Thyrsostachys siamensis*, *Gigantochloa albociliata*, *G. nigrociliata* and *Cephalostachyum pergracile*. The mixed deciduous forest with teak and bamboos sub-association usually has few ground cover due to the low light intensity.

The quantitative data from this study reflected that the density of trees over 10 centimetres diameter at breast height is 130-240 stems with basal area cover of 22-24 square metres and the number of bamboo culm is 135-800 culms per hectare. The profile diagram of this sub-association is shown in fig. 1



**Figure 1 :** Profile diagram of the mixed deciduous forest with teak and bamboos sub-association in the Salwin Wildlife Sanctuary; Tg = *Tectona grandis*, Qk = *Quercus kerrii*, Vp = *Vitex pinnta*, VI = *V. limonifolia* Ta = *Terminalia alata*, Pe = *Phyllanthus emblica*, Dd = *Dalbergia dongnaiensis*, Sn = *Strychnos nux-vomica*, Ds = *Dendrocalamus strictus*, and Cp = *Cephalostachyum pergracile* (from Forest Research Center 1991).

The mixed deciduous forest without teak with bamboos sub-association as mentioned by Forest Research Centre (1991) has *Xylia xylocarpa* var. *kerrii*, *Pterocarpus macrocarpus*, *Terminalia bellerica* as the leading dominant species but the other layers are similar to those in the previous sub-association. However, the basal area cover of trees is only 14 square metres per hectare, but the bamboos density is as high as 1,440 culms per hectare. Nakhasathien & Stewart-Cox (1990) described this forest type in Thung Yai-Huai Kha Khaeng wildlife sanctuaries as the commonest forest type of the area which is dominated by *Lagerstroemia calyculata* but *Xylia xylocarpa* var. *kerrii* also occurs in rather pure stands in many places. This forest type is structurally quite varied, with many tall trees growing in the moisture areas but shorter ones on drier ridges and slopes. Bamboos occur quite commonly among the middle storey species but they are absent in many places forming the mixed deciduous forest without teak and bamboos. The undergrowth of this forest type is often dense. Ground flora consists of grasses, herbs, shrubs, climbers and seedlings and a rich variety of geophytes.

### Deciduous Dipterocarp Forest

In a good site, the deciduous dipterocarp forest has its structure quite similar to that of the mixed deciduous forest with teak sub-association, but the bamboos are rarely seen. It also has three vertical layers with the top canopy 20-30 metres high comprising mainly of characteristic species of the type: *Dipterocarpus tuberculatus*, *D. obtusifolius*, *Shorea siamensis* and *S. obtusa* while *Dipterocarpus intricatus* is found only in limited areas in the northeastern part of the country. In good stands, the upper canopy of this community is composed of the two dipterocarpus species as the leading dominants intermixing with *Quercus kerrii* and *Lithocarpus dealbatus*. The other trees at this layer are: *Pterocarpus macrocarpus*, *Xylia xylocarpa* var. *kerrii*, *Schleichera oleosa*, *Canarium subulatum*, *Albizia procera*, *Eugenia* spp., *Mangifera* spp., *Terminalia alata*, *Lagerstroemia calyculata* and *Dalbergia cultrata*.

At the middle layer, trees are of medium size intermixing with tall shrubs such as *Diospyros ehretioides*, *Phyllanthus emblica*, *Morinda elliptica*, *M. coreia*, *Cratoxylum formosum*, *Melanorrhoea usitata*, *Millettia brandisiana*, *Terminalia chebula*, *Buchanania latifolia*, *Mitragyna brunonis* and *Careya arborea*. The shrubs species less than 7 metres high are : *Strychnos nux-vomica*, *S. nux-blanda*, *Dalbergia kerzii*, *Symplocos racemosa*, *Aporosa villosa* and some species which are found in the mixed deciduous forest.

The lower canopy has fire resistant plants which reproduce tuber, budding, roots and seedling such as *Arundinaria pusilla*, *A. ciliata*, *Linostoma persimile*, *Enkleia siamensis*, *Pygmaeopremna herbacea*, *Dillenia hookeri*, *Kaempferia marginata*, *K. pulchra*, *K. roscoeana*, *K. rotunda*, *Habenaria dentata*, *Decaschistia harmandii*, *Pecteilis susannae* and many varieties of *Curcuma* spp., *Hibiscus* spp. *Cyperus* spp., *Eriocaulon* spp., *Fimbristylis* spp., *Scleria* spp., *Spathoglottis* spp. and *Utricularia* spp. Two species of palms, *Phoenix acaulis* and *Cycas siamensis* are associated with grasses and herbs in many areas.



Orchids and epiphytes are similar to those which are found in mixed deciduous forest. Most of them flower in the dry season.

The *Shorea siamensis* - *S. obtusa* sub-association usually occurs on rather dry sites and has many thorny shrubs such as *Zizyphus cambodiana*, *Z. oenoplia*, *Randia oocarpa*, *R. tomentosa*, and *Cratoxylum* spp. The top canopy is about 25 metres high in good sites but only 12 metres in poor sites which is classified as the scrub type and has only two layers (tree layer and grass layer).

The *Dipterocarpus obtusifolius* - *D. tuberculatus* sub-association usually occurs in plain areas of good soils. The top canopy is usually higher than the previous sub-association and has a high number of species and of stems. In very good sites, the two dipterocarp species may reach 35 metres high and form a continuous crown cover. The second layer is dominated by *Shorea obtusa* intermixing with other species.

The mixed deciduous dipterocarp sub-association structure is composed of more than two of the characteristic species which are well mixed. In very good sites, the forest also has three vertical layers with the top canopy about 25 metres high or more, while in poor sites, it can reach only 15 metres or less with crooked trees. The forest floor is dense with grasses and herbs in the rainy season. In fact, this community is the transition between the deciduous dipterocarp forest and the deciduous dipterocarp savanna sub-association.

Nakhasathien & Stewart - Cox (1990) mentioned that the *Shorea siamensis* - *S. obtusa* and the *Dipterocarpus tuberculatus* - *D. obtusifolius* sub-associations are also found in the Thung Yai Narasuan and Huai Kha wildlife sanctuaries. In some places, *D. tuberculatus* forms nearly a pure top canopy while in others, bamboos join the middle-storey species in which such sub-association is uncommon in other parts of the country. On the high mountain ridges in the north and eastern parts of the Thung Yai Narasuan wildlife sanctuary, there is a dwarf deciduous dipterocarp forest on granite intrusion where bedrock is often visible and the soils look crumbly and shallow. This association is recognized as the deciduous dipterocarp scrub type. (Kutintara & Bhumpakphun 1988).

At Sakaerat, Nakhon Ratchasima province, the *Shorea siamensis* - *S. obtusa* sub-association has 18 tree species, 12 shrub species, 4 climber species, 6 herbaceous species and a number of grass species in the sample area of 245 m<sup>2</sup>. (Ogawa *et al.* 1961).

According to the research team from the Faculty of Forestry in their annual reports in 1976 and 1977 on Quantitative Studies of the Seasonal Tropical Forest Vegetation in Thailand, from 51 sample stands with 10x400 m. sample plot size in deciduous dipterocarp forests in northern and northeastern Thailand, there were 79 species identified, 24 identified by genera and 22 trees yet left unidentified. These figures are for trees having diameter from 5 cm. and over at breast height. In pine-deciduous dipterocarp sub-association, the data from 8 stands reflected that there occurred 20

identified species and 2 identified by genera. The profile diagrams of the two sub-associations are shown in figures 2 and 3.

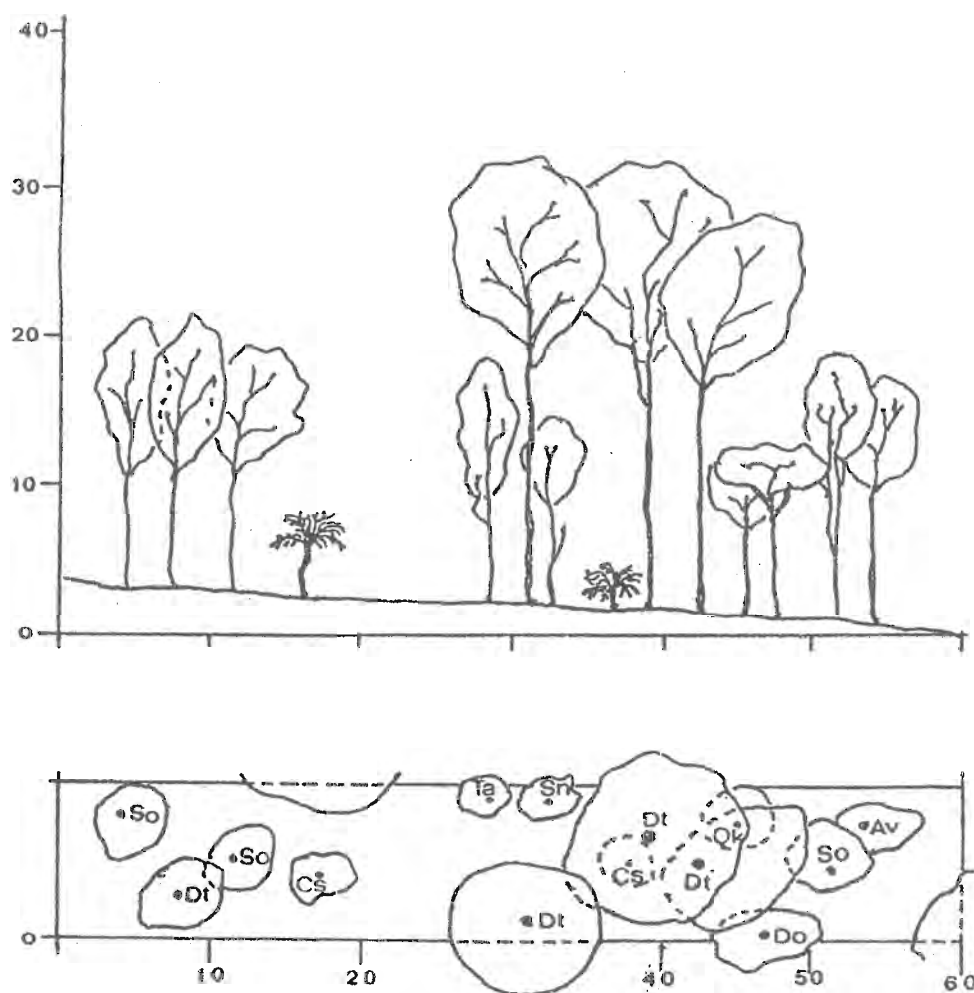


Figure 2 : Profile diagram of the mixed deciduous dipterocarp sub-association in Salwin Wildlife Sanctuary; Dt = *Dipterocarpus tuberculatus*, Do = *Dillenia obovata*, Cs = *Cycas siamensis*, Qk = *Quercus kerrii*, Av = *Aporosa vilosa*, So = *Shorea obtusa*, Sn = *Strychnos nux-vomica* and Ta = *Terminalia alata* (from Forest Research Center 1991).

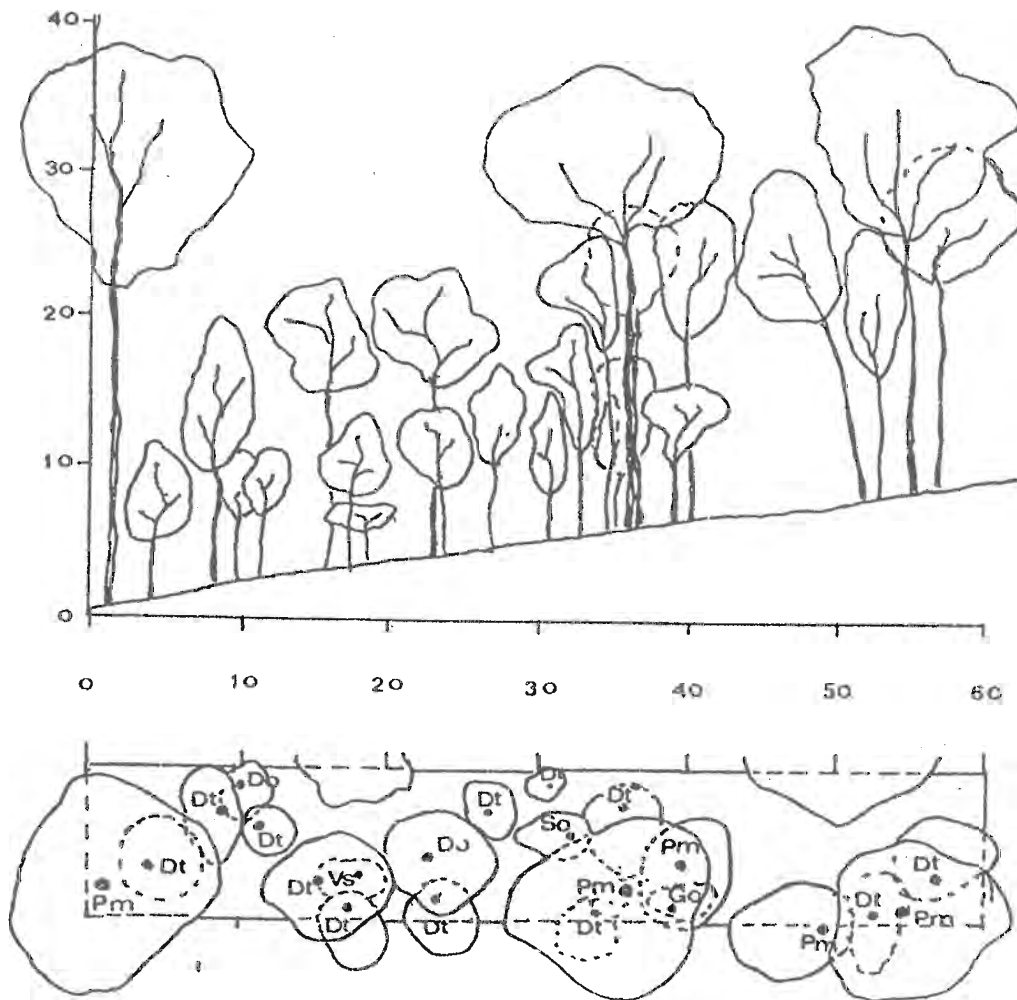


Figure 3 : Profile diagram of the pine-dipterocarp forest sub-association in Salwin Wildlife Sanctuary; Pm = *Pinus merkusii*, Dt = *Dipterocarpus tuberculatus*, Do = *Dillenia obovata*, So = *Shorea obtusa*, Go = *Gardenia obovata* and Vs = *Vaccinium sprengelii* (from Forest Research Center 1991).

## Savanna

This association comprises trees with shrubs and grasses. Many kinds of plants in the savanna resemble those in the mixed deciduous and deciduous dipterocarp forests especially the high fire tolerant species. Bamboos are uncommon due to shallow soil and very low moisture.

In the deciduous dipterocarp savanna, the dominant trees and shrubs are *Shorea siamensis*, *S. obtusa*, *Dipterocarpus obtusifolius* intermixing with *Lithocarpus dealbatus*, *Quercus kerrii*, *Aporosa villosa*, *Acacia tomentosa*, *Mitragyna brunonis*, *Careya sphaerica*, *Antidesma montana* and *Ochna wallichii*. Naturally, the trees and the shrubs are about 7 metres high with wide crown and flat top.

Grass layer is composed of various species, but in many places, *Imperata cylindrica* is the dominant species and the associated other grasses are *Vetiveria zizanioides*, *Panicum notatum*, *P. repens*, *Themeda triandra*, *T. australis*, *Sorghum prorepens*, *Eriochloa procera* and *Eremochloa bimaculata*, while *Curcuma sparganifolia*, *Kaempferia marginata* and *Aeginetia* spp. are the common herbs.

The mixed deciduous savanna sub-association is similar to the deciduous dipterocarp savanna, but it has no deciduous dipterocarp species in the tree and shrub layer. Dominant tree species are *Lagerstroemia macrocarpa*, *Stereospermum neuranthum*, *Terminalia chebula*, *Dalbergia cultrata*, *D. dongnaiensis*, *Quercus kerrii*, *Zyzyphus* spp., *Engelhardtia spicata*, *Careya sphaerica*, *Gardenia erythroclada* and *Urena lobata* (Kutintara & Bhumpakphun 1989). *Cycas pectinata* and *Phoenix acaulis* are commonly present.

Nakhasathien & Stewart - Cox (1990) reported that seventeen tree species are found in the savanna type of central Thung Yai Narasuan wildlife sanctuary; none are dipterocarp species and there is no bamboo. It is the mixed deciduous savanna type which has trees shorter than ten metres and does not form crown canopy. The ground cover is similar to that of the mixed deciduous forest, except that clusters of bright pink *Curcuma aeruginosa* commonly appear soon after the annual forest fire.

The quantitative data of the savanna community in Thung Yai Narasuan Wildlife Sanctuary, the Natural World Heritage in Thailand showed that the mixed deciduous savanna had 12 tree species with 118 stems in a sample plot of 40000 square metres, 14 species of saplings (with 7 new species) and 64 stems in a 320 square metres sample area, while seedlings of one year upto 1.30 metres high are composed of 9 species but one is a newcomer with 139 stems per 20 square metres.

## Tropical Grassland

This community has a structure similar to that of the savanna except that it has fewer trees and shrubs. The natural grassland is very rare, but the area increased rapidly during the last few years due to shifting cultivation, and they are maintained by annual forest fire.

The *Imperata cylindrica* sub-association usually originated from human activities such as shifting cultivation, mining, and deforestation and other forms. Patthanakait (1987) confirmed that the *Imperata* grass is the dominant sub-association in the grassland area of Khao Yai National Park, northeast of Thailand. This grass is intermixing with many other grasses, herbs and ferns, forming various sub-types ranging from nearly pure *Imperata* grass community to nearly completely dominated by other species. The common associated species include *Pteridium aquilinum*, *Borreria laevis*, *Fimbristylis dichotoma*, *Eupatorium odoratum*, *Cyperus alternifolius*, *Crassocephalum crepidioides*, *Saccharum fuscum*, *S. spontaneum*, *Themeda arundinacea*, *Hedyotis capitellata*, *H. corymbosa*, *Desmodium heterocarpon*, *Eriocaulon henryanum*, *Panicum repens*, *Brachiaria mutica* and *Paspalum scrobiculatum*. The common shrubs and small trees are *Cratocylum formosum*, *Holarrhena antidysenterica*, *Osbeckia watanae* and *Melastoma normale*.

The mixed grassland sub-association usually occurs on problem soils such as saline soil, clay hardpan soils or water interlocked soils. In such habitats, *Imperata cylindrica* cannot survive, which allows other species becoming dominant species in the area.

In Thung Yai Narasuan Wildlife Sanctuary, pockets of grassland occur in every elevation; most are no bigger than 0.5 km<sup>2</sup>, but two big fields are recognized (Nakhasathien & Stewart - Cox 1990). The Thung Yai from which the sanctuary gets its name covers about 140 km<sup>2</sup> at the centre of the sanctuary and it is separated into several fields of 5-15 km<sup>2</sup>. This grassland is surrounded by 99 km<sup>2</sup> of savanna sub-associations. Another area of about 10 km<sup>2</sup> occurs in the north of the sanctuary on level land beneath the central ridges of the mountain chain dividing this sanctuary from the Huai Kha Kheang wildlife sanctuary, but nothing is known of its structure and species composition.

## ECOLOGICAL CHARACTERISTICS

### Annual Phenological Cycle

Presently, only a few researchers have undertaken studies on the phenological cycle of the deciduous forests in Thailand. Trees in these forest types begin to shed their leaves in late October as the cool air masses from north-east direction hit the area. The complete defoliation occurs in late February or early March depending on location and variation of

the climate of each year. Annual forest fire usually consumes all leaves and debris on the forest floor by late March providing open ground for seeds. Leaf shedding is generally assumed to be caused by the cool air of the early northeast monsoon wind. The forest becomes more colourful if the temperature abruptly changes and the cool weather is maintained for a number of days. However, close observation will reveal that relationships are somewhat more complicated. Leaf shedding of some species depends on soil moisture in which the same species may vary according to the degree of this factor. Thus, some species may shed or not shed their leaves depending on site and habitat.

Leafing of trees in the deciduous forests of Thailand has also not been studied. In general, leaves are produced as soon as the first rain of the wet season increases soil moisture. However, some thropophyllus species may produce leaves without depending on the soil moisture; they flush new leaves a few days after complete shedding. The species of this kind are: *Pterocarpus macrocarpus*, *Dalbergia oliveri*, *D. ovata* and *Anogeissus acuminata*. Most of the trees have full leaves by June in which soil moisture is high enough for plant growth.

Many species flower during the dry period after the fire season and fruits ripen at the end of the season. They drop their seeds in the early rainy season when the annual forest fire opens the forest floor to provide a good seedbed for seed germination and survival. Seed can hit the ground getting moisture and sending roots into the soil for protection from desiccation. Some species flower in the rainy season and drop their seeds before the fire season in order to use fire as a trigger for seed germination such as Teak, *Afzylia xylocarpa*, *Terminalia chebula* and *Pterocarpus macrocarpus*. Trees which shed their seeds before the onset of the annual forest fire usually produce thick-coated seeds.

During the rainy season, seedlings are found abundantly on the forest floor, but only a small percentage can survive the fire hazard of the succeeding year. The survivors usually form a strong underground portion for coppices in the rainy season. Some species need more than 15 years at burnback phenomena before sending strong shoots which can thrive and withstand the forest fire. The severity of the succeeding dry season also influences the survival of seedlings. The growing season starts from the beginning of the wet season in early April and ends in the cool season in November, but growing period of bamboos usually lasts longer until March (Kutintara *et al.* 1995).

### Ecological Adaptation

The important characteristic of trees and shrubs growing in the deciduous forest is the possession of ability to coppice, such as teak, *Shorea obtusa*, *S. siamensis*, *Dipterocarpus tuberculatus*, *D. intricatus*, *D. obtusifolius*, *Terminalia alata* etc. However, the trees with larger diameters do not possess this character. The species are very resistant to felling; they can regenerate themselves well by means of sprouts from stumps.

In response to forest fire, trees and shrubs in the deciduous forests adapt many characteristics such as producing leaves, a few days after completing defoliation such as *Pterocarpus macrocarpus* and *Dalbergia* spp. The undergrowth species form new leaves before the crown cover is fully - leaved. The deciduous forests are completely green by April.

Most species have flowers during the shedding period such as *Ochna wallichii*, *Shorea siamensis*, *S. obtusa* and *Vitex* spp. and fruits which are formed a few days after flowering. In general, they have a tendency for fruit ripening at the end of the dry season and dropping their seeds in the early rainy season. The seeds can touch the ground and germination occurs as soon as possible. Many species flower in the rainy season and drop their seeds in the early dry season before the annual forest fire.

Trees in the deciduous forests do not flower profusely every year. Good seed years occur at periodic intervals of 3-5 years. The heavy seed species such as teak, *Azizlia xylocarpa*, *Terminalia* spp and many others usually drop their seeds before the annual forest fires which induce seed germination. These heavy seeds usually have a longer germination period, while the dipterocarpaceae seeds have a very short life. They have to germinate within 2 weeks after ripening. They adjust their phenological cycle to harmonize with the fire season, possessing coppicing ability, having a thick bark for cambium protection and dropping their leaves to prevent crown fire. Many undergrowth species are hemicriptophytes, criptophyte and geophytes. They protect their dormant buds by keeping their rhizomes, bulbs, tubers and stolons under the ground to protect them from fire damages. Some species have a very short life cycle; they can complete germination, growth, flowering, seeding and death within a few weeks in the rainy season. The seeds are kept in the ground for the next growing season.

### **Biomass Production**

Biologically, the tropical forests are high productive ecosystems because of high energy flow and nutrient cycle. However, the standing crops of the open forest types are rather low. Ogawa *et al.* (1961) estimated the productivity of the deciduous dipterocarp forests of two communities; the dry weight of various categories was 44.7 ton/ha. for stems and branches, 4.9 ton/ha for leaves and 65.9 ton/ha for total (including undergrowth and root) for *Shorea siamensis* - *S. obtusa* sub-association type while it was 52.6, 4.9 and 77.0 ton/ha. respectively for the mixed deciduous dipterocarp forest stand.

Due to the lack of alometrical model for biomass estimation of trees in the mixed deciduous forest, there is no information of this kind in this forest type. However, Kutintara *et al.* (1995) estimated the biomass of bamboos in the mixed deciduous forest without teak with bamboos and the results were 14.57 ton/ha for annual culm, 18.82 ton/ha for mature culm, and 33.41 ton/ha for total living biomass with 3.72 ton/ha of standing death culm.



Patthanakait (1987) measured the dry weight biomass of the grassland in Khao Yai National Park in various sub-communities. The data are presented in Table 3.

**Table 3: Biomasses of various grassland community types in Khao Yai National Park**

| Community type                                                                       | Biomass<br>Dry weight g/m <sup>2</sup> |
|--------------------------------------------------------------------------------------|----------------------------------------|
| 1. <i>Imperata cylindrica</i>                                                        | 290.7                                  |
| 2. <i>Imperata cylindrica</i> - <i>Eupatorium odoratum</i>                           | 331.4                                  |
| 3. <i>Imperata cylindrica</i> - <i>Saccharum fuscum</i>                              | 338.7                                  |
| 4. <i>Imperata cylindrica</i> - <i>Hedyotis capilelata</i>                           | 318.1                                  |
| 5. <i>Imperata cylindrica</i> - <i>Eupatorium odoratum</i> - <i>Saccharum fuscum</i> | 321.7                                  |
| 6. <i>Imperata cylindrica</i> - <i>Eriocaulon henryanum</i>                          | 91.8                                   |
| 7. <i>Cratoxylum</i> - <i>Holarrhena</i> - Grasses (savanna type)                    | 341.2                                  |

### Succession

Nearly all associations of the deciduous vegetation types in Thailand are classified as the pyrix climax community in which fire is the limiting factor. If fire is protected for a period of years, they will proceed towards more mesic type especially to the dry evergreen forest. Preliminary observation at Sakaerat Environmental Research Station, Nakhon Rachasima province showed that *Arundinaria pusilla*, a common grass species in the community, had been replaced by seedling of species in the dry evergreen forest, and many big *Shorea obtusa* and *S. siamensis* were dying and replaced by *Crotocylun* spp. and many others which can occur in both forest types.

Marod (1995) made a study on secondary successional pattern in the mixed deciduous forest of Mae Klong Watershed Research Station, Changwat Kanchanaburi; his results revealed that it is composed of 8 pioneer communities or consociates, including *Trema orientalis*, *Eupatorium odoratum*, *Arundo donax*, *Gigantochloa hasskarliana*, *Musa acuminata*, *Sterculia macrophylla*, *Bauhinia viridescens* and climbers associates. The distribution of these pioneer plant communities relates to topography and soil moisture regime of the sites.

### CONSERVATION STATUS

The alarming loss of forest area including the deciduous forests during the last decade forced the Thai Government to stop all logging concessions within the country except the mangrove forest. However, the forest area, including the deciduous forests are still destroyed due to many causes which are mostly related to the population growth and socio-economic status of the people. The principal causes are shifting cultivation which



are commonly practised by local people and hill tribes, illegal logging, fuelwood collection, agricultural land expansion and development of basic infrastructure by government agencies.

Currently, Thailand tries to stop forest destruction and biodiversity loss, but the knowledge of her forests is not enough for protection planning. Only a few studies have been done at the community level especially the classification of forest types and basic ecological characteristics of the plant communities.

In fact, civilizations in the country had some relationships to the deciduous forests. Many signs and historical elements have been found in this vegetation type. The evidence indicated that man in Southeast Asian countries has lived and utilized the deciduous forest ecosystems for millenniums.

Many tree species in the deciduous forests are valuable for economic purposes. They have good quality for construction and various other uses such as teak, *Shorea obtusa*, *Azilia xylocarpa*, *Pterocarpus macrocarpus*, *Xylia xylocarpa* var. *kerrii*, *Dalbergia* spp. and *Diospyros* spp. In recent years, bamboos are more valuable, thus over harvesting of these species is considered as one of serious destruction of the deciduous forests of the country.

Presently, Thailand tries to conserve the deciduous forest areas by establishing wildlife sanctuaries, national parks, non hunting areas and first class watershed areas. There are 37 wildlife sanctuaries, 81 national parks and 40 non hunting areas within the country. They cover at least 14 percent of the total land area of the kingdom. All these protected areas in the central, north and northeast regions mainly comprise the mixed deciduous and deciduous dipterocarp forests. Especially, Hui Kha Kheang and Thung Yai Naresuan wildlife sanctuaries reserve nearly all sub-associations of this forest type. (Nakhasathien & Stewart-Cox 1990).

## CONCLUSION

Thailand has many environmental factors especially, climate, geography, topography, soil, and history of landform which favour her to have many plant communities. The vegetative covers are broadly classified into two main biomes: the evergreen forests and the deciduous forests. The evergreen forests have their main distribution range in the southern part of the country, but some associations are found in some special sites in the other regions. At least 6 associations or forest types have been recognized: mangrove forest, swamp forest, beach forest, tropical moist evergreen forest, dry evergreen forest and montane forest. The deciduous forest biome occurs from the lower part of the central region and extends to the north and northeastern regions. It has four main associations: mixed deciduous forest, deciduous dipterocarp forest, savanna and tropical grassland.

The deciduous biome is characterized by all trees and shrubs shedding their leaves during the dry season which is commonly associated with the subtropical or monsoonal climate. Based on dominant life forms and dominant taxonomic groups of tree species, the mixed deciduous forest is predominated by deciduous tree species over 10 metre high except the deciduous dipterocarp species, while the deciduous dipterocarp forest is dominated by the deciduous dipterocarp species which has *Dipterocarpus tuberculatus*, *D. obtusifolius*, *D. intricatus*, *Shorea siamensis* and *S. obtusa* and no bamboos. Both types usually form a rather continuous top canopy with small forest gaps. The savanna is characterized by intermixing of trees or shrubs with grass life-forms in equal proportion of crown cover, while the tropical grassland must have grass and herb life-forms covering more than 70 percent.

The mixed deciduous forest association is sub-divided into four sub-associations based on presence and absence of teak and bamboo, namely mixed deciduous forest with teak and bamboos, mixed deciduous forest with teak without bamboos, mixed deciduous forest without teak with bamboos and mixed deciduous without teak and bamboos.

The deciduous dipterocarp forest association is also broadly classified into four sub-associations based on the dominant species in the top canopy: *Shorea siamensis* - *S. obtusa*, *Dipterocarpus obtusifolius* - *D. tuberculatus*, sub-association, mixed deciduous dipterocarp, and pine-dipterocarp sub-associations.

The Savanna is classified into two sub-associations based on the trees and shrubs. The deciduous dipterocarp savanna has the deciduous dipterocarp species as the dominant trees in the structure and the mixed deciduous savanna has deciduous trees other than the dipterocarps in the composition.

The tropical grassland is divided into three sub-associations: the *Imperata cylindrica* grassland, the mixed grassland and the fernland.

Each sub-association of the deciduous forest occupies special habitat type, especially, depending on moisture gradient in soils during the dry season except that grassland usually occurs on problem soils such as saline soils, water interlocked soils or others. Altitude also plays an important role upon the distribution of this forest sub-association in Thailand. Teak forests have their limit at about 800 metres above mean sea level while the deciduous dipterocarp forest may climb up high as much as 1,000 metres elevation.

In general, the complexity of the forest structure and species composition of the vegetation types in Thailand tends to follow soil moisture gradient.

Thus, the complexity of the deciduous sub-associations also follow this rule. They range from the mixed deciduous forest as the highest diversity, followed by the deciduous dipterocarp type, the savanna and the tropical grassland respectively.

The mixed deciduous forest in good site usually has three vertical layers, the top canopy is about 20-35 metres high which has teak as the dominant species intermixing with other deciduous trees of nearly the same height such as *Terminalia alata*, *Xylia xylocarpa* var *kerrii*, *Pterocarpus macrocarpus* etc. The second layer is about 7-20 metres high, comprising medium size trees and shrubs such as *Combretum quadrangulare*, *Careya arborea*, *Millettia brandisiana*, *Dalbergia ovata* etc., while the undergrowth consists of small shrubs, seedlings and herbs with grasses in forest gaps. Non - teak sub-associations usually have the same vertical structure and species composition except teak. Bamboos are commonly found in some sub-associations and are the dominant species in the middle layer. In poor sites, they may form a scrub community which has the top canopy not over 15 metres high.

Naturally the structure of the deciduous dipterocarp forest resembles the mixed deciduous forest, but teak and bamboos are not present. In good sites, the top canopy is about 20-30 metres high, comprising the characteristic species of the association. *Quercus kerrii* and *Lithocarpus dealbatus* are also common. In very dry sites, it usually has two vertical layers in which the top canopy is less than 12 metres high. It is called the scrub community. The forest floor has more grasses than in the mixed deciduous forests.

The savanna comprises trees with shrubs and grasses at about the same ratio of crown cover. The trees and shrubs resemble those in the mixed deciduous forest or in the deciduous dipterocarp forest. Bamboos are uncommon. Generally, *Imperata cylindrica* is the dominant grass intermixing with other species such as *Vertiveria zizanioides*, *Panicum notatum*, *P. repens*, *Themeda triandra* and many others.

The tropical grassland has a structure quite similar to that of the savanna except that it has a fewer number of trees and shrubs. *Imperata cylindrica* is very common and forms one sub-association. It can be associated with many other grasses, herbs, ferns and even small shrubs. The mixed grass sub-association is usually composed of many species such as *Themeda arudinacea*, *Saccharum fuscum*, *Fimbristylis dichotoma* and many others.

Trees in the deciduous forests shed their leaves in late October and complete defoliation in March. Many species flower in the dry season in which the seeds ripen and drop at the early rainy season, while the other group produces flowers in the rainy season and drop their seeds before the annual fire season in order to use fire to induce their seed germination. Seedlings are abundant in the rainy season but most of them cannot succeed to the next growing season.

Plants in the deciduous forests adapt many characteristics to survive under fire and dryness pressure of the site. They adapt their phenological cycle to the climatic factors and forest fire. They have a good ability for coppicing, having thick bark for cambium protection and many species have a short life cycle to keep their seeds in the ground.

In general, the biomass production of the deciduous forest is low because of the short growing season. All of the mixed deciduous forests are maintained by fire. Protection of this limiting factor will lead to drastic change in their species composition. They will proceed to the more mesic community.

Many sub-associations of the deciduous vegetation type in Thailand are rated as the most valuable forest of the country, especially, the mixed deciduous and the deciduous dipterocarp tall communities. They have many economically valuable species in their composition such as teak, *Xylia xylocarpa* var. *kerrii*, *Afzylia xylocarpa*, *Pterocarpus macrocarpus*, *Shorea obtusa* and *Dalbergia* spp. The Thai Government promised to protect this forest biome of the country for the benefit of the people and the world both for destructive and non-destructive uses. Thus, many kinds of protected areas, such as national park, wildlife sanctuary, first class watershed area and non-hunting area have been established and cover a large percent of this forest biome.

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## FLORAL DIVERSITY OF KALATUWAWA - LABUGAMA FOREST RESERVE

*G.I. Seneviratne, K. Abeynayake and M.R.K. Lenagala*

### INTRODUCTION

At present the two reservoirs in Kalatuwawa and Labugama together with the Kelani River meet the water requirement of the capital city, Colombo. The Labugama reservoir was completed in 1886 and Kalatuwawa in 1960. There are about 32 main streams (Dola) and streamlets (Ela) feeding towards these reservoirs. The catchment area associated with the two reservoirs (5300 acres) was declared a protected government property in 1932 and after the drought period experienced, this was declared a reserve in 1992. The Kalatuwawa - Labugama reserve is located between the latitudes  $6^{\circ} 49'$  -  $6^{\circ} 54'$  north and longitudes  $80^{\circ} 10'$  -  $80^{\circ} 12'$  east and it is a tropical rain forest patch in Sri Lanka which has not been researched upon before. Its topography is hilly ranging between the elevations of 120 - 900 m. According to the land use and vegetation map produced by the Survey Department in 1960 the forest includes some natural forest patches as well as the recovering forest in the previous village settlements (see Fig. 1). At present a general taxonomic collection and sampling is being carried out to include all possible habitats and communities.

### OBJECTIVES

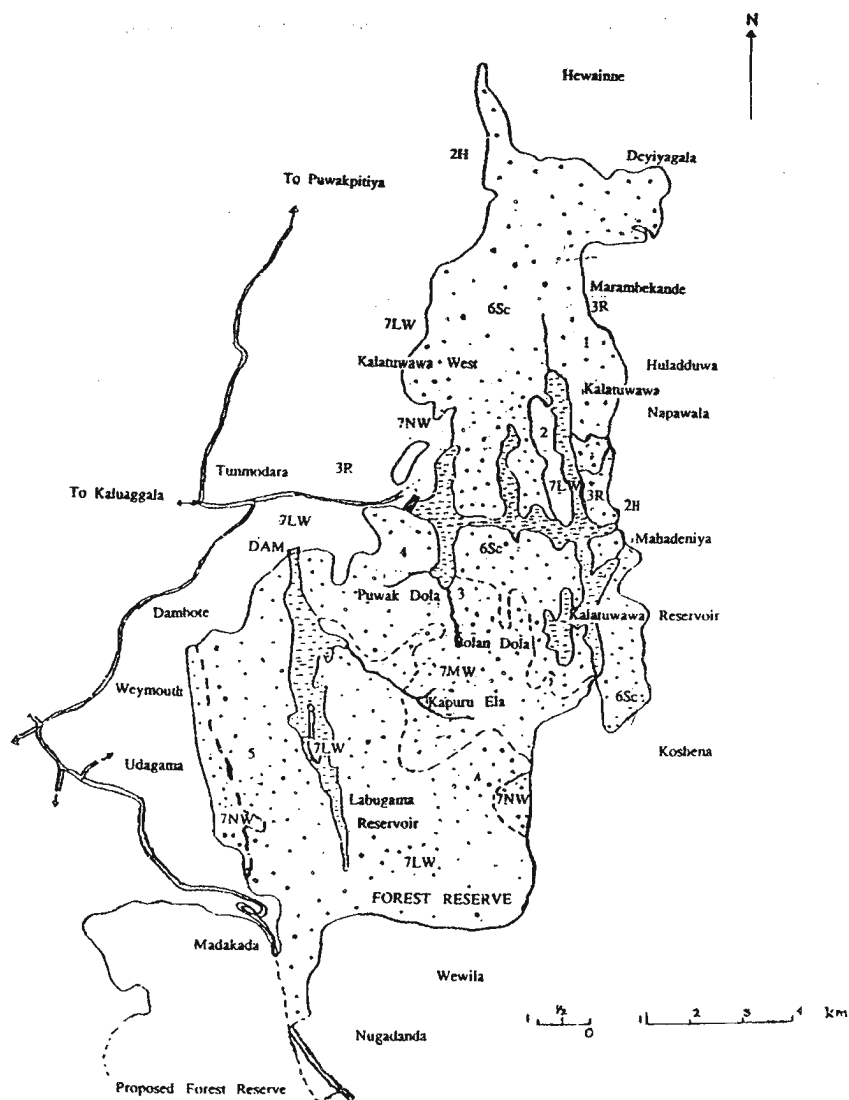
Results presented here are a part of a continuing project geared to find the species diversity, composition and vegetation structure of this forest and to study differences, if any, between original forest areas and regenerated forests in what were once village settlements.

### METHODOLOGY

Initially a general taxonomic collection was carried out along the main foot paths starting from the major dams and interior where access was possible. Later, permanent sample plots were demarcated to collect data for future analysis.

Aerial photographs were not released due to security reasons and therefore plots were demarcated using the land use and vegetation map produced in 1960, which showed the vegetation types present at that time. Upto now 34 permanent plots of 25x25m have been demarcated in the five areas (1-5) given in Fig. 1. In each area a minimum of four sample plots have been demarcated and usually two plots were located adjacent to each other so that the plot size could be doubled if required during analysis.

Area I which is given as a part of scrubland, represents a small hill known as Ginigathkanda, which was close to the previous Kalatuwawa village and according to the villagers this is a natural forest patch which was conserved as such by the community because of the presence in it of many valuable medicinal plants.



Forest cover legend (as in Land Use and Forest Cover map – 1960)

- 2H Homestead garden
- 3R Rubber
- 4S Shifting cultivation
- 6Sc Scrubland
- 7LW Low –yield wet zone forest
- 7MW Medium yield wet zone forest
- 7NW Non-productive wet zone forest



Forest Reserve

Reservoir

**Figure 1 :** Kalatuwawa – Labugama Forest Reserve



Table 1: List of tree species recorded in the five areas (Number of tree species over 10 cm dbh per species is indicated)

| AREA 1 (Ginigathkanda)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | AREA 2 (Meddekanda)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | AREA 3 (Near Bolandola)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | AREA 4 (Near Puwakdola)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | AREA 5 (Udagama)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Dipterocarpus zeylanicus</i> 33<br><i>Anisophyllea cinnamomoides</i> 15<br><i>Semecarpus gardneri</i> 14<br><i>Artocarpus nobilis</i> 10<br><i>Gyrinops walla</i> 9<br><i>Semecarpus</i> sp. (2) 6<br><i>Humboldtia laurifolia</i> 3<br><i>Nephilium longana</i> 3<br><i>Stemonoporus</i> sp. 2<br><i>Syzygium makul</i> 2<br><i>Diospyros insignis</i> 2<br><i>Palaquium</i> sp. 2<br><i>Canarium zeylanicum</i> 2<br><i>Mangifera zeylanica</i> 2<br><i>Cryptocarya wightiana</i> 2<br><i>Neolitsea casia</i> 2<br><i>Cyathocalyx zeylanicus</i> 1<br><i>Semecarpus</i> sp. (1) 1<br><i>Pagiatha dichotoma</i> 1<br><i>Gomphia serrata</i> 1<br><i>Alstonia scholaris</i> 1<br><i>Diospyros</i> sp. 1<br><i>Chaetocarpus castanocarpus</i> 1<br><i>Persea macrantha</i> 1<br><i>Bhesa zeylanica</i> 1<br><i>Myristica dactyloides</i> 1 | <i>Dipterocarpus zeylanicus</i> 75<br><i>Chaetocarpus castanocarpus</i> 28<br><i>Dillenia retusa</i> 20<br><i>Cyathocalyx zeylanicus</i> 13<br><i>Gomphia serrata</i> 9<br><i>Myristica dactyloides</i> 7<br><i>Bridelia moonii</i> 4<br><i>Artocarpus nobilis</i> 3<br><i>Carallia brachiata</i> 3<br><i>Calophyllum bracteatum</i> 2<br><i>Syzygium operculatum</i> 3<br><i>Syzygium makul</i> 3<br><i>Bhesa zeylanica</i> 1<br><i>Dillenia triquetra</i> 1<br><i>Schumacheria castaneaefolia</i> 1<br><i>Horsfieldia iryaghedhi</i> 1<br><i>Mangifera zeylanica</i> 1<br><br>No. of trees in the area 177<br>No. of identified sp. 17<br>No. of unidentified trees 2 | <i>Chaetocarpus castanocarpus</i> 16<br><i>Dillenia retusa</i> 13<br><i>Dillenia triquetra</i> 10<br><i>Campanosperma zeylanicum</i> 7<br><i>Vitex altissima</i> 7<br><i>Canarium zeylanicum</i> 6<br><i>Cyathocalyx zeylanicus</i> 6<br><i>Mallotus fuscescens</i> 6<br><i>Gyrinops walla</i> 5<br><i>Urandra apicalis</i> 4<br><i>Semecarpus</i> sp. 4<br><i>Garcinia quaesita</i> 4<br><i>Anisophyllea cinnamomoides</i> 4<br><i>Shorea</i> sp. 3<br><i>Palaquium</i> sp. 3<br><i>Artocarpus nobilis</i> 3<br><i>Mastixia macrophylla</i> 2<br><i>Terminalia parviflora</i> 2<br><i>Samadera inidca</i> 2<br><i>Syzygium makul</i> 2<br><i>Mangifera zeylanica</i> 2<br><i>Dipterocarpus zeylanicus</i> 1<br><i>Carallia brachiata</i> 1<br><i>Calophyllum calaba</i> 1<br><i>Bhesa zeylanica</i> 1<br><i>Xylopia parvifolia</i> 1<br><i>Myristica dactyloides</i> 1<br><br>No. of trees in the area 126<br>No. of identified sp. 27<br>No. of unidentified trees 9 | <i>Mallotus fuscescens</i> 25<br><i>Garcinia quaesita</i> 21<br><i>Dipterocarpus zeylanicus</i> 14<br><i>Diospyros insignis</i> 14<br><i>Chaetocarpus castanocarpus</i> 12<br><i>Xylopia parvifolia</i> 11<br><i>Gyrinops walla</i> 8<br><i>Semecarpus</i> sp. 7<br><i>Anisophyllea cinnamomoides</i> 7<br><i>Artocarpus nobilis</i> 7<br><i>Shorea</i> sp. 4<br><i>Myristica dactyloides</i> 4<br><i>Cryptocarya wightiana</i> 4<br><i>Vitex altissima</i> 4<br><i>Dillenia retusa</i> 4<br><i>Palaquium</i> sp. 1<br><i>Adenathera pavonina</i> 3<br><i>Cyathocalyx zeylanicus</i> 3<br><i>Gomphia serrata</i> 2<br><i>Calophyllum calaba</i> 2<br><i>Mangifera zeylanica</i> 2<br><i>Bridelia moonii</i> 1<br><i>Mastixia tetrandra</i> 1<br><i>Syzygium makul</i> 1<br><i>Ixora jucunda</i> 1<br><i>Schumacheria castaneaefolia</i> 1<br><i>Dillenia triquetra</i> 1<br><i>Alstonia macrophylla</i> 1<br><i>Euphoria longana</i> 1<br><br>No. of trees in the area 183<br>No. of identified sp. 29<br>No. of unidentified trees 14 | <i>Cyathocalyx zeylanicus</i> 19<br><i>Semecarpus</i> sp. (1) 14<br><i>Bhesa zeylanica</i> 14<br><i>Myristica dactyloides</i> 13<br><i>Garcinia morella</i> 8<br><i>Cryptocarya wightiana</i> 8<br><i>Garcinia quaesita</i> 7<br><i>Campanosperma zeylanicum</i> 6<br><i>Mangifera zeylanica</i> 4<br><i>Dillenia retusa</i> 6<br><i>Shorea</i> sp. 4<br><i>Chaetocarpus castanocarpus</i> 4<br><i>Macaranga peltata</i> 2<br><i>Xylopia parvifolia</i> 1<br><i>Artocarpus nobilis</i> 1<br><i>Canthium coromandelicum</i> 1<br><i>Vitex altissima</i> 1<br><i>Acronychia pedunculata</i> 1<br><i>Palaquium</i> sp. 1<br><i>Anisophyllea cinnamomoides</i> 1<br><br>No. of trees in the area 125<br>No. of identified sp. 20<br>No. of unidentified trees 9 |

Area 2 is an isolated patch of forest known as Meddekanda. In area 3 sampling was carried out on either side of the Bolan Dola and area 4 represents an area near Puwak Dola. Area 5 at Udagama is a forest patch where there is very little undergrowth compared to the other areas studied. In general out of the five areas studied, the area close to Bolan Dola and Puwak Dola are disturbed areas with dense undergrowth.

All plots were marked at the four corners either with galvanized pipes (1m) or orange polythene. In each plot all species were identified as far as possible (to family, generic or species level) and trees over 10 cm in dbh were labelled. Plant specimens were collected and herbarium specimens were prepared. For identification, the two publications on Floras (Trimen 1893 - 1990 and Dassanayake & Fosberg 1980 - 1995) were used. For this study the University of Colombo Herbarium (a collection of herbarium specimens checked with PDA and confirmed) was extensively used. The emphasis so far was on flowering plants. However some lower plants collected and identified are also given in Appendix 1. Although the project was started in April 1995, the field visits were curtailed due to security reasons.

## RESULTS

A total of 174 species belonging to 138 genera and 62 families have been identified and the list is given in Appendix 1. There are more than 32 species still unidentified. Out of the identified species, 51 are endemic to Sri Lanka. Among these, two species of the two endemic genera *Schumacheria* and *Stemonoporus* are also included. The collection also includes many medicinal plants and two threatened flowering plants of Sri Lanka namely *Adenanthera bicolor* and *Coscinium fenestratum*. Among the lower plant species listed four species namely, *Lycopodium phlegmaria* L. *squarrosum* *Ophioglossum pendulum* and *Schizaea digitata* are also considered as threatened (Wijesinghe et al. 1993).

As for the permanent plots, a summary of the total number of tree species (over 10 cm dbh) identified in the five areas sampled, is given in table 1. For comparison, the number of species present in only four plots from each area is also given.

## DISCUSSION

There is no record of a systematic study carried out before on this reserve. The list given here shows species common to the wet zone forest species found in other reserves like Sinharaja (Gunatilleke & Gunatilleke 1980). The list is an under estimate of the species present, since some species have not been identified due to the absence of reproductive parts.

In general the forest has emergents, canopy species, sub canopy species and shrubs and herbs. The main emergent species are *Dipterocarpus zeylanicus*, *Shorea trapezifolia* and in relatively disturbed areas *Xylopia parvifolia* is found as emergents.

Based on the distribution of canopy species one can tentatively propose the presence of at least 3 community types. However, the validity of these has to be tested in future by further field studies and data analysis. As given in table 1 many tree species show localized distribution and are rare. According to the villagers this forest has harboured the threatened endemic species, *Diospyros quaesita*. However, during our visits we have not come across this species in the field. Although *Dipterocarpus hispidus* is present in the nearby Waga forest reserve this was also not detected at Kalatuwawa - Labugama reserve.

The forest shrub layer has most of the typical rain forest species such as *Aporosa lanceolata*, *Lijndenia gardneri* and *Memecylon* spp. The woody climbers such as *Entada pusaetha*, *Coscinium fenestratum*, and *Tetracera sarmentosa* are very common.

At present this is a forest reserve with a high security and therefore in future it will be possible to use this forest for scientific research such as the enrichment planting trials, using primary forest timber and non timber species as well as endangered species.

## ACKNOWLEDGEMENTS

The work was initiated because of the financial support given by NARESA to which we are grateful. The working in the forest would not have been possible if not for the help given by the Forest officers at Waga Forest office specially Mr Rajakaruna, Mr Laxman Rathnaweera, Mr. M. Wilson and the villagers. The advice given by Prof. B. A. Abeywickrama and Dr. B. M.P Singhakumara and the assistance given by Miss C. M. Hewawasam and Miss P.M. Arunareka is appreciated.

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## Appendix - 1

## LIST OF SPECIES COLLECTED FROM KALATUWAWA - LABUGAMA FOREST RESERVE

| FAMILY           | BOTANICAL NAME                                                                                                                                                                                                                                                                                                                                                                                                            |
|------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Anacardiaceae    | <ul style="list-style-type: none"> <li>* <i>Camptosperma zeylanicum</i> Thw.</li> <li>* <i>Mangifera zeylanica</i> (Blume) Hook.f</li> <li>* <i>Semecarpus gardneri</i> Thw.</li> <li><i>Semecarpus</i> sp 1</li> <li><i>Semecarpus</i> sp 2</li> </ul>                                                                                                                                                                   |
| Anisophylleaceae | <i>Anisophyllea cinnamomoides</i> (Gardn. & Champion) Alston                                                                                                                                                                                                                                                                                                                                                              |
| Annonaceae       | <ul style="list-style-type: none"> <li><i>Annona glabra</i> L.</li> <li>* <i>Artabotrys zeylanicus</i> Hook. f. &amp; Thoms.</li> <li>* <i>Cyathocalyx zeylanicus</i> champ. Ex. Hook. f &amp; Thoms</li> <li>* <i>Goniothalamus gardneri</i> Hook. f &amp; Thoms.</li> <li><i>Polyalthia korinti</i> (Dunal) Thw.</li> <li>* <i>Xylopiia parvifolia</i> (Wight) Hook f. &amp; Thoms</li> <li><i>Uvaria</i> sp</li> </ul> |
| Apocynaceae      | <ul style="list-style-type: none"> <li><i>Alstonia scholaris</i> (L.) R.Br.</li> <li><i>Alstonia macrophylla</i> Wall.</li> <li><i>Anodendron manubriatum</i> Merr.</li> <li><i>Pagiantha dichotoma</i> (Roxb.) Markgraf.</li> </ul>                                                                                                                                                                                      |
| Araceae          | <ul style="list-style-type: none"> <li><i>Pothos scandens</i> L.</li> <li><i>Pothos</i> sp</li> </ul>                                                                                                                                                                                                                                                                                                                     |
| Aristolochiaceae | <ul style="list-style-type: none"> <li><i>Apama siliquosa</i> Lam.</li> <li><i>Aristolochina indica</i> L.</li> </ul>                                                                                                                                                                                                                                                                                                     |
| Asclepiadaceae   | <i>Hemidesmus indicus</i> (L.) Ait. f.                                                                                                                                                                                                                                                                                                                                                                                    |
| Balsaminaceae    | * <i>Impatens thwaitesii</i> . Hook.f. ex. Gery-Wilson.                                                                                                                                                                                                                                                                                                                                                                   |
| Bombacaceae      | <i>Cullenia rosayroana</i> Kosterm                                                                                                                                                                                                                                                                                                                                                                                        |
| Burseraceae      | * <i>Canarium zeylanicum</i> (Rtz) BI                                                                                                                                                                                                                                                                                                                                                                                     |
| Celastraceae     | <ul style="list-style-type: none"> <li><i>Bhesa zeylanica</i> (Arn. Ex Thw.) Ding Hon</li> <li>* <i>Euonymus walkeri</i> Wight.</li> </ul>                                                                                                                                                                                                                                                                                |

|                  |                                                                                                                                                                                                                                                                                                                                                                    |
|------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Clusiaceae       | <ul style="list-style-type: none"> <li>* <i>Calophyllum bracteatum</i> Thw.</li> <li>* <i>Calophyllum calaba</i>. L.</li> <li><i>Calophyllum</i> sp</li> <li><i>Garcinia quaestia</i> Pierre</li> <li><i>Garcinia morella</i> (Gaertn.) Dest.</li> <li>* <i>Mesua ferrea</i> L.</li> <li><i>Mesua nagasarium</i> (Burm.f.) Kosterm.</li> </ul>                     |
| Combretaceae     | <ul style="list-style-type: none"> <li>* <i>Terminalia parviflora</i> Thw.</li> </ul>                                                                                                                                                                                                                                                                              |
| Connaraceae      | <i>Connarus monocarpus</i> L.                                                                                                                                                                                                                                                                                                                                      |
| Convolvulaceae   | <i>Stictocardia tiliifolia</i> (Desr.) Hall f.                                                                                                                                                                                                                                                                                                                     |
| Cornaceae        | * <i>Mastixia macrophylla</i>                                                                                                                                                                                                                                                                                                                                      |
| Cyperaceae       | <ul style="list-style-type: none"> <li><i>Cyperus</i> sp.</li> <li><i>Fimbristylis dichotoma</i> L</li> <li><i>Hypolytrum latifolium</i> Rich</li> <li><i>Scleria lithosperma</i> (L) Sw</li> </ul>                                                                                                                                                                |
| Dilleniaceae     | <ul style="list-style-type: none"> <li><i>Achrotrema</i> sp</li> <li><i>Dillenia indica</i> L.</li> <li>* <i>Dillenia retusa</i> Thunb</li> <li>* <i>Dillenia triquetra</i> Rottb.</li> <li><i>Dillenia suffruticosa</i></li> <li>* <i>Schumacheria castaneaefolia</i> Vahl</li> <li><i>Tetracera sarmentosa</i> (L). Vahl.</li> </ul>                             |
| Dioscoreaceae    | <i>Trichopus zeylanicus</i> Gaertn.                                                                                                                                                                                                                                                                                                                                |
| Dipterocarpaceae | <ul style="list-style-type: none"> <li>* <i>Dipterocarpus zeylanicus</i> Thw.</li> <li>* <i>Hopea jucunda</i> Thw.</li> <li>* <i>Shorea megistophylla</i> Ashton.</li> <li>* <i>Shorea trapezifolia</i> (Thw.). Ashton.</li> <li>* <i>Shorea affinis</i> (Thw.). Ashton.</li> <li>* <i>Vateria copallifera</i> Retz.</li> <li>* <i>Stemonoporus</i> sp.</li> </ul> |
| Ebenaceae        | <ul style="list-style-type: none"> <li><i>Diospyros insignis</i> Thw.</li> <li><i>Diospyros</i> sp</li> </ul>                                                                                                                                                                                                                                                      |

|                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Eriocaulaceae  | <i>Eriocaulon</i> sp                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Elaeocarpaceae | <i>Elaeocarpus serratus</i> L.<br><i>Elaeocarpus subvillosus</i> Arn.                                                                                                                                                                                                                                                                                                                                                                                              |
| Euphorbiaceae  | <i>Agrostistachys coriacea</i><br>* <i>Aporosa lanceolata</i> . Thw. Enum.<br><i>Aporosa</i> sp<br>* <i>Bridelia mooni</i> Thw<br><i>Bridelia retusa</i> Willd.<br><i>Chaetocarpus castanocarpus</i> Thw.<br><i>Croton laciferus</i> L.<br>* <i>Glochidion mooni</i> Thw.<br><i>Glochidion</i> sp<br><i>Macaranga indica</i> Wight.<br><i>Macaranga peltata</i> Wight.<br><i>Mallotus albus</i> (Roxb) Muell Arg.<br><i>Mallotus fuscescens</i> (Thw. ) Muell Arg. |
| Fabaceae       | <i>Albizia lebbeck</i> (L.) Pierre.<br><i>Dalbergia</i> sp<br><i>Humboldtia laurifolia</i> Benth.<br><i>Pericopsis mooniana</i> Thw.<br><i>Pongamia pinnata</i> L.                                                                                                                                                                                                                                                                                                 |
| Flacourtiaceae | <i>Homalium zeylanicum</i><br>* <i>Trichadenia zeylanica</i>                                                                                                                                                                                                                                                                                                                                                                                                       |
| Gesneriaceae   | * <i>Chirita zeylanica</i> Hook                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Hypoxidaceae   | <i>Curculigo</i> sp                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Icacinaceae    | <i>Urandra apicalis</i> Thw.                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Lamiaceae      | <i>Scutellaria violacea</i> Heyne.                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Lauraceae      | <i>Cinnamomum zeylanicum</i> Bl<br><i>Cryptocarya wightiana</i> Thw.<br><i>Litsea cauliflora</i> . Trim.<br><i>Litsea gardneri</i> (Thw.) Hook.f.<br>* <i>Litsea longifolia</i> (Nees) Alston<br>* <i>Neolitsea cassia</i> (L.) Kostermans<br><i>Persea macrantha</i> (Nees.) Kosterm                                                                                                                                                                              |

|                 |                                                                                                                                                                                                                                                                             |
|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Leeaceae        | <i>Leea indica</i> (Burm.f.). Merr.                                                                                                                                                                                                                                         |
| Liliaceae       | <i>Dracaena</i> sp<br><i>Gloriosa superba</i> L.<br><i>Asparagus falcatus</i> L.                                                                                                                                                                                            |
| Malvaceae       | <i>Hibiscus furcatus</i> Roxb.                                                                                                                                                                                                                                              |
| Melastomataceae | <i>Clidemia hirta</i> (L.) D. Don<br><i>Lijndenia garderi</i> (Thw.) Bremer<br><i>Melastoma malabathricum</i> . (L.).<br>* <i>Memecylon capitellatum</i><br>* <i>Memecylon rostratum</i> Thw.<br>* <i>Memecylon rivulare</i> Bremer.<br>* <i>Osbeckia oktandra</i> (L.) DC. |
| Meliaceae       | <i>Aglaia apiocarpa</i> (Thw.) Hiern<br><i>Chickrassia tabularis</i> A. Juss                                                                                                                                                                                                |
| Menispermaceae  | * <i>Coscinium fenestratum</i> (Gaertn.) Colibr.<br><i>Cyclea burmanni</i> (DC) Miers. Ex Hook f. & Thoms.                                                                                                                                                                  |
| Mimosaceae      | * <i>Adenanthera bicolor</i> Moon.<br><i>Adenanthera pavonina</i> L.<br><i>Entada pusaetha</i> DC.                                                                                                                                                                          |
| Moraceae        | <i>Ficus diversiformis</i> Miq.<br><i>Ficus exasperata</i> Vahl.<br><i>Ficus hispida</i> L.f.<br><i>Artocarpus nobilis</i> Thw.                                                                                                                                             |
| Myristicaceae   | <i>Horsfieldia iryaghedhi</i> (Gaertn.) Warf.<br><i>Myristica dactyloides</i> Gaertn.                                                                                                                                                                                       |
| Myrtaceae       | * <i>Syzygium makul</i> . Gaertn.<br><i>Syzygium operculatum</i> . (Roxb.). Niedz<br><i>Syzygium Caryophyllatum</i> (L.) Alston<br><i>Syzygium</i> sp                                                                                                                       |
| Nepanthaceae    | * <i>Nepenthus distillatoria</i> .L.                                                                                                                                                                                                                                        |
| Ochnaceae       | <i>Gomphia serrata</i> . (Gaertn.). Kanis.<br><i>Ochna squarrosa</i> L.<br><i>Ochna</i> sp                                                                                                                                                                                  |

|                         |                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Orchidaceae             | <i>Eria</i> sp<br><i>Liparis</i> sp<br>* <i>Malaxis discolor</i> (Lindl) Kuntze.<br><i>Malaxis versicolor</i> . (Lindl). Abeywick.<br>* <i>Podochilus sexatilis</i> Lindl.<br><i>Sarcanthus</i> sp                                                                                                                                                                                                                           |
| Oxalidaceae             | <i>Averrhoa carambola</i> L.                                                                                                                                                                                                                                                                                                                                                                                                 |
| Pandanaceae             | <i>Freycinetia pycnophylla</i> Solms.                                                                                                                                                                                                                                                                                                                                                                                        |
| Piperaceae              | <i>Piper sylvestre</i> Lam.<br><i>Piper</i> sp.                                                                                                                                                                                                                                                                                                                                                                              |
| Palmae<br>(Arecaeaceae) | * <i>Onchosperma fasciculatum</i> Thw.<br><i>Calamus</i> sp.<br><i>Caryota urens</i> L.                                                                                                                                                                                                                                                                                                                                      |
| Poaceae                 | <i>Digitaria</i> sp<br>* <i>Ochlandra stridula</i> Thw.                                                                                                                                                                                                                                                                                                                                                                      |
| Polygalaceae            | <i>Xanthophyllum geminiflorum</i> (Dennst). Alst.                                                                                                                                                                                                                                                                                                                                                                            |
| Rhizophoraceae          | <i>Carallia brachiata</i> (Lour.). Merr.                                                                                                                                                                                                                                                                                                                                                                                     |
| Rubiaceae               | <i>Canthium coromandelicum</i> (Burm. f.) Alston<br>* <i>Gaertnera vaginas</i> (D.C.) Merr<br><i>Hedyotis fruiticosa</i> L.<br><i>Ixora coccinea</i> L.<br>* <i>Ixora jucunda</i> Thw.<br><i>Mussenda frondosa</i> L.<br><i>Ophiorrhiza pectinata</i> Arn.<br><i>Psychotria sarmentosa</i> Blume.<br><i>Timonius jambosella</i> . Thw.<br>* <i>Urophyllum ellipticum</i> (Wight.). Thw.<br><i>Wendlandia notoniana</i> Wall. |
| Rutaceae                | <i>Acronychia pendunculata</i> . (L.) Miq.<br><i>Micromelum ceylanicum</i> B.C. Stone<br>* <i>Luvunga angustifolia</i> . (Oliv.). Tanata<br><i>Toddalia asiatica</i> (L.) Lam.                                                                                                                                                                                                                                               |



|               |                                                                                                                                                      |
|---------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sapindaceae   | <i>Filicium decipiens</i> (Wight & Arn. ) Thw.<br><i>Lepisanthes erecta</i> (Thw) Leenh<br><i>Nephilium longana</i> . Camb.<br><i>Pometia pinata</i> |
| Sapotceae     | * <i>Palaquium grande</i> (Thw.) Engl.<br><i>Palaquium</i> sp                                                                                        |
| Simarubaceae  | <i>Samadera indica</i> . Gaertn.                                                                                                                     |
| Symplocaceae  | <i>Symplocus cochinchinensis</i> . (Lovr.). S. Moore.                                                                                                |
| Thymelaeaceae | * <i>Gyrinops walla</i> . Gaertn.                                                                                                                    |
| Ulmaceae      | <i>Trema orientale</i> (L.) B1.                                                                                                                      |
| Verbenaceae   | <i>Vitex altissima</i> . L. f.<br><i>Clerodendron</i> sp                                                                                             |
| Vitaceae      | <i>Cissus trilobata</i> . Lam.                                                                                                                       |
| Zingiberaceae | <i>Costus</i> sp<br>* <i>Zingiber cylindricum</i> . Thw.                                                                                             |

-----  
\* Endemic species

Lower Plants

|                |                                                                                |
|----------------|--------------------------------------------------------------------------------|
| Adiantaceae    | <i>Pteris quadriaurita</i> Retz.                                               |
| Aspleniaceae   | <i>Asplenium</i> sp                                                            |
| Blechnaceae    | <i>Blechnum orientale</i>                                                      |
| Cyatheaceae    | <i>Cyathea</i> sp                                                              |
| Lycopodiaceae  | <i>Lycopodium phlegmaria</i> L.<br><i>Lycopodium squarrosum</i> Forst.         |
| Ophioglosaceae | <i>Ophioglossum pendulatum</i>                                                 |
| Polypodiaceae  | <i>Microsorium nigrescens</i> (Bl.) Capel.<br><i>Drynaria quercifolia</i> (L.) |

## Schizaeaceae

*Schizaea digitata* (L.) Sw*Lygodium* sp

## Selaginellaceae

*Selaginella brachystachya* (Hook & Grev.) Spring.*Selaginella* sp

# SEEDLING GROWTH OF FOUR CO-OCCURRING CANOPY TREE SPECIES ON DIFFERENT LIGHT AND SOIL MOISTURE ENVIRONMENTS

B.M.P. Singhakumara and P.M.S. Ashton

## ABSTRACT

Seeds of canopy trees *Mesua ferrea* L., *M. nagassarium* (Burm.f.) Kosterm., *Dipterocarpus hispidus* Thw. and *D. zeylanicus* Thw. were gathered from the Sinharaja rain forest and grown in treatments that reflected a range of light and soil moisture environments that had been measured within the rain forest for a two year period. *M. nagassarium* is a canopy tree of ridge sites; *M. ferrea* and *D. hispidus* are canopy trees of lower slopes and small valleys; and *D. zeylanicus* is a canopy tree of lowlands and large riverways. The two soil moisture treatments simulated: (i) continuous moist conditions; and (ii) periodic dryness. The light treatments exposed seedlings to (i) full sun (FS); (ii) direct light at the centre of a 200 m<sup>2</sup> canopy opening (SO); (iii) direct light like that of a 400 m<sup>2</sup> canopy opening (LO) (iv) 50% shade with a quality similar to the outside edge on the shaded side of a 400 m<sup>2</sup> canopy opening (OE); (v) 20% shade with a quality similar to the inside edge on the shaded side of a 400 m<sup>2</sup> canopy opening (FE); and (vi) 99% shade with quality similar to the forest understorey (FU).

The percentage of mortality by species and soil moisture availability revealed *D. hispidus* to have highest percentage mortality followed in declining order by *D. zeylanicus*, *M. ferrea* and *M. nagassarium*. The heights of seedlings grown in dry soils were considerably lower than those seedlings grown in the moist soils. *D. zeylanicus* showed greatest height in moist soils followed in declining order by *M. nagassarium*, *M. ferrea* and *D. hispidus*. *M. nagassarium* had higher stem length per root length of seedlings in almost all light treatments irrespective of soil moisture status, except for seedlings in FE and OE light treatments of moist soils where *D. zeylanicus* was greatest. In moist and dry soils greatest dry mass for all light treatments was attained by *D. zeylanicus*. Ratios of dry mass allocation to roots, stem and leaves suggest greater proportional allocation to roots and stem with the bright light treatment.

Results suggest that *D. zeylanicus* competitively grows best in brighter light environments of open edge where moisture is freely available. Both *Mesua* species are light demanding but can tolerate greater amounts of shade than *Dipterocarpus* species. *M. nagassarium* is overall the most drought tolerant species while the most drought intolerant species is *D. hispidus*.

## INTRODUCTION

Canopy species richness of trees in tropical moist forest regions of southeast Asia are largely a function of species differentiation within a relatively few genera (Ashton 1992;

Whitmore 1984). Previous studies in this region have examined *Shorea* section *Doona*, an endemic section of nine species confined to mixed-dipterocarp forest of southwest Sri Lanka. These studies have investigated possible factors that have promoted their site specialization within a forest landscape. Field and controlled environment investigations have examined *Shorea* section *Doona* seedling response in relation to light, soil moisture availability and soil nutrition (Ashton & Berlyn 1992; Ashton 1995; Ashton et al. 1995; Gunatilleke et al. 1996; in press).

This study continued this examination by selecting two more canopy genera, *Mesua* and *Dipterocarpus*, for investigation following the same methodological protocol. The genera *Mesua* and *Dipterocarpus* co-exist with *Shorea* section *Doona* in the same forest type that is defined by their dominance. The forest has therefore been typed *Mesua-Doona* by de Rosayro (1942) and later verified by Gunatilleke & Ashton (1987).

Four species were investigated (*Dipterocarpus hispidus* Thw., *D. zeylanicus* Thw., *Mesua ferrea* L, and *M. nagassarium* (Burm. f.) Kosterm) that were observed to dominate the canopy of late-successional forest on different parts of the topography. *Mesua nagassarium* is a canopy tree of ridge sites; *M. ferrea* and *D. hispidus* are canopy trees of lower slopes and small valleys; and *D. zeylanicus* is a canopy tree of lowlands and large riverways. We tested seedling survival and growth of these species in relation to variation in quality and amount of light and availability of soil water. We hypothesized that light and soil moisture were important factors determining their site specialization.

## METHODS AND MATERIALS

### Site Description

The study was carried out at the Field Station of the Sinharaja Man and the Biosphere Reserve located in the southwest lowland wet zone of Sri Lanka. Annual precipitation is about 5000 mm with a larger proportion of the rain falling during the southwest (May-July) and northeast (October-December) monsoons. Mean monthly temperature ranges between 25 and 27°C with greater diurnal variation of  $\pm 4^{\circ}\text{C}$ . The forest is undulating ridge to valley topography with elevational differences generally not more than 200. The soils would be considered Ultisols (US Department of Agriculture, 1975) with humults thin to bedrock on ridges and udults at lower lying sites. The geology underlying these soils consists of metamorphic khondalite and charnokites (Cooray 1967).

### Experimental Design

Well ventilated shelters were constructed in the full open at the Sinharaja field station. They were designed to create light treatments that represented a range of different photon photosynthetic flux density (PPFD) regimes found within the Sinharaja forest. Six light

treatments exposed seedlings to (i) full sun (FS); (ii) direct light like that at the centre of a 400 m<sup>2</sup> canopy opening (LO); (iii) direct light like that at the centre of a 200 m<sup>2</sup> canopy opening (SO) ; (iv) 50% shade with a quality similar to the outside edge on the shaded side of a 400 m<sup>2</sup> canopy opening (OE) ; (v) 20% shade with a quality similar to the inside edge of the shaded side of a 400 m<sup>2</sup> canopy opening (FE); and (vi) 99% shade with quality similar to the forest understorey (FU). For shelters that altered the quality and intensities of light (FU, FE, OE) a mix of pigments in a varnish base was sprayed onto clear plastic film that was durable in UV. The amount that was sprayed regulated the red: far red ratio and the intensity of light (Lee 1985; Ashton 1995). Shelters that altered duration of direct light (LO, SO) were created by constructing a series of parallel vertical slats aligned north-south, horizontally placed 2 m above the ground and across the complete interior of a shelter. The duration of direct light was controlled by the depth of the slats and the width.

Within each light treatment two watering treatments were set up to create (i) ever moist soils maintained at field capacity and (ii) droughty soils that reflected soil moisture content during prolonged periods of no rain which can occur during the months of January - April. The ever moist treatment was maintained at field capacity by applying 2 l m<sup>-2</sup> water thrice weekly. Droughty conditions were obtained by applying 2 l m<sup>-2</sup> water when the relative moisture content (RMC) of the soil declined below 30% of field capacity (100%). Soils were monitored using a battery operated soil moisture meter that could be attached to permanently buried gypsum blocks (Bouyoucos 1953, 1972).

Seeds of each species were collected from several different parent trees, mixed and germinated on a nursery bed. When the seedlings were one month old they were taken and planted into the treatments. In each light-soil moisture treatment combination there were four blocks. Each block contained nine seedlings of each species in random mixture but at equal 25x 25 cm spacing. One block comprised a 1.5 x 1.5 m by 30 cm deep tray that contained forest top soil from one valley site location mixed equally with sand obtained from an adjacent stream. Soil nutrients (NPK: 15:15:15) were added every 3 months to maintain fertility.

### Data analysis

Seedlings were grown for two years and their survival monitored. At the end of two years, seedlings were measured for height, root length and number of leaves. Sixteen seedlings (four per block) per species for each light-soil moisture combination were randomly selected and taken for destructive sampling. Destructive samples were oven dried at 80°C for 48 hours. Stem, leaves and root were then weighed separately for dry mass.

Analyses of variance were done on seedling height, stem length to root length ratio, number of leaves and dry mass using the GLM procedure of SAS (Ray 1982).

## RESULTS

### Mortality

After two years percentage mortality by species and soil moisture availability revealed *Mesua* species to be lower than *Dipterocarpus* species. Trends for both soil water availability treatments revealed *D. hispidus* to have highest percentage mortality followed in declining order by *D. zeylanicus*, *M. ferrea* and *M. nagassarium*. The only difference among soil water treatments was that the droughty soil greatly accentuated percentage mortality particularly for *D. hispidus* (Fig. 1).

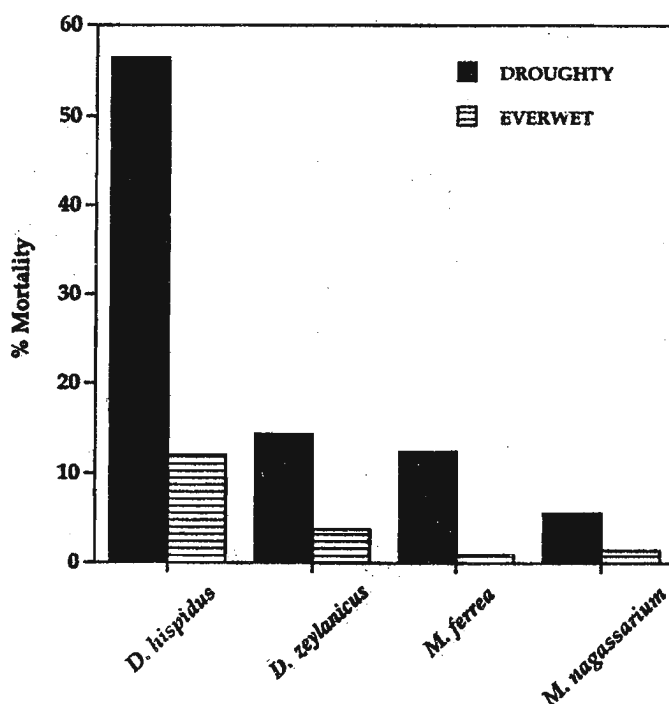


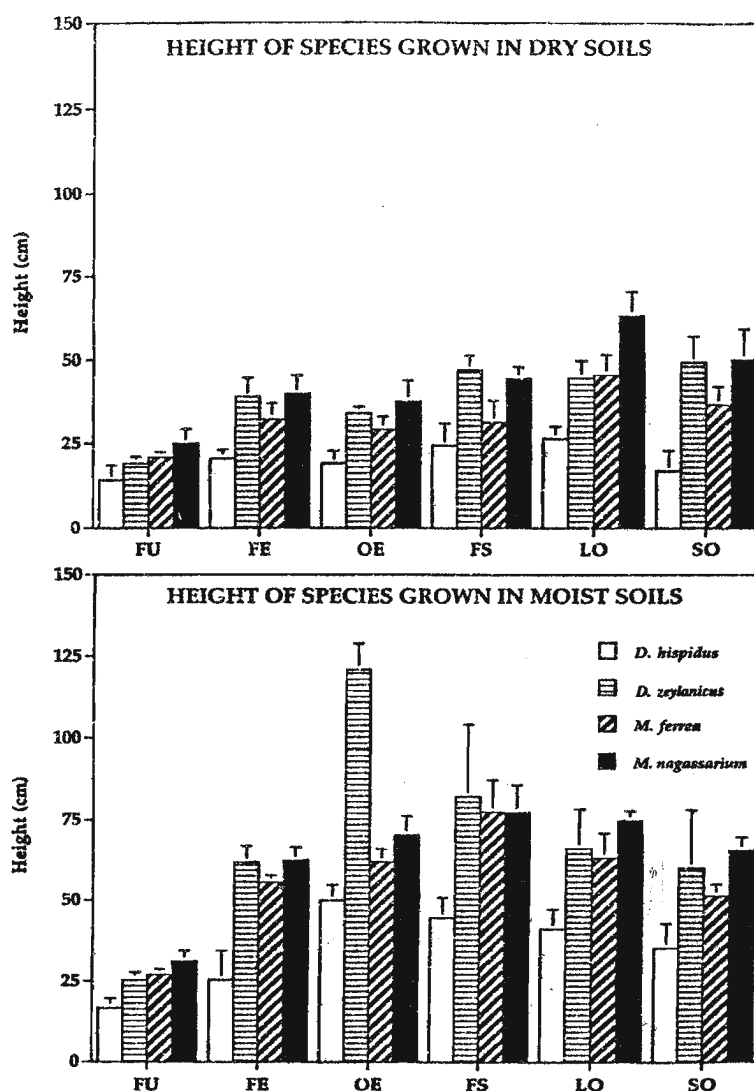
Figure 1 : Percentage of mortality of *Dipterocarpus* and *Mesua* species under ever moist and droughty conditions.

### Height Growth, Stem-Root : Ratio, and Leaf Number

Analysis of variance of seedling heights, shoot to root length, and leaf number showed significant differences among light treatments, among soil moisture treatments and in interactions between both. Analysis of variance showed no significant difference among treatment blocks. Differences among the species for each light-soil moisture treatment combination was determined at the 5% significance level using Tukey's student test (Table 1).

Comparison among the two soil moisture treatments showed that the heights of seedlings grown in dry soils were considerably lower than those seedlings grown in the moist soils (Fig. 2). In the higher light environments of moist soils seedling heights were almost

double those of seedlings in dry soils. For conditions with moist soils both *Dipterocarpus* species had greatest seedling heights in the OE treatment. Both *Mesua* species had greatest seedling heights in the FS treatment for moist soils. Overall *D. zeylanicus* showed greatest height in moist soils followed in declining order by *M. nagassarium*, *M. ferrea* and *D. hispidus*. However, *D. zeylanicus* showed considerably higher variation among individuals for the higher light treatments of moist soils, as depicted by the standard errors (Fig. 2, Table 1). For dry soils both *Mesua* species showed greatest height in the LO treatment. For *Dipterocarpus* the FS and LO treatments (and SO for *D. zeylanicus*) showed greatest heights. *Mesua nagassarium* showed greatest height in dry soils within *D. hispidus* having the least.



**Figure 2:** Height of *Dipterocarpus* and *Mesua* species grown in dry and moist soils under different light treatments. (FU-forest understorey; FE-inside forest edge; OE-outside forest edge; FS-full sun; SO-centre of small opening; LO-centre of large opening).

Table 1: Summary of differences among treatments for each species of height, leaves, S/R ratio and dry mass. Uncapitalized letters denote differences between the light treatments for each soil treatment and for each species at 5% level of significance. Light treatments followed by the same letter for a species are not significantly different from each other. (FU-forest undersotrey; FE – inside forest edge; OE – outside forest edge; FS – full sun; SO – centre of small opening; LO – centre of large opening).

|                       | Moist Soil |    |    |    |    |     | Dry Soil |    |    |    |    |    |
|-----------------------|------------|----|----|----|----|-----|----------|----|----|----|----|----|
|                       | FU         | FE | OE | FS | LO | SO  | FU       | FE | OE | FS | LO | SO |
| <b>Height</b>         |            |    |    |    |    |     |          |    |    |    |    |    |
| <i>D. hispidus</i>    | b          | c  | c  | b  | b  | c   | b        | b  | b  | b  | c  | b  |
| <i>D. zeylanicus</i>  | a          | ab | a  | a  | a  | abc | ab       | a  | a  | a  | b  | a  |
| <i>M. ferrea</i>      | a          | b  | b  | a  | a  | b   | ab       | a  | a  | b  | b  | a  |
| <i>M. nagassarium</i> | a          | a  | b  | a  | a  | a   | a        | a  | a  | a  | a  | a  |
| <b>Leaves</b>         |            |    |    |    |    |     |          |    |    |    |    |    |
| <i>D. hispidus</i>    | c          | d  | c  | d  | d  | c   | b        | c  | c  | c  | d  | c  |
| <i>D. zeylanicus</i>  | bc         | c  | b  | c  | c  | bc  | b        | b  | b  | b  | c  | b  |
| <i>M. ferrea</i>      | ab         | b  | b  | b  | b  | b   | a        | b  | b  | bc | b  | b  |
| <i>M. nagassarium</i> | a          | a  | a  | a  | a  | a   | a        | a  | a  | a  | a  | a  |
| <b>S/R ratio</b>      |            |    |    |    |    |     |          |    |    |    |    |    |
| <i>D. hispidus</i>    | d          | c  | d  | d  | c  | c   | d        | c  | c  | c  | c  | c  |
| <i>D. zeylanicus</i>  | c          | a  | a  | b  | a  | b   | c        | b  | b  | b  | b  | b  |
| <i>M. ferrea</i>      | b          | bc | c  | c  | b  | ab  | b        | b  | b  | b  | b  | b  |
| <i>M. nagassarium</i> | a          | ab | b  | a  | a  | a   | a        | a  | a  | a  | a  | a  |
| <b>Dry mass</b>       |            |    |    |    |    |     |          |    |    |    |    |    |
| <i>D. hispidus</i>    | b          | b  | b  | b  | b  | b   | b        | c  | c  | c  | c  | d  |
| <i>D. zeylanicus</i>  | a          | a  | a  | a  | a  | a   | a        | a  | a  | a  | a  | a  |
| <i>M. ferrea</i>      | b          | c  | c  | c  | c  | c   | a        | b  | b  | b  | b  | b  |
| <i>M. nagassarium</i> | c          | d  | d  | d  | d  | d   | b        | c  | c  | b  | c  | c  |



*Mesua nagassarium* had noticeably longer length stems per root length of seedlings in almost all light treatments irrespective of soil moisture status, except for seedlings in FE and OE light treatments of moist soils where *D. zeylanicus* was greatest. This phenomenon for *M. nagassarium* as compared to the other species was more accentuated in the dry soil as compared to the moist soil treatment. The species with the least stem length per root length was *D. hispidus* in all treatment combinations (Fig. 3). Within genus comparisons always revealed *D. zeylanicus* to have greater stem length per root length than *M. ferrea*.

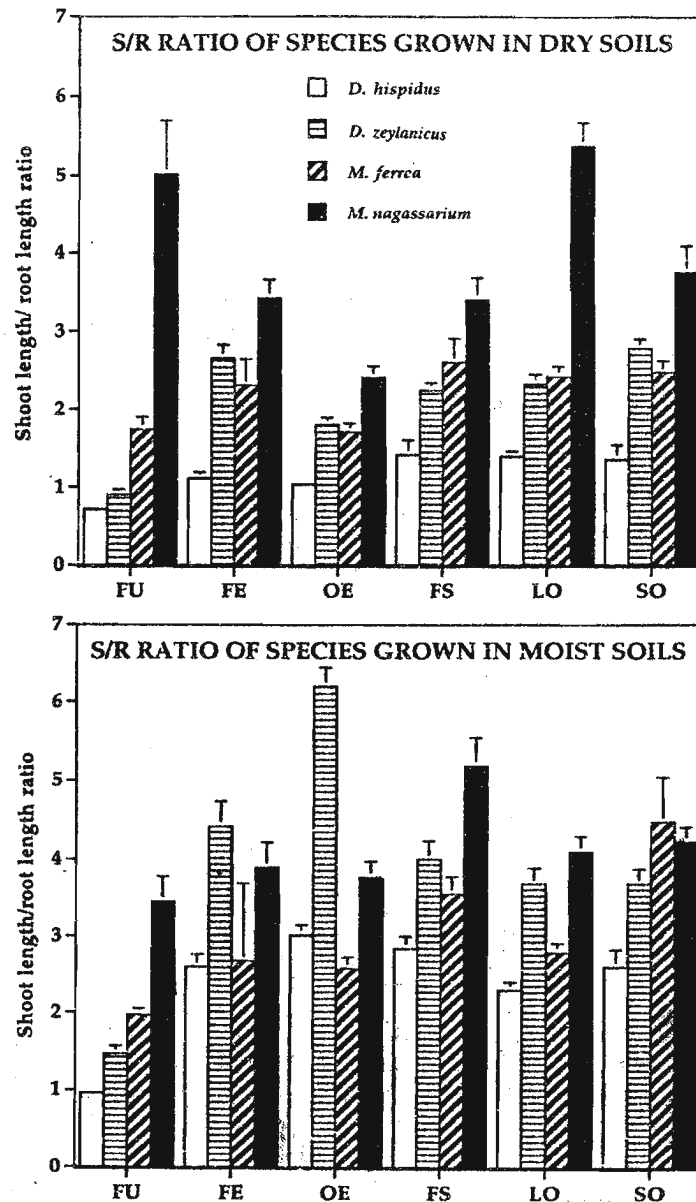


Figure 3: Shoot length/root length ratio of *Dipterocarpus* and *Mesua* species grown in dry and moist soils under different light treatments.

Trends in leaf number among species for all light-soil treatment combinations showed *M. nagassarium* to have the greatest number of leaves followed by *M. ferrea*, *D. zeylanicus* and lastly *D. hispidus* (Fig. 4). Greatest number of leaves of all species were in the brightest light treatments. Moist soils had almost 50% higher number of leaves per seedling for any given light treatment as compared to the dry soil treatments.

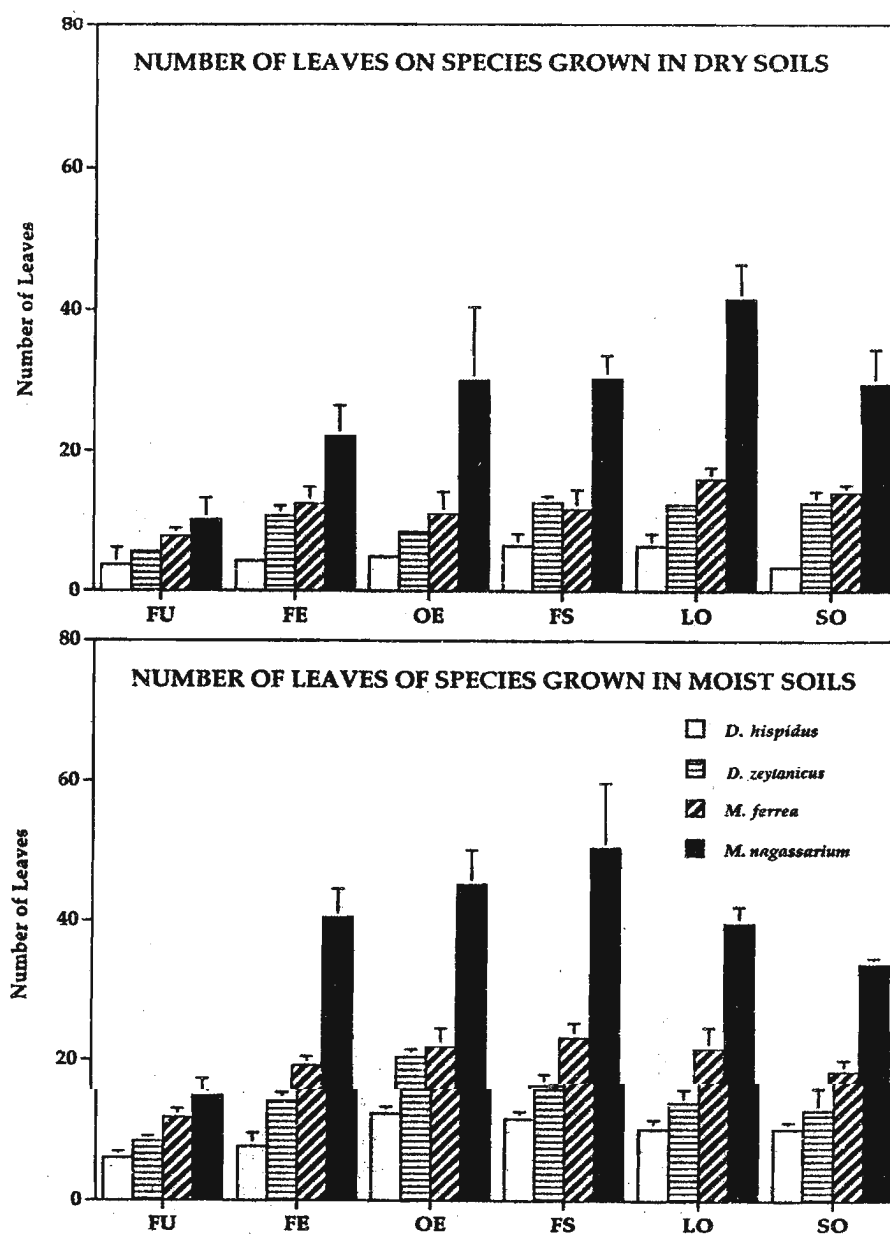


Figure 4 : Number of leaves on *Dipterocarpus* and *Mesua* species grown in dry and moist soils under different light treatments.

### Dry Mass and Mass Ratios

Analyses of variance for seedling dry mass showed significant differences among soil treatments, among light treatments, and in the interactions among both. Analyses of variance showed no significant difference among blocks for any given light-soil treatment combination. Differences among the species for each light-soil treatment combination was determined at the 5% significance level using Tukey's student test (Table 1).

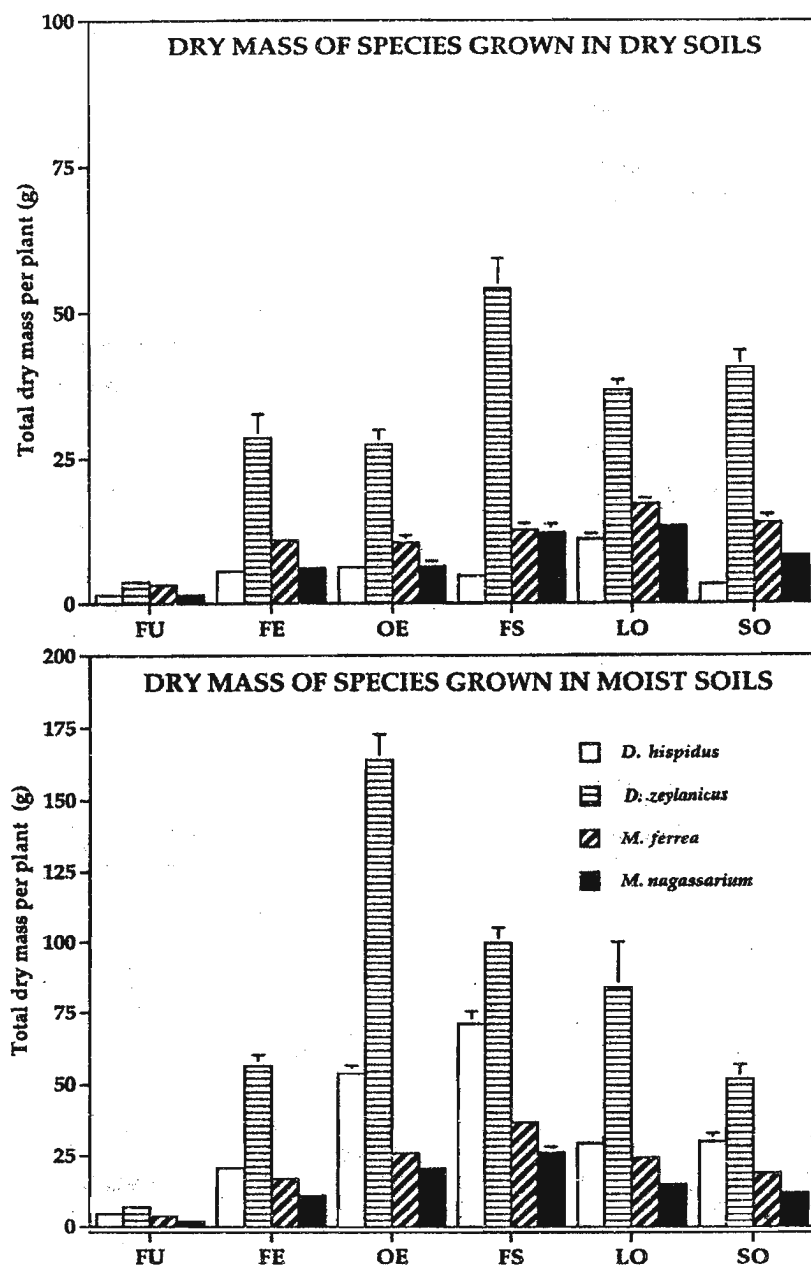


Figure 5 : Total dry mass of *Dipterocarpus* and *Mesua* species grown in dry and moist soils under different light treatments.

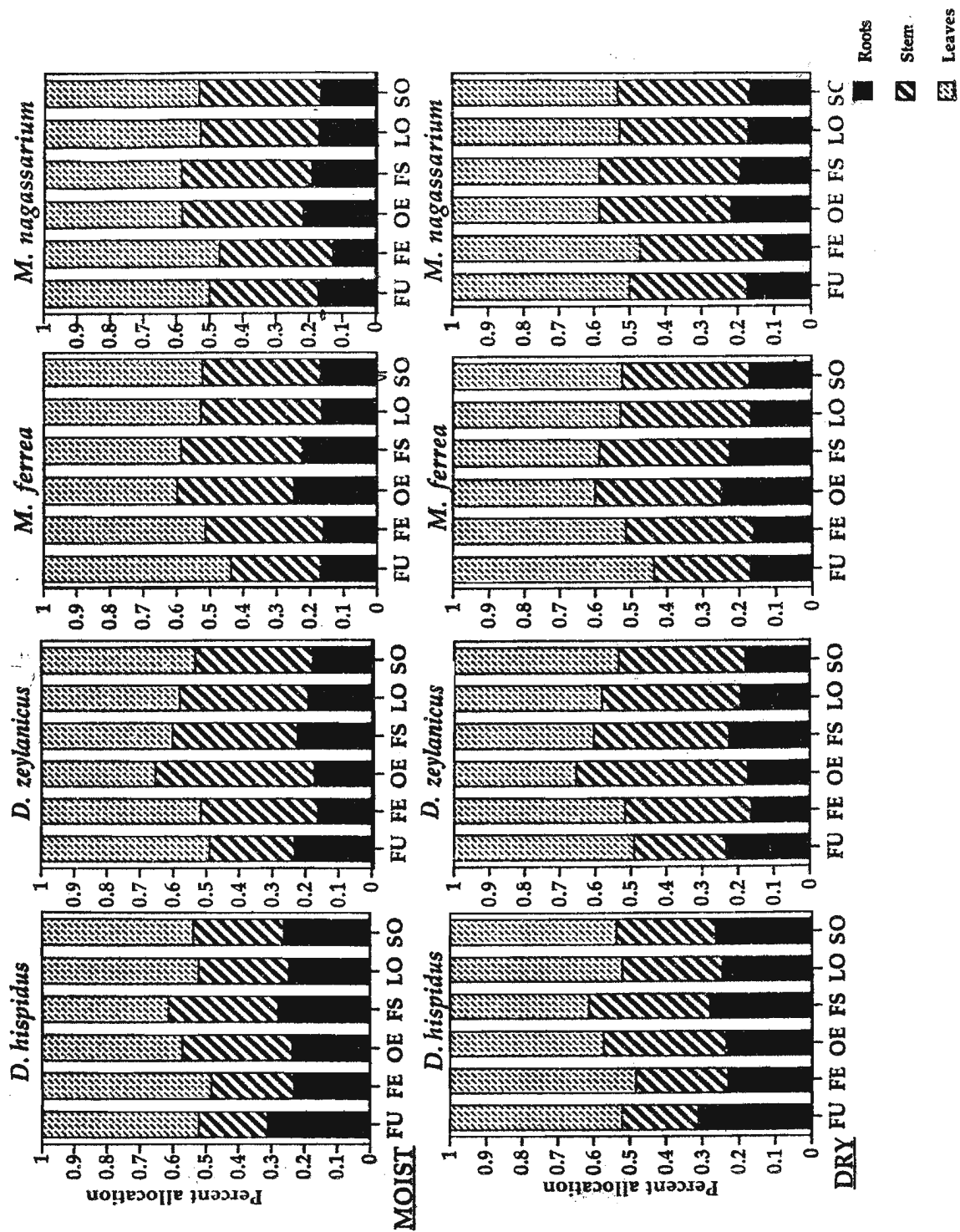


Figure 6: Percentage of allocation to roots, stem and leaves of *Dipterocarpus* and *Mesua* species grown in dry and moist soils under different light treatments.

In the moist soils, highest dry masses for all light treatments were attained by *D. zeylanicus* followed in order by *D. hispidus*, *M. ferrea*, and lastly *M. nagassarium* (Fig. 4). In moist soils *D. zeylanicus* had highest dry mass in the OE treatment, whilst the other species had greatest dry mass in FS. For seedlings that grow in dry soils, higher dry masses for all light treatments were again attained by *D. zeylanicus*, but *M. ferrea* and *M. nagassarium* were higher than *D. hispidus*. In dry soils *D. zeylanicus* had highest dry mass in the FS treatment, whilst the other species had highest dry mass in LO. Dry masses for all species growing within light treatments with moist soils were more than double those corresponding light treatments in the dry soils (Fig. 5).

Ratios of dry mass allocation to roots, stem and leaves are depicted in Fig. 6. General trends suggest greater proportional allocation to roots and stems with the brighter light treatments with overall greater proportional allocation to roots shown by *D. hispidus* followed in order by *D. zeylanicus* and *M. ferrea*, and lastly to *M. nagassarium*.

## DISCUSSION

In this experiment, mortality best reveals an overall picture of comparative success and failure of the species among the different soil moisture treatments. Using only mortality as a measure would suggest *M. nagassarium* to be the most drought tolerant followed in declining order by *M. ferrea*, *Dipterocarpus zeylanicus* and then *D. hispidus*.

Other measures of performance in some cases support this ranking and in others change it. Using height as a measure of performance would indicate that in moist soils both *Mesua* have optimum growth in the brightest light treatments whilst *Dipterocarpus* clearly prefers less than full sun. In both moist and dry soils of forest understorey treatments *Mesua* has greater height than *Dipterocarpus*. These results suggest that *Mesua* species have a wider amplitude of light tolerance than the *Dipterocarpus* species i.e. *Mesua* species grew optimally in full sun but also did better than *Dipterocarpus* species in forest understorey.

The ratio of stem length to root length again suggests differences among the species. *Mesua nagassarium* has a much greater stem length per root length than the other species particularly at low light levels. Reasons for this are unclear because most drought tolerant species have greater allocation to roots than above ground structures. This result suggests that *M. nagassarium* has some physiological or morphological advantage that allows it to afford greater growth in height above ground in both forest understorey and dry soil conditions compared with the other species in this study.

Using dry mass as a measure of growth performance suggests a different result as compared to height. In moist soils *Dipterocarpus* species clearly have higher dry mass per unit length as compared to *Mesua* species. This suggests the stocky nature of

*Dipterocarpus* which would make them structurally stronger with potentially greater storage of carbohydrate reserves as compared to *Mesua* species. However, in dry soils *D. hispidus* does not do well.

In summary, results from this experiment would suggest *D. zeylanicus* to competitively grow best in brighter light environments of open edge where moisture is freely available. Both *Mesua* species are light demanding but can tolerate greater amounts of shade than *Dipterocarpus* species. *Mesua nagassarium* is overall the most drought tolerant though mechanisms for its success in relation to the other study species in these conditions are not clear. *Dipterocarpus hispidus* is clearly the most drought intolerant. However apart from this it is difficult to ascertain under what circumstances *D. hispidus* has a competitive advantage over its associates in this study.

### ACKNOWLEDGEMENT

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# SEEDLING LEAF-STRUCTURE OF SOME LATE-SUCCESSIONAL CANOPY TREE SPECIES IN SIMULATED LIGHT AND SOIL MOISTURE ENVIRONMENTS OF A SRI LANKAN RAIN FOREST

H.K.Gamage, B.M.P.Singhakumara and P.M.S.Ashton

## ABSTRACT

*This study examines the variation in leaf structure among seedlings of four canopy tree species that have been characterized as late-successional and relatively shade-tolerant. Seedlings of Dipterocarpus zeylanicus Thw., D. hispidus Thw., Mesua ferrea L., and M. nagassarium (Burm.f) Kosterm., were grown for two years within replicated environmental shelters that had various light and soil moisture treatments. These treatments reflected the range of microenvironments that have been observed within the mixed-dipterocarp forest of southwestern Sri Lanka. Three light treatments exposed seedlings to uniform diffuse light conditions that simulated amounts and qualities of radiation like that of the forest understorey and forest edge (PPFD, 50, 350, and 800 mol m<sup>-2</sup> s<sup>-1</sup>). Two treatments also exposed seedlings to amounts of direct radiation that were comparable to the centres of 200m<sup>2</sup> and 400m<sup>2</sup> canopy openings. A control treatment exposed seedlings to full sun (1600 mol m<sup>-2</sup> s<sup>-1</sup>). For each light treatment seedlings were grown in either soil that was regularly watered to field capacity or soil that was consistently <30% of field capacity. At the end of two years leaf samples were taken for each species and light-soil moisture combination. Measurements were made of leaf blade thickness, stomatal frequency, and thicknesses of upper epidermal, palisade mesophyll, and lower epidermal cell layers. Significant differences in leaf structure were shown among species and among the various treatments.*

*In general all species showed leaf dimensions and cell layers that increased with increase in amount of light and decrease in availability of soil moisture. Largest dimensions were therefore recorded from leaves exposed to full sun but grown in relatively dry soil. Mesua ferrea exhibited the thickest leaf blades followed by M. nagassarium, D. zeylanicus and lastly D. hispidus. Dipterocarpus zeylanicus had greater thicknesses of epidermal and palisade mesophyll layers than M. ferrea. This suggested that M. ferrea has a much thicker spongy mesophyll layer than the other species. Unlike Mesua, both Dipterocarpus species exhibited double rows of cells within the palisade mesophyll and lower epidermal layers in certain treatments. This phenomenon increased in frequency with the amount of light. Greatest densities of stomata were measured for D. hispidus followed in declining order by M. ferrea, M. nagassarium and D. zeylanicus. Difference in shade and drought tolerance among species in relation to site specialization is discussed.*



## INTRODUCTION

Within a forest, different microenvironments can be observed due to disturbance of the canopy. Type, size and periodicity of disturbance affects the nature of the forest groundstorey (Ashton, Gunatilleke & Gunatilleke 1993). Disturbances in moist tropical forests allow understorey vegetation to survive when a canopy opening is created. Many tropical rain forest tree species seem to depend on, or benefit from, canopy openings for successful regeneration (Popma & Bongers 1988). Depending upon the size of the opening, the temperature, relative humidity, amount and quality of light, and availability of soil moisture can change. Seedlings at the groundstorey must respond to these changes in order to survive and grow.

In particular these microenvironmental changes will affect the anatomy and morphology of seedling leaves. The ability of seedling leaves to change in their anatomy and morphology in response to change in environment has been termed phenotypic plasticity (Young & Giese 1990). For example, seedling leaves that are exposed to high amounts of light have physiological and anatomical adaptations similar to drought avoiding plants, while shade leaves often resemble those of drought intolerant species. Shade leaves are larger and thinner, while sun leaves are smaller and thicker (Transeau *et al.* 1940; Jackson 1966 Vogel 1968; Nobel 1977; Kramer 1983; Keller *et al.* 1987).

Many studies have shown that leaf anatomy and morphology differ between tree species categorized as pioneers and late-successional, or sun-loving and shade-tolerant (Carpenter & Smith 1975; Fetcher *et al.* 1983; Vogel 1968; Loach 1967). But few studies have examined the changes in leaf structure among tree species considered to belong to the same ecological grouping (e.g. successional status, light tolerance), (Ashton & Berlyn 1992). There are no studies on these changes within an ecological grouping, under differing availability of soil moisture.

Our study examined the variation in leaf structure among seedlings of four canopy tree species that have been characterized as late-successional and relatively shade-tolerant. We tested the hypotheses that anatomical attributes of seedling leaves can be modified by growing them under different light intensities and soil moisture regimes of the forest. Specially we examined seedling leaf adaptation of four species *Dipterocarpus zeylanicus* Thw., *D.hispidus* Thw., *Mesua ferrea* L., *M. nagassarium* (Burm.f.) Kosterm that occur in the rain forest of southwest Sri Lanka.

## METHODS AND MATERIALS

### Site description

The study was carried out at the field station of the Sinharaja Man and the Biosphere Reserve of southwest Sri Lanka. The annual rainfall is about 5000mm with mean monthly

temperatures ranging between 25 and 27°C (Ashton 1992). The topography is undulating between valley and ridge with a mean elevation above sea level of about 600m. The forest has been classified by De Rosayro (1942) and Gunatilleke & Ashton (1987) as a *Mesua-Shorea* type. The four species in this study belong to the family Dipterocarpaceae (Dipterocarpus) and Clusiaceae (*Mesua*). *Dipterocarpus zeylanicus*, *D. hispidus* and *Mesua ferrea* are endemic to southwest Sri Lanka. All four species are often dominant in the canopy stratum of late-successional forest. Both *D. zeylanicus* and *D. hispidus* are widespread in the lower elevations that are below 300m altitude (Dassanayake, 1980; FAO, 1985). They are often gregarious on river banks and well drained moist soils. *Mesua ferrea* occurs in or near streams, but not on low lying poorly drained land. *Mesua nagassarium* is generally restricted to ridgetops.

## EXPERIMENTAL DESIGN

In order to examine the anatomical differences of the four species, six controlled environmental shelters were constructed. These shelters were built to study the growth performance of *Dipterocarpus* and *Mesua* under different light and soil moisture regimes. The quality, quantity and duration of light and the degree of soil moisture were controlled in each shelter. The quality of light was altered by using a mix of particular pigments in a varnish base that was sprayed onto a clear plastic film. Three light treatments exposed seedlings to uniform diffuse light conditions that simulated amounts and qualities of radiation like that of the forest understorey (FU) and inside forest edge (FE) and outside forest edge (OE), (maximum photon photosynthetic fluxes (PPFD) of 50, 350 and 800 mol m<sup>-2</sup> s<sup>-1</sup>). Two treatments also exposed seedlings to amounts of direct radiation, that were comparable to the centers of 100m<sup>2</sup> (SO) and 400m<sup>2</sup> (LO) canopy openings respectively. This was created by a series of parallel vertical slats aligned north-south 1.5m above seedlings growing within the shelter space. As the sun rose from the east and set in the west the duration and number of sunlight periods were controlled by slat orientation (N-S). Lastly, a control treatment exposed seedlings to full sun (FS), (maximum 2000 mol m<sup>-2</sup> s<sup>-1</sup>). There were four replicates per light treatment.

In each light treatment two watering treatments were set up that were designed to examine the effect of soil moisture on seedling growth. The ever moist soil condition (100% relative moisture content, RMC) had 2 l m<sup>-2</sup> water thrice a week. The dry soil condition had 2 l m<sup>-2</sup> water applied when the RMC declined below 30%. In each watering regime RMC was monitored by using a battery-operated soil moisture meter (Bouyocos, 1953, 1972) that was attached to gypsum blocks buried in the soil.

Seeds of each species were collected from different parent trees, mixed, and germinated on a nursery bed. In January 1993, when the seedlings were one month old, they were taken from the nursery and planted in the shelters. Seedlings were planted in forest top-soil mixed with sand in 1:1 ratio. Seedlings of each species were placed together in groups of nine. Four groups of seedlings, each group representing a different species, comprised a block. Four blocks were represented for each light-soil moisture combination.

### Anatomy measurements

To study the internal leaf structures, permanent slides were prepared. For each light-soil moisture combination three sample leaves were taken from different seedlings for each species. Seedlings were two years old when the leaf samples were taken. All leaves selected for the study were fully expanded, undamaged and with no signs of herbivory. A 0.5x1 cm section was taken from the middle portion of the lamina across the mid-rib of each leaf. These strips were immediately fixed in FAA (formalin:acetic acid:ethanol), dehydrated in ethanol, immersed in a xylene series and then embedded in wax. A rotary microtome was used to cut 10  $\mu$ m thickness sections. These were stained with safranin and fast green and then mounted in Canada balsam (Berlyn & Miksche 1976). Three slides were made from each leaf strip.

In each slide, leaf blade thickness and component dimensions (palisade cell depth, palisade layer thickness, ratio of double layering of palisade cells, upper epidermal cell depth, lower epidermal cell depth, lower epidermal cell layer thickness), were measured. Six measurements were made on a slide for each parameter, avoiding the region of mid-rib. This was done by viewing through a Leitz light microscope using a 0.05x100 mm micrometer eye-piece and 0.01x100 mm objective. Cell dimensions were taken at 400 x magnification and leaf thickness at 100 x magnification.

For *D. zeylanicus* and *M. nagassarium* stomatal frequencies were observed from cellulose acetate positives of silicone rubber impressions (Heichel 1971). In *M. ferrea* the stomata were chambered and *D. hispidus* comprised hairs on the leaf under-surface. Peels were therefore taken and boiled with alcohol in order to observe the stomata. Each impression or peel was taken midway between the base and tip on the adaxial and abaxial surfaces of a separate leaf. Five leaf impressions/peels, were used for each species and light-soil moisture combination. For each impression or peel, three different fields of view were sampled. Number of stomata was counted using an eye-piece graticule at 400 x magnification.

### Data analysis

Data were analyzed by ANOVA using the general linear model,(GLM) procedure of SAS (Ray 1982). Analyses tested for differences between species, light treatments, soil moisture treatments and interactions between species and treatments. Differences among the treatments and species were determined at the 5% significance level using Tukey's method.

## RESULTS

### Stomatal frequency

In all four species stomata were found only on the abaxial surface and this corroborates many other studies of tree species (Metcalf & Chalk 1965). Stomatal frequency increased

with increasing amounts of light intensity. The highest stomatal frequency was observed in leaves that were exposed to full sun. Differences between species were also apparent within the same light treatment. Between the dipterocarps, *D. hispidus* had higher stomatal frequency, but in *Mesua*, both species were similar in stomatal frequency in some light treatments, but overall *M. ferrea* had higher stomatal frequency than *M. nagassarium*. Comparing all four species *D. hispidus* had highest stomatal frequency followed in declining order by *M. ferrea*, *M. nagassarium* and lastly *D. zeylanicus*. In general, within the same light treatment and when comparing the same species, stomatal frequency was significantly ( $p < 0.05$ ), different between leaves of seedlings grown in ever moist soils. However this was the case in only about two thirds of the species-treatment comparisons.

### Leaf blade thickness

Leaf blade thickness increased with increase in amount of light (Table 2, Fig.2). The thickest leaf blade was observed in full sun treatment for all species. Differences between species were significant ( $p < 0.05$ ) within the same light treatment. In *Dipterocarpus* the thickest leaf blade was observed in *D. zeylanicus*. For *Mesua*, the leaf blade was not significantly different ( $p < 0.05$ ) among species, within same light treatment excepting LO and SO light treatments. In these environments, *M. ferrea* had the thickest leaf blade. When comparing all species together, leaf blade thickness was greatest for *M. ferrea* followed in declining order by *M. nagassarium*, *D. zeylanicus* and lastly by *D. hispidus*. *Mesua* species therefore had a higher blade thickness than *Dipterocarpus* species.

In most instances significant differences ( $p < 0.05$ ) in leaf blade thickness could not be observed between ever moist and dry soil moisture treatments. The only exception was the understorey light intensity for all species except light treatment (FU). In this treatment *D. zeylanicus*, *M. ferrea* and *M. nagassarium* showed differences. These species had thicker blades when seedlings had been grown in the ever moist soil treatment.

### Component dimensions

Significant differences ( $p < 0.05$ ) in epidermal cell thickness were shown among the different light and soil moisture treatments. These differences were apparent for both upper (Table 3, Fig. 3) and lower epidermal cells (Table 4). Both upper and lower epidermal cell depth was greatest in FS treatment ( $2000 \mu \text{mol m}^{-2} \text{s}^{-1}$ ). In dipterocarps, *D. zeylanicus* had the greatest upper epidermal cell thickness but in *Mesua* both species were usually similar within the same light treatment. Dipterocarps had significantly thicker upper epidermal cells than both *Mesua* species.

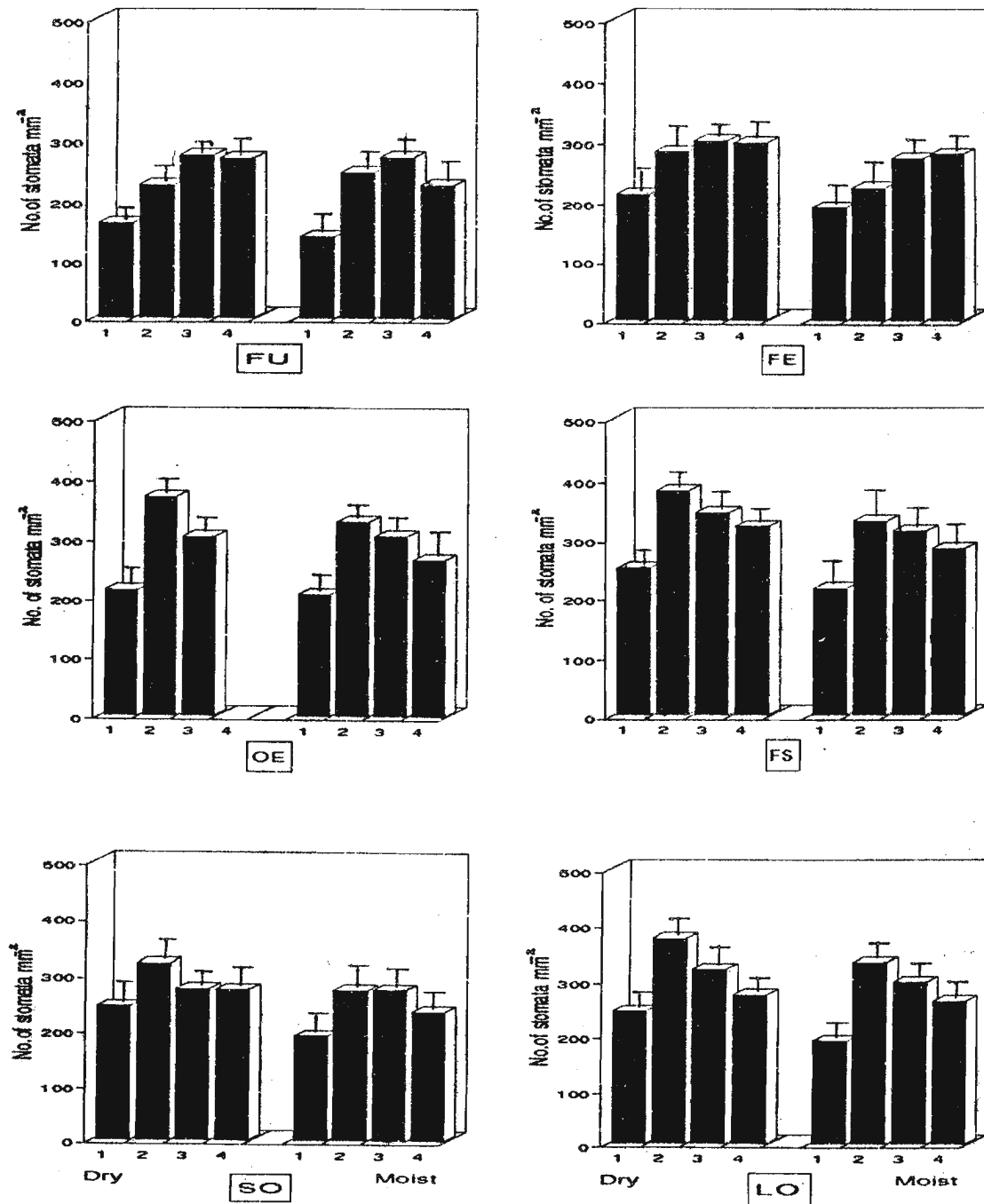


Figure 1 : Stomatal frequency of leaves for *D. zeylanicus* (1), *D. hispidus* (2), *M. ferrea* (3) and *M. nagassarium* (4); under different light and soil moisture treatments (FU-forest understorey; FE-inside forest edge; OE-outside forest edge; FS-full sun; SO-centre of small opening; LO-centre of large opening).

**Table 1 : Summary of stomatal frequency for each species for six light and two soil moisture treatments. Data are means from different leaves with standard errors in parentheses. Lower case letters beside the means denote differences between the soil moisture treatments for each species at the 5% level of significance. Capital letters denote differences between species for each light treatment at the 5% level of significance. Treatments or species followed by the same letter are not significantly different from each other.**

(FU-forest understorey; FE-inside forest edge; OE-outside forest edge; FS-full sun; SO-centre of small opening; LO-centre of large opening).

| Stomatal frequency (No.mm <sup>-2</sup> ) | Species |               | Moisture |                |
|-------------------------------------------|---------|---------------|----------|----------------|
|                                           |         | Dry           |          | Moist          |
| <b>FU</b>                                 |         |               |          |                |
| <i>D.zeylanicus</i>                       | B       | 162.22(1.28)a |          | 140.00(7.81)b  |
| <i>D.hispidus</i>                         | A       | 226.66(16.7)b |          | 247.41(12.7)a  |
| <i>M.ferrea</i>                           | A       | 275.56(9.25)a |          | 271.85(9.01)a  |
| <i>M.nagassarium</i>                      | A       | 270.37(14.8)a |          | 225.93(13.0)b  |
| <b>FE</b>                                 |         |               |          |                |
| <i>D.zeylanicus</i>                       | B       | 212.59(8.73)a |          | 191.11(6.42)a  |
| <i>D.hispidus</i>                         | A       | 282.22(21.8)a |          | 224.44(8.01)b  |
| <i>M.ferrea</i>                           | A       | 300.74(7.06)a |          | 271.85(4.51)b  |
| <i>M.nagassarium</i>                      | A       | 296.30(20.5)a |          | 241.484(9.49)b |
| <b>OE</b>                                 |         |               |          |                |
| <i>D.zeylanicus</i>                       | C       | 213.33(14.3)a |          | 207.41(7.84)a  |
| <i>D.hispidus</i>                         | A       | 369.63(8.15)a |          | 2328.15(5.79)b |
| <i>M.ferrea</i>                           | B       | 302.96(4.86)a |          | 304.45(5.59)a  |
| <i>M.nagassarium</i>                      | NA      |               |          | 266.67(14.79)  |
| <b>FS</b>                                 |         |               |          |                |
| <i>D.zeylanicus</i>                       | C       | 250.37(11.2)a |          | 215.55(16.8)b  |
| <i>D.hispidus</i>                         | A       | 380.74(8.15)a |          | 331.85(22.1)b  |
| <i>M.ferrea</i>                           | AB      | 345.19(8.54)a |          | 314.07(7.07)b  |
| <i>M.nagassarium</i>                      | B       | 322.22(3.40)a |          | 283.70(5.79)b  |
| <b>SO</b>                                 |         |               |          |                |
| <i>D.zeylanicus</i>                       | B       | 244.44(11.8)a |          | 190.37(12.1)b  |
| <i>D.hispidus</i>                         | A       | 318.52(17.3)a |          | 274.08(20.8)b  |
| <i>M.ferrea</i>                           | A       | 276.30(3.70)a |          | 274.82(10.7)a  |
| <i>M.nagassarium</i>                      | AB      | 274.81(15.7)a |          | 236.30(13.5)a  |
| <b>LO</b>                                 |         |               |          |                |
| <i>D.zeylanicus</i>                       | D       | 245.93(9.97)a |          | 191.11(8.98)b  |
| <i>D.hispidus</i>                         | A       | 375.55(8.41)a |          | 332.59(7.30)b  |
| <i>M.ferrea</i>                           | B       | 320.00(7.70)a |          | 297.78(10.2)b  |
| <i>M.nagassarium</i>                      | C       | 275.56(1.28)a |          | 264.44(7.15)a  |

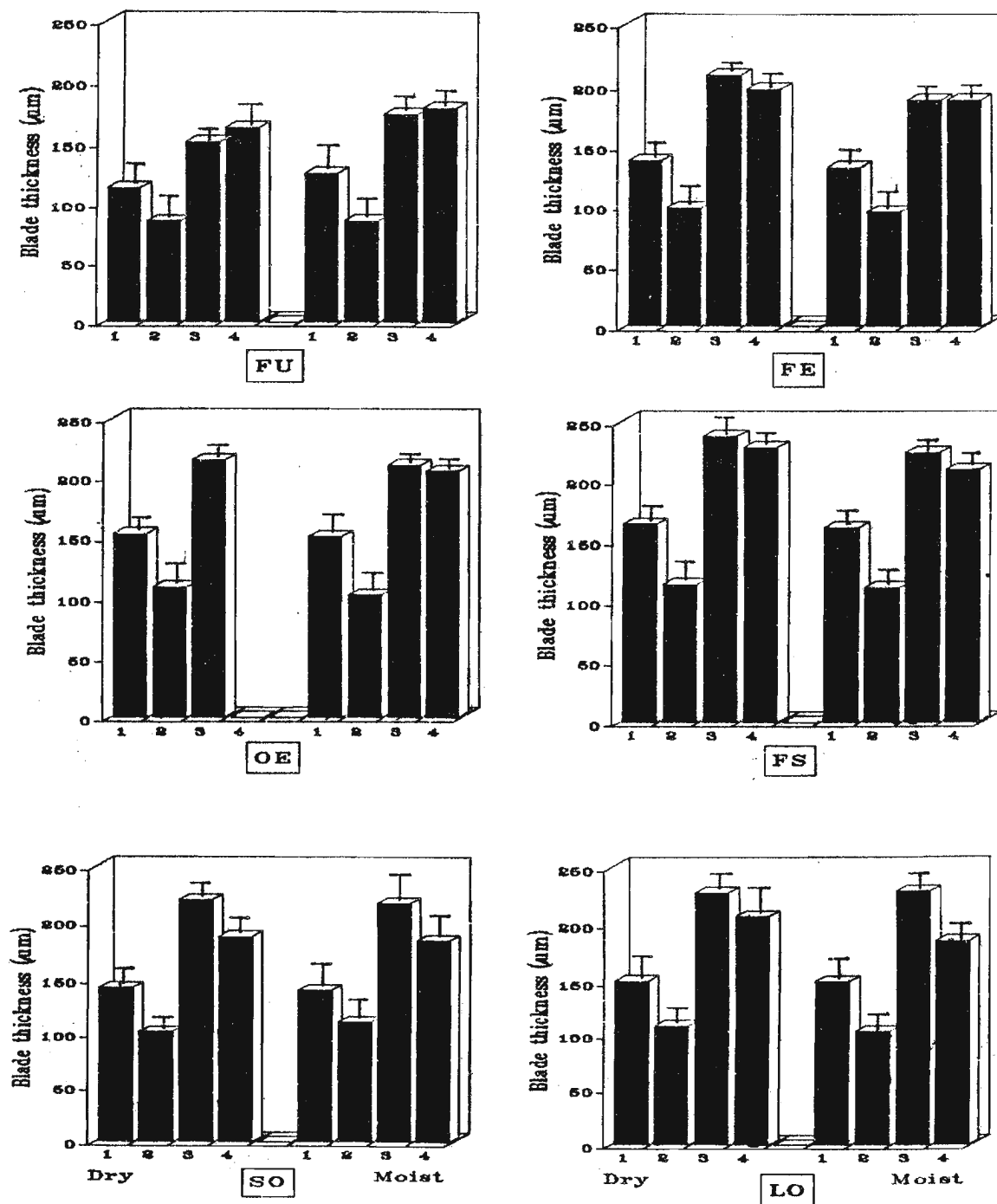


Figure 2 : Leaf blade thickness of leaves for *D. zeylanicus* (1), *D. hispidus* (2), *M. ferrea* (3) and *M. nagassarium* (4); under different light and soil moisture treatments.

**Table 2 :** Summary of leaf blade thickness for the four species in each of the six light and two soil moisture treatments. Data are means from different leaves with standard errors in parentheses. Lower case letters beside the means denote differences between the soil moisture treatments for each species at the 5% level of significance. Capital letters denote differences between species at the 5% level of significance. Treatments or species followed by the same letter are not significantly different from each other.

| Blade thickness( $\mu\text{m}$ ) | Species | Moisture      |               |
|----------------------------------|---------|---------------|---------------|
|                                  |         | Dry           | Moist         |
| <b>FU</b>                        |         |               |               |
| <i>D.zeylanicus</i>              | B       | 113.87(2.08)b | 126.07(3.39)a |
| <i>D.hispidus</i>                | C       | 85.30(5.03)a  | 85.60(1.64)a  |
| <i>M.ferrea</i>                  | A       | 151.07(0.88)b | 173.90(3.85)a |
| <i>M.nagassarium</i>             | A       | 162.57(3.44)b | 179.40(0.68)a |
| <b>FE</b>                        |         |               |               |
| <i>D.zeylanicus</i>              | B       | 138.67(2.81)a | 133.50(0.86)a |
| <i>D.hispidus</i>                | C       | 99.23(2.36)a  | 96.07(1.16)a  |
| <i>M.ferrea</i>                  | A       | 209.20(2.16)a | 189.20(2.02)b |
| <i>M.nagassarium</i>             | A       | 197.83(4.17)a | 189.27(3.97)a |
| <b>OE</b>                        |         |               |               |
| <i>D.zeylanicus</i>              | B       | 152.93(2.46)a | 150.73(1.54)a |
| <i>D.hispidus</i>                | C       | 109.07(6.48)a | 102.67(2.68)a |
| <i>M.ferrea</i>                  | A       | 214.97(3.75)a | 210.33(2.01)a |
| <i>M.nagassarium</i>             |         | NA            | 205.80(2.25)  |
| <b>FS</b>                        |         |               |               |
| <i>D.zeylanicus</i>              | B       | 163.93(2.75)a | 161.13(2.46)a |
| <i>D.hispidus</i>                | C       | 114.87(2.65)a | 112.07(4.78)a |
| <i>M.ferrea</i>                  | A       | 238.43(10.7)a | 224.56(2.06)b |
| <i>M.nagassarium</i>             | A       | 228.87(2.92)a | 209.94(1.56)b |
| <b>SO</b>                        |         |               |               |
| <i>D.zeylanicus</i>              | C       | 143.50(5.92)a | 141.94(4.69)a |
| <i>D.hispidus</i>                | D       | 102.44(0.73)a | 112.47(3.93)a |
| <i>M.ferrea</i>                  | A       | 220.89(3.09)a | 218.20(6.38)a |
| <i>M.nagassarium</i>             | B       | 187.70(1.49)a | 184.45(2.60)a |
| <b>LO</b>                        |         |               |               |
| <i>D.zeylanicus</i>              | C       | 150.97(6.73)a | 150.47(4.89)a |
| <i>D.hispidus</i>                | D       | 109.63(2.93)a | 103.93(1.47)a |
| <i>M.ferrea</i>                  | A       | 228.20(0.76)a | 229.07(1.35)a |
| <i>M.nagassarium</i>             | B       | 206.78(8.38)a | 185.22(4.18)b |



**Table 3 :** Summary of upper epidermal cell thickness for each species for six light and two soil moisture treatments. Data are means from different leaves with standard errors in parentheses. Lower case letters beside the means denote differences between the soil moisture treatments for each species at the 5% level of significance. Capital letters denote differences between species for light treatment at the 5% level of significance. Treatments or species followed by the same letter are not significantly different from each other.

| Upper epidermal cell thickness ( $\mu\text{m}$ ) | Species | Moisture      |               |
|--------------------------------------------------|---------|---------------|---------------|
|                                                  |         | Dry           | Moist         |
| <b>FU</b>                                        |         |               |               |
| <i>D. zeylanicus</i>                             | A       | 25.56(1.27)a  | 25.30(0.402)a |
| <i>D. hispidus</i>                               | B       | 17.96(0.399)a | 14.63(0.693)b |
| <i>M. ferrea</i>                                 | C       | 7.26(0.253)a  | 7.53(0.067)a  |
| <i>M. nagassarium</i>                            | C       | 6.36(0.091)b  | 6.83(0.114)a  |
| <b>FE</b>                                        |         |               |               |
| <i>D. zeylanicus</i>                             | A       | 29.96(0.499)a | 26.93(0.392)b |
| <i>D. hispidus</i>                               | B       | 20.48(0.448)a | 16.02(0.450)b |
| <i>M. ferrea</i>                                 | C       | 8.06(0.130)a  | 7.19(0.106)a  |
| <i>M. nagassarium</i>                            | C       | 8.55(0.314)a  | 7.83(0.196)a  |
| <b>OE</b>                                        |         |               |               |
| <i>D. zeylanicus</i>                             | A       | 29.30(0.610)a | 29.61(1.18)a  |
| <i>D. hispidus</i>                               | B       | 22.80(1.27)a  | 16.64(0.27)b  |
| <i>M. ferrea</i>                                 | C       | 8.40(0.254)a  | 7.64(0.286)a  |
| <i>M. nagassarium</i>                            | C       | NA            | 7.73(0.084)   |
| <b>FS</b>                                        |         |               |               |
| <i>D. zeylanicus</i>                             | A       | 33.22(1.33)a  | 32.20(0.937)a |
| <i>D. hispidus</i>                               | B       | 22.88(1.31)a  | 17.86(0.499)b |
| <i>M. ferrea</i>                                 | C       | 9.81(0.046)a  | 8.20(0.115)b  |
| <i>M. nagassarium</i>                            | C       | 8.28(0.135)a  | 8.36(0.053)a  |
| <b>SO</b>                                        |         |               |               |
| <i>D. zeylanicus</i>                             | A       | 30.94(1.22)a  | 29.42(3.32)a  |
| <i>D. hispidus</i>                               | B       | 18.40(1.31)a  | 16.67(0.617)a |
| <i>M. ferrea</i>                                 | C       | 7.87(0.115)a  | 7.30(0.205)a  |
| <i>M. nagassarium</i>                            | C       | 8.15(0.260)a  | 7.00(0.412)a  |
| <b>LO</b>                                        |         |               |               |
| <i>D. zeylanicus</i>                             | A       | 28.66(0.637)a | 26.70(0.325)a |
| <i>D. hispidus</i>                               | B       | 22.46(0.695)a | 18.26(0.505)b |
| <i>M. ferrea</i>                                 | C       | 7.86(0.184)a  | 8.06(0.173)a  |
| <i>M. nagassarium</i>                            | C       | 8.01(0.230)a  | 8.06(0.199)a  |

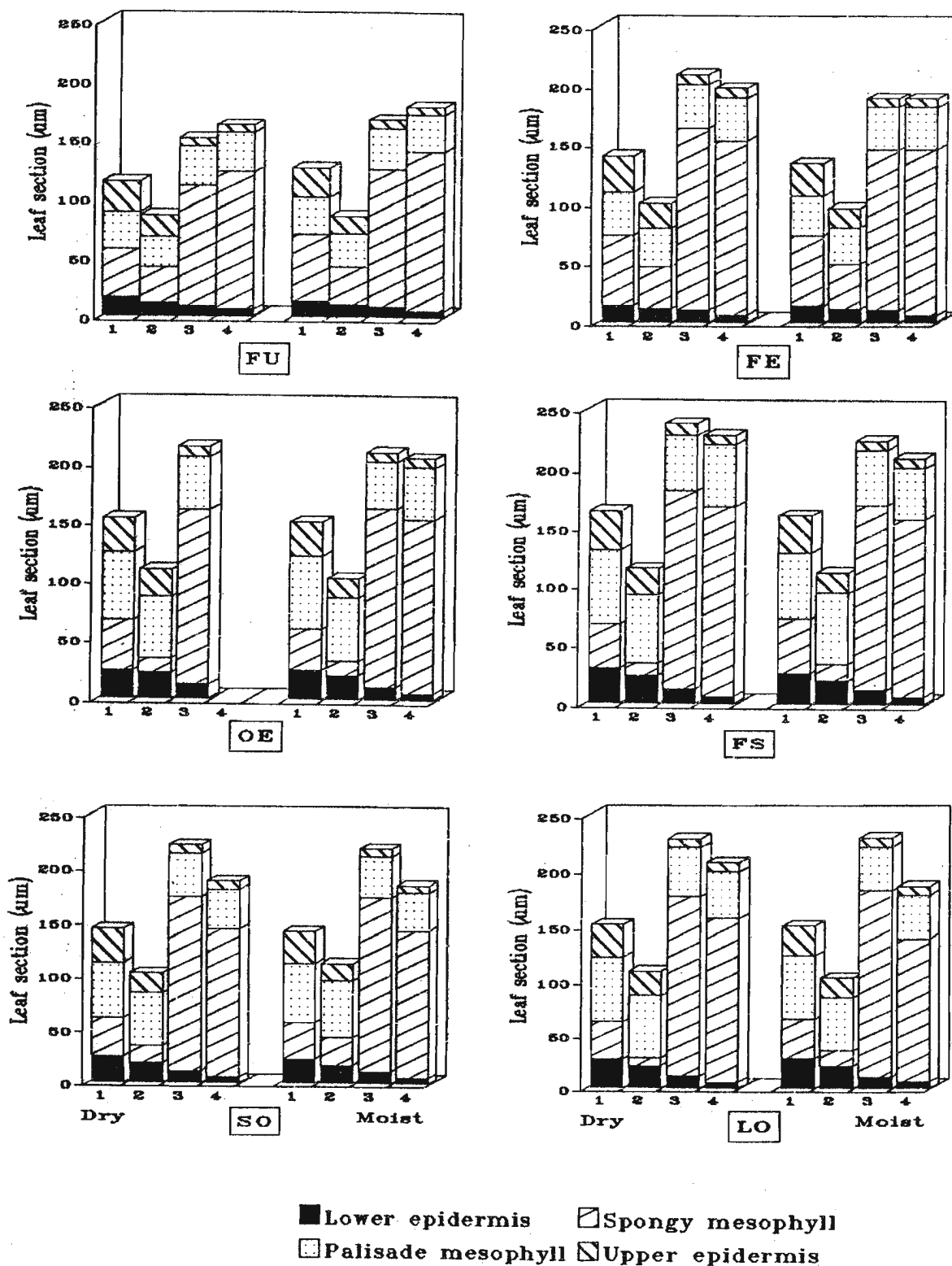


Figure 3 : Stylized leaf cross-sections of leaves for *D. zeylanicus* (1), *D. hispidus* (2), *M. ferrea* (3) and *M. nagassarium* (4); under different light and soil moisture treatments.

**Table 4 :** Summary of lower epidermal cell thickness for the four species in of six light and two soil moisture treatments. Data are means from different leaves with standard errors in parentheses. Lower case letters beside the means denote differences between the soil moisture treatments for each species at the 5% level of significance. Capital letters denote differences between species for each light treatment at the 5% level of significance. Treatments or species followed by the same letter are not significantly different from each other.

| Lower epidermal cell thickness ( $\mu\text{m}$ ) | Species | Dry           |  | Moisture      |  |
|--------------------------------------------------|---------|---------------|--|---------------|--|
|                                                  |         | Dry           |  | Moist         |  |
| <b>FU</b>                                        |         |               |  |               |  |
| <i>D. zeylanicus</i>                             | A       | 15.38(0.608)a |  | 13.39(0.264)b |  |
| <i>D. hispidus</i>                               | B       | 11.23(0.232)a |  | 10.70(0.274)a |  |
| <i>M. ferrea</i>                                 | C       | 8.63(0.340)a  |  | 9.10(0.071)a  |  |
| <i>M. nagassarium</i>                            | D       | 5.86(0.903)a  |  | 5.26(0.137)a  |  |
| <b>FE</b>                                        |         |               |  |               |  |
| <i>D. zeylanicus</i>                             | A       | 13.75(0.569)a |  | 13.36(0.148)a |  |
| <i>D. hispidus</i>                               | B       | 11.16(0.347)a |  | 10.80(0.252)a |  |
| <i>M. ferrea</i>                                 | C       | 9.85(0.406)a  |  | 9.95(0.301)a  |  |
| <i>M. nagassarium</i>                            | D       | 5.96(0.048)a  |  | 5.56(0.302)a  |  |
| <b>OE</b>                                        |         |               |  |               |  |
| <i>D. zeylanicus</i>                             | A       | 14.53(0.947)a |  | 12.83(0.287)a |  |
| <i>D. hispidus</i>                               | B       | 12.81(0.305)a |  | 11.83(0.517)a |  |
| <i>M. ferrea</i>                                 | B       | 11.91(0.209)a |  | 10.74(0.254)b |  |
| <i>M. nagassarium</i>                            |         | NA            |  | 5.40(0.106)   |  |
| <b>FS</b>                                        |         |               |  |               |  |
| <i>D. zeylanicus</i>                             | A       | 17.93(0.888)a |  | 15.58(0.551)b |  |
| <i>D. hispidus</i>                               | B       | 12.79(0.301)a |  | 11.83(0.517)a |  |
| <i>M. ferrea</i>                                 | B       | 12.55(0.497)a |  | 11.86(0.340)a |  |
| <i>M. nagassarium</i>                            | C       | 6.27(0.179)a  |  | 6.29(0.081)a  |  |
| <b>SO</b>                                        |         |               |  |               |  |
| <i>D. zeylanicus</i>                             | A       | 14.27(0.680)a |  | 13.57(0.342)a |  |
| <i>D. hispidus</i>                               | B       | 10.77(0.395)a |  | 11.46(0.684)a |  |
| <i>M. ferrea</i>                                 | B       | 11.66(0.139)a |  | 10.93(0.575)a |  |
| <i>M. nagassarium</i>                            | C       | 5.63(0.485)a  |  | 5.36(0.167)a  |  |
| <b>LO</b>                                        |         |               |  |               |  |
| <i>D. zeylanicus</i>                             | A       | 15.53(0.700)a |  | 15.36(0.231)a |  |
| <i>D. hispidus</i>                               | B       | 12.36(0.140)a |  | 12.60(0.199)a |  |
| <i>M. ferrea</i>                                 | C       | 11.86(0.231)a |  | 11.30(0.415)a |  |
| <i>M. nagassarium</i>                            | D       | 5.70(0.144)a  |  | 6.10(0.256)a  |  |

Lower epidermal cell thickness was significantly different ( $p < 0.05$ ) among all species for any given light treatment. *D. zeylanicus* had the greatest lower epidermal cell thickness, followed in declining order by *D. hispidus*, *M. ferrea* and lastly by *M. nagassarium*. *Mesua ferrea* also had a papillated lower epidermal cell layer with sunken stomata. In most

comparisons between ever moist and dry soils, differences in lower epidermal cell thicknesses for a species were not significant. This was also generally the case for comparisons between ever moist and dry soil, treatments for upper epidermal cell thickness. Where it was not the case, the dry soil treatment usually showed thicker cell dimensions than the ever moist soil treatment.

Unlike *Mesua*, both dipterocarps exhibited double rows of lower epidermal cells. This could be observed only in the higher light treatments, declining in the following order FS>LO>OE>SO (Table 5). *D. zeylanicus* had the thickest epidermal cell layer compared to *D. hispidus* for each light treatment. When grown in the same light treatment species lower epidermal layer thicknesses of *Dipterocarpus* did not change significantly ( $p<0.05$ ), when comparing ever moist and dry soil moisture treatments.

For all species palisade mesophyll thicknesses were significant ( $p<0.05$ ), (Table 6). Since the palisade cell structure largely depends upon the intensity of light (Simon *et al.* 1973), the palisade cell depth increased with increase in light intensity and varied among treatments as follows: FS>LO>OE>SO>FE>FU. Significant differences ( $p<0.05$ ) were also apparent among species within a light treatment. Between the dipterocarps palisade cell depth was highest in *D. zeylanicus*, for all light treatments. However for *Mesua* there was no significant difference ( $p<0.05$ ) in palisade cell depth between the two species except for the SO treatment. Among all four species *Mesua* had thicker palisade cell depth than *Dipterocarpus*. *M. ferrea* had the thickest cell depth followed in declining order by *M. nagassarium*, *D. zeylanicus* and lastly by *D. hispidus*. As compared to *Dipterocarpus* species, both *Mesua* species significantly increased palisade cell depth in the dry soils of the higher light treatments.

Unlike *Mesua*, *Dipterocarpus* was observed to have several palisade cells stacked upon each other. This phenomenon increased with increasing light intensity (Table 7). Therefore the thickest cell layers were in the FS treatment for both species. This double stacking phenomenon was not a continuous layer. Hence the ratio of double layering was also recorded (Table 8). This ratio also increased with increase in amount of light. In all treatments *D. zeylanicus* had a significantly higher ratio than *D. hispidus*. No difference could be observed in cell layer thickness between soil moisture treatments.

## DISCUSSION

An array of anatomical characteristics can in combination, partly determine the morphological light and drought tolerance of a species (Ashton & Berlyn 1992). The effect of light on the leaf morphology of woody angiosperms is well-known. Several investigators have reported that anatomical changes at the leaf level such as stomatal frequency, leaf blade thickness, and other cell component dimensions vary with the amount of exposure to light (Cutter 1978; Simon *et al.* 1990). For example, stomatal frequency increases with increasing light intensity. This variation in stomatal frequency among differing light environments has been attributed to change in leaf size. Higher light intensities promote reduction in leaf size in order to prevent desiccation (Chia & Brun 1975). However this is not true for all species.

For *Shorea*, section *Doona* at least two of the species showed little change in leaf size between light environments (Ashton 1995). However stomatal frequency can be used to gauge drought tolerance of species with similar morphology (Table 9), (Ashton & Berlyn 1992). For example, because *Dipterocarpus hispidus* had higher stomatal frequency than *D. zeylanicus* it could be less drought tolerant. Similarly *M. ferrea* with a high stomatal frequency could be less drought tolerant than *M. nagassarium*.

**Table 5 : Summary of lower epidermal cell layer thickness for two *Dipterocarpus* species in each of the four light and two soil moisture treatments. Data are means from different leaves with standard errors in parentheses. Lower case letters beside the means denote differences between the soil moisture treatments for each species at the 5% level of significance. Capital letters denote differences between species for each light treatment at the 5% level of significance. Treatments or species followed by the same letter are not significantly different from each other.**

| Lower epidermal cell layer thickness<br>( $\mu\text{m}$ ) | Species | Dry           | Moisture<br>Moist |
|-----------------------------------------------------------|---------|---------------|-------------------|
| <b>OE</b>                                                 |         |               |                   |
| <i>D.zeylanicus</i>                                       | A       | 23.37(0.610)a | 24.20(0.626)a     |
| <i>D.hispidus</i>                                         | B       | 21.33(0.265)a | 20.27(0.511)a     |
| <b>FS</b>                                                 |         |               |                   |
| <i>D.zeylanicus</i>                                       | A       | 29.42(1.040)a | 26.23(0.643)a     |
| <i>D.hispidus</i>                                         | B       | 23.10(0.583)a | 19.60(0.161)b     |
| <b>SO</b>                                                 |         |               |                   |
| <i>D.zeylanicus</i>                                       | A       | 24.77(0.836)a | 22.93(0.185)a     |
| <i>D.hispidus</i>                                         | B       | 18.30(0.268)a | 17.30(0.381)a     |
| <b>LO</b>                                                 |         |               |                   |
| <i>D.zeylanicus</i>                                       | A       | 27.07(0.597)a | 28.17(0.940)a     |
| <i>D.hispidus</i>                                         | B       | 21.03(0.053)a | 20.68(0.600)a     |

**Table 6 :** Summary of palisade cell depth for the species in each of six light and two soil moisture treatments. Data are means from different leaves with standard errors in parentheses. Lower case letters beside the means denote differences between the soil moisture treatments for each species at the 5% level of significance. Capital letters denote differences between species for a light treatment at the 5% level of significance. Treatments or species followed by the same letter are not significantly different from each other.

| Palisade cell depth ( $\mu\text{m}$ ) | Species |               | Moisture |               |
|---------------------------------------|---------|---------------|----------|---------------|
|                                       | Dry     |               | Moist    |               |
| <b>FU</b>                             |         |               |          |               |
| <i>D. zeylanicus</i>                  | A       | 31.00(0.887)a |          | 31.14(0.948)a |
| <i>D. hispidus</i>                    | B       | 25.96(1.620)a |          | 28.63(0.554)a |
| <i>M. ferrea</i>                      | A       | 33.13(0.600)a |          | 34.86(1.290)a |
| <i>M. nagassarium</i>                 | A       | 34.03(0.978)a |          | 31.80(0.657)a |
| <b>FE</b>                             |         |               |          |               |
| <i>D. zeylanicus</i>                  | B       | 35.60(0.523)a |          | 33.83(0.342)b |
| <i>D. hispidus</i>                    | C       | 32.13(1.410)a |          | 31.43(0.187)a |
| <i>M. ferrea</i>                      | A       | 38.36(0.727)a |          | 37.33(0.798)a |
| <i>M. nagassarium</i>                 | AB      | 37.06(0.658)a |          | 36.16(0.456)a |
| <b>OE</b>                             |         |               |          |               |
| <i>D. zeylanicus</i>                  | B       | 35.76(1.230)a |          | 39.25(1.25)a  |
| <i>D. hispidus</i>                    | C       | 31.80(0.702)a |          | 33.26(1.14)a  |
| <i>M. ferrea</i>                      | A       | 45.65(0.213)a |          | 39.88(1.28)b  |
| <i>M. nagassarium</i>                 | A       | NA            |          | 44.867(1.33)  |
| <b>FS</b>                             |         |               |          |               |
| <i>D. zeylanicus</i>                  | B       | 40.75(0.797)a |          | 42.73(1.05)a  |
| <i>D. hispidus</i>                    | BC      | 37.56(1.59)a  |          | 38.36(2.43)a  |
| <i>M. ferrea</i>                      | AB      | 46.66(2.19)a  |          | 46.23(1.77)a  |
| <i>M. nagassarium</i>                 | A       | 51.75(0.54)a  |          | 43.20(0.046)b |
| <b>SO</b>                             |         |               |          |               |
| <i>D. zeylanicus</i>                  | C       | 30.94(1.22)a  |          | 32.53(1.53)a  |
| <i>D. hispidus</i>                    | C       | 31.50(0.448)a |          | 32.660.274)a  |
| <i>M. ferrea</i>                      | A       | 40.30(0.228)a |          | 38.12(0.376)b |
| <i>M. nagassarium</i>                 | B       | 36.00(0.932)a |          | 34.25(0.074)a |
| <b>LO</b>                             |         |               |          |               |
| <i>D. zeylanicus</i>                  | AB      | 37.75(2.28)a  |          | 38.30(1.10)a  |
| <i>D. hispidus</i>                    | B       | 36.65(1.65)a  |          | 33.93(0.641)a |
| <i>M. ferrea</i>                      | A       | 44.53(1.37)a  |          | 39.56(0.381)b |
| <i>M. nagassarium</i>                 | A       | 42.10(1.19)a  |          | 38.20(0.459)b |

**Table 7 :** Summary of palisade cell layer thickness for the two *Dipterocarpus* species in each for four light and two soil moisture treatments. Data are means from different leaves with standard errors in parentheses. Lower case letters beside the means denote differences between the soil moisture treatments for each species at the 5% level of significance. Capital letters denote differences between species for each light treatment at the 5% level of significance. Treatments or species followed by the same letter are not significantly different from each other.

| Palisade layer thickness ( $\mu\text{m}$ ) |                   | Species |  | Dry           | Moisture<br>Moist |
|--------------------------------------------|-------------------|---------|--|---------------|-------------------|
| <b>OE</b><br><i>D.zeylanicus</i>           | <i>D.hispidus</i> | A       |  | 57.51(1.64)a  | 61.89(0.917)a     |
|                                            |                   | B       |  | 52.83(1.03)a  | 54.18(1.52)a      |
| <b>FS</b><br><i>D.zeylanicus</i>           | <i>D.hispidus</i> | A       |  | 63.64(0.830)a | 56.34(5.31)a      |
|                                            |                   | A       |  | 57.91(1.33)a  | 60.61(2.31)a      |
| <b>SO</b><br><i>D.zeylanicus</i>           | <i>D.hispidus</i> | A       |  | 52.19(1.44)a  | 55.61(1.70)a      |
|                                            |                   | A       |  | 49.25(0.522)a | 52.67(0.965)b     |
| <b>LO</b><br><i>D.zeylanicus</i>           | <i>D.hispidus</i> | A       |  | 59.66(1.85)a  | 57.93(0.570)a     |
|                                            |                   | A       |  | 58.55(2.26)a  | 50.21(0.288)b     |

The amount of light can also have a direct influence upon blade thickness (Simon *et al.* 1990). For the study species, this may be due to increases in mesophyll and palisade tissue in the brighter light treatments. All spongy mesophyll, palisade and epidermal cells were densely packed in the high light treatments reducing air space within the leaf. This can increase leaf blade thickness and also promote greater water-use efficiency. Leaf blade thickness can also be used as a gauge in determining both light and drought tolerance of similar species (Ashton & Berlyn 1992). *Dipterocarpus zeylanicus* which had a thicker leaf blade than *D. hispidus* could be considered more light and drought tolerant. Similarly, though in most comparisons no difference could be found between the *Mesua*, for the SO and LO treatments *M. ferrea* had a thicker leaf blade, suggesting it to be more light and drought tolerant.

Anatomical differences among species are also apparent for epidermal cell dimensions and epidermal cell layer thicknesses. The upper epidermal layer is the cell layer most exposed to direct radiation. Upper epidermal cell dimensions can also suggest light tolerance (Ashton & Berlyn, 1992). In this study *D. zeylanicus* had thicker upper epidermal cells than *D. hispidus*, and for *M. ferrea* upper epidermal cells were thicker than *M. nagassarium*.

**Table 8 :** Summary of ratio of layering of palisade cells for the two *Dipterocarpus* species in the four light and two soil moisture treatments. Data are means from different leaves with standard errors in parentheses. Lower case letters beside the means denote differences between the soil moisture treatments for each species at the 5% level of significance. Capital letters denote differences between species for each light treatment at the 5% level of significance. Treatments or species followed by the same letter are not significantly different from each other.

| Ratio of double layering of palisade cells | Species | Moisture       |                |
|--------------------------------------------|---------|----------------|----------------|
|                                            |         | Dry            | Moist          |
| <b>OE</b>                                  |         |                |                |
| <i>D. zeylanicus</i>                       | A       | 0.330(0.0128)a | 0.309(0.0214)b |
| <i>D. hispidus</i>                         | A       | 0.296(0.0295)a | 0.279(0.0074)b |
| <b>FS</b>                                  |         |                |                |
| <i>D. zeylanicus</i>                       | A       | 0.401(0.0105)a | 0.381(0.0127)a |
| <i>D. hispidus</i>                         | B       | 0.350(0.0177)a | 0.343(0.0106)a |
| <b>SO</b>                                  |         |                |                |
| <i>D. zeylanicus</i>                       | A       | 0.269(0.0238)a | 0.261(0.0098)a |
| <i>D. hispidus</i>                         | B       | 0.217(0.0077)a | 0.238(0.0191)a |
| <b>LO</b>                                  |         |                |                |
| <i>D. zeylanicus</i>                       | A       | 0.304(0.0092)a | 0.327(0.0179)a |
| <i>D. hispidus</i>                         | B       | 0.292(0.0095)a | 0.274(0.0080)a |

*Mesua ferrea* also had lower epidermal cells that were papillated and that promoted sunken stomata—a characteristic that would make it more drought tolerant than *M. nagassarium*. Unlike *Mesua*, both *Dipterocarpus* species exhibited double rows of cells in lower epidermal layer. This would promote greater water-use efficiency.

Both the palisade cell depth and layer thickness increased with increase in exposure to light in all four species. Increased palisade cell layers can reduce the spaces in the leaf by dense packing as compared to the irregular-shaped spongy mesophyll cells. This dense packing in high light environments can promote greater capture of light radiation and can promote greater protection of leaves from desiccation. The thicker cell depth in *D. zeylanicus* indicates that it is more light demanding than *D. hispidus*. *Mesua ferrea* appears to be more light demanding because of its thicker palisade cell depth as compared to *M. nagassarium*. Stacking of palisade cells upon each other was observed only in *Dipterocarpus*. This phenomenon was observed only in the higher light treatments and declined in the following order FS>LO>OE>SO. The ratio of double layering of palisade also increased with the increase in amount of light. The ratio of double layering of palisade cells was higher in *D. zeylanicus* as compared to *D. hispidus*, which suggested that *D. zeylanicus* could be more use efficient in capturing light.



**Table 9 :** Comparisons of leaf anatomical attributes. The relationship of the attribute size or amount are illustrated in decreasing order by species. Symbols: + signifies dimensions increase with increasing light intensities; \* signifies dimensions increase from moist to dry; \*\* signifies dimensions increase from dry to moist. The factor that appears to determine the species order is identified.

| ANATOMICAL ATTRIBUTE        | HIGH-SPECIES ORDER-LOW | DETERMINING FACTOR |
|-----------------------------|------------------------|--------------------|
| STOMATAL FREQUENCY          | +                      |                    |
| Number                      | +                      |                    |
|                             | +                      |                    |
|                             | +                      |                    |
|                             | DH>MF>MN>DZ            | DROUGHT TOLERANCE  |
|                             | DZ.* * * *             |                    |
| BLADE THICKNESS             | +                      |                    |
| Dimensions                  | +                      |                    |
|                             | +                      |                    |
|                             | +                      |                    |
|                             | MF>MN>DZ>DH            | DROUGHT AND        |
|                             | FU:* * * *             | LIGHT TOLERANCE    |
|                             | +                      |                    |
|                             | +                      |                    |
|                             | +                      |                    |
| UPPER EPIDERMAL THICKNESS   | DZ>DH>MN>MF            | DROUGHT AND        |
| Dimensions                  | DH:* * * *             | LIGHT TOLERANCE    |
|                             | +                      |                    |
|                             | +                      |                    |
|                             | +                      |                    |
| PALISADE CELL THICKNESS     | MF=MN>DZ>DH            | LIGHT TOLERANCE    |
| Dimensions                  | SO:MF>MN               |                    |
|                             | +                      |                    |
|                             | +                      |                    |
| PALISADE LAYER THICKNESS    | DZ>DH                  | LIGHT TOLERANCE    |
| Dimensions                  | DH:* * *               |                    |
|                             | +                      |                    |
|                             | +                      |                    |
| RATIO OF DOUBLE LAYERING OF | DZ>DH                  | LIGHT TOLERANCE    |
| PALISADE CELLS              |                        |                    |

Available soil moisture is also an important determination of leaf anatomy and morphology (Young & Giese 1990). In this study stomatal frequency was higher in the dry soil treatment in only a few instances, most notably *D. zeylanicus*. In these conditions, leaves exhibited more xerophytic characteristics that are similar to leaves exposed to high amounts of desiccating radiation. When there are more stomata the distance in between two stomata is less and the amount of transpired water higher. This increases the humidity of the leaf surface. The moisture gradient between the leaf and its surrounding environment is therefore reduced with a net reduction in water loss. In this experiment water was added to the soil to full capacity when the moisture content reached less than 30%. We speculate that under these conditions, excepting *D. zeylanicus*, the species were able to avoid droughty conditions by controlling stomatal aperture.

In most cases blade thickness, upper and lower epidermal cell thicknesses did not change significantly ( $p < 0.05$ ) with availability of soil moisture. Palisade cell depth was significantly greater in the dry soil moisture treatment as compared to the ever moist for three of the species (*D. zeylanicus*, *M. ferrea*, *M. nagassarium*). This was apparent in all light treatments except FS. The increase in palisade cell thickness in dry soil treatment promoted denser packing and therefore presumably a reduction in water loss.

In conclusion, this study demonstrated that species classified as late-successional canopy trees have morphological and anatomical leaf characteristics that change with light and soil moisture availability. The largest differences in dimensions were observed among light treatments rather than with availability of soil moisture. Among the two dipterocarps, *D. zeylanicus*, which had thicker leaf blade, upper epidermal cell depth, lower epidermal cell depth and palisade cell depth, could be regarded as more light tolerant than *D. hispidus*. Its low stomatal frequency and its greater variation under the two soil moisture treatments also reveals it to probably be more drought tolerant than *D. hispidus*. In *Mesua* most of the anatomical and morphological dimensions between the two species differed within the direct sun treatments (SO, LO). In these treatments the thicker leaf blade and palisade cell depth of *M. ferrea* would suggest it to be more light tolerant than *M. nagassarium*. The lower stomatal frequency in *M. nagassarium* would perhaps make it more drought tolerant.

Comparing between genera the higher blade thickness and palisade cell depth of the *Mesua* species would promote speculation that they are more light demanding than *Dipterocarpus* species. When comparing stomatal frequency *D. hispidus* was highest followed in declining order by *M. ferrea*, *M. nagassarium* and lastly by *D. zeylanicus*. These observations would make *D. zeylanicus* the most drought tolerant. However, anatomical features are genus specific. Examples such as double layering of palisade and lower epidermal cells shape of palisade cells, and stomatal size make between genus comparisons difficult. *M. ferrea* also had sunken stomata with an external air-chamber. *D. hispidus* contained hairs on the leaf surface. These facts can confuse even within genus comparisons and are important when speculating about species differences in light and drought tolerance, solely based on leaf morphology.

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# SOUTHERN AFRICAN FORESTS: THEIR BIOGEOGRAPHY, CONSERVATION AND UTILIZATION

Coert J Geldenhuys

## ABSTRACT

*Mixed evergreen forests from the smallest (about 3000 km<sup>2</sup>), most widely distributed and most fragmented biome in southern Africa, occur along the escarpment and east coast in areas with a mean annual rainfall >525 mm with strong winter rain and > 725 mm with strong summer rain. The few large forest complexes are widely separated. The large ratio of forest margin to forest area accentuates the importance of forest margins in forest survival. Fires associated with hot, desiccating winds (berg winds during winter) are the main cause of fragmentation of the forests. The natural fragmentation has been aggravated by current landuse practices. Development of commercial forestry of pine and eucalyptus in the grasslands and shrublands surrounding the forests contributed to conservation of forests. The plantation stands also nurse the establishment of shade-tolerant forest species. This succession process is used to restore the forest in selected areas.*

*Two main forest types occur whose floras have strong affinities to the tropical forest flora: forests of the Afromontane Region along the escarpment, and forests of the Tongaland- Pondoland Regional Mosaic along the coastal dunes and lowlands. Scrub forests occur in the drier areas between the coast and escarpment. The forests cover only 0.08% of the area and 5.35% of the species, but have a relatively rich 0.514 species /km<sup>2</sup>. Species richness remains relatively constant along the tropical-temperate gradient of southern Africa except for the south-western extreme. The general patterns in species richness suggest that undisturbed forest is somewhat richer than disturbed forest, and that mature forest is richer than regrowth or seral forest. Conservation of the forests has two major components: maintenance of the components and critical processes within a forest ecosystem in forest reserves, and maintenance of gene flow between the different forests through management of forest corridors. The National and Provincial Governments and statutory bodies manage and control a very large proportion of the forests and the largest forests, and only a small portion is privately owned.*

*Studies of forest composition and dynamics, of recruitment, growth and mortality, and of disturbance, recovery and restoration processes, have provided a basis for sustainable resource utilization. Forest management ranges from a sophisticated multiple-use management system (timber, minor forest products, ecotourism) applied in the State Forests, to a low income subsistence utilization of the headmen's forests applied in rural areas for building material, fuelwood and household goods. Two systems for removal of marketable timber are in use: optimal productivity harvesting of trees selected on the basis of species growth and mortality rates; and harvesting of dead and drying trees of commercially valuable species. Large utilizable trees are topped before felling to reduce canopy damage and special extraction equipment is used to minimize soil compaction and drainage disturbances.*

## INTRODUCTION

The major concern about uncontrolled destruction of forests is focused on forests of the tropical regions. There are however other regions with important forests in terms of biodiversity and socio-economic resources which often escape the attention of the world. Mixed evergreen forests from the smallest, most widely distributed and most fragmented biome in southern Africa (the area south of the Kunene and Limpopo rivers) cover only about 3 000 km<sup>2</sup>, or 0.08% of the country (Anonymous 1982, 1987; Huntley 1984; Rutherford & Westfall 1986) yet these forests play a role in the welfare of society which is disproportionately greater than their small extent and low potential for commercial exploitation.

The objective of this paper is to review information relating to the distribution, phytogeography and composition of the mixed evergreen forests of southern Africa, the impact of past and present landuse practices and the measures currently taken for their conservation and sustainable resource utilization.

## PRESENT AND PAST DISTRIBUTION OF THE FORESTS

### Geographical distribution

Forests occur along the eastern coast and escarpment of the region from the Cape Peninsula (34°S) to the Soutpansberg (22°40'S) and the Tongaland coast (27°S) (Figure 1; Cooper 1985; Anonymous 1987). These forests are related to the Afromontane and Indian Ocean Coastal forest which occur further north in Zimbabwe, Malawi and elsewhere (Chapman & White 1970; White 1983; Timberlake & Shaw 1994). High forest (10 to 35 m tall) and scrub forest (3 to 10 m tall) persist in areas with mean annual rainfall > 525 mm with strong winter rain and >725 mm with strong summer rain (Rutherford & Westfall 1986). They occur on a wide range of geological formations (Geldenhuys 1993a).

There are a few large forest complexes and these are widely separated (Figure 1). The largest single forest (25 706 ha) is around Knysna in the south (east of George) and is part of a complex of 60 560 ha at 34°S and between 22°E and 24°30'E (Geldenhuys 1991 a). The Amatole forests in the Eastern Cape cover 40 550 ha between 32°S and 33°S latitude, and 26°E and 27°30'E longitude (Thompson 1991). In Kwazulu-Natal the Dukuduku forest is the largest (3 500 ha) but is seriously threatened by uncontrolled settlement of people (Cooper 1985). The Woodbush-De Hoek forest (6 626 ha) is the largest forest along the Transvaal Escarpment (Scheepers 1978; Cooper 1985). The majority of forests are less than 100 ha in size (Cooper 1985; Geldenhuys 1991a). Smaller isolated but geographically important forests are in the areas between the larger forest complexes around Knysna, the Amatole forests, the Kwazulu-Natal coastal and montane forests, and the Transvaal Escarpment forests (Cooper 1985; Anonymous 1987; Von Breitenbach 1990; Geldenhuys 1991 a, 1992a; Cooper & Swart 1992; Everard & Hardy 1993). The forests are surrounded by fire-adapted vegetation: sclerophyllous

shrublands (Fynbos) in the south and grasslands and deciduous woodland in the summer-rainfall areas.

### Agents of forest fragmentation

The relic nature of the forests within the grasslands and shrublands had been attributed to the destructive activities of man during the relatively recent 100 to 300 years (for example, Acocks 1953; White 1983). However, patterns of forest distribution were affected by climatic and landscape changes over geological time-scales (Deacon *et al.* 1983). Scholtz (1986) demonstrated from palynological and charcoal studies the climatic changes which occurred in the southern Cape over the last 60 000 years. The period between 14 000 and 12 000 BP was the most mesic (with forest expansion) since the last cold, dry Glacial Maximum. This was followed by a hot, dry period (forest regression) until the climatic optimum period for forest spread during the period 4 000 to 2 500 BP. Another period of warm, dry summers (forest regression) followed, but since about 1 400 BP the climate is considered similar to the present (forest spread).

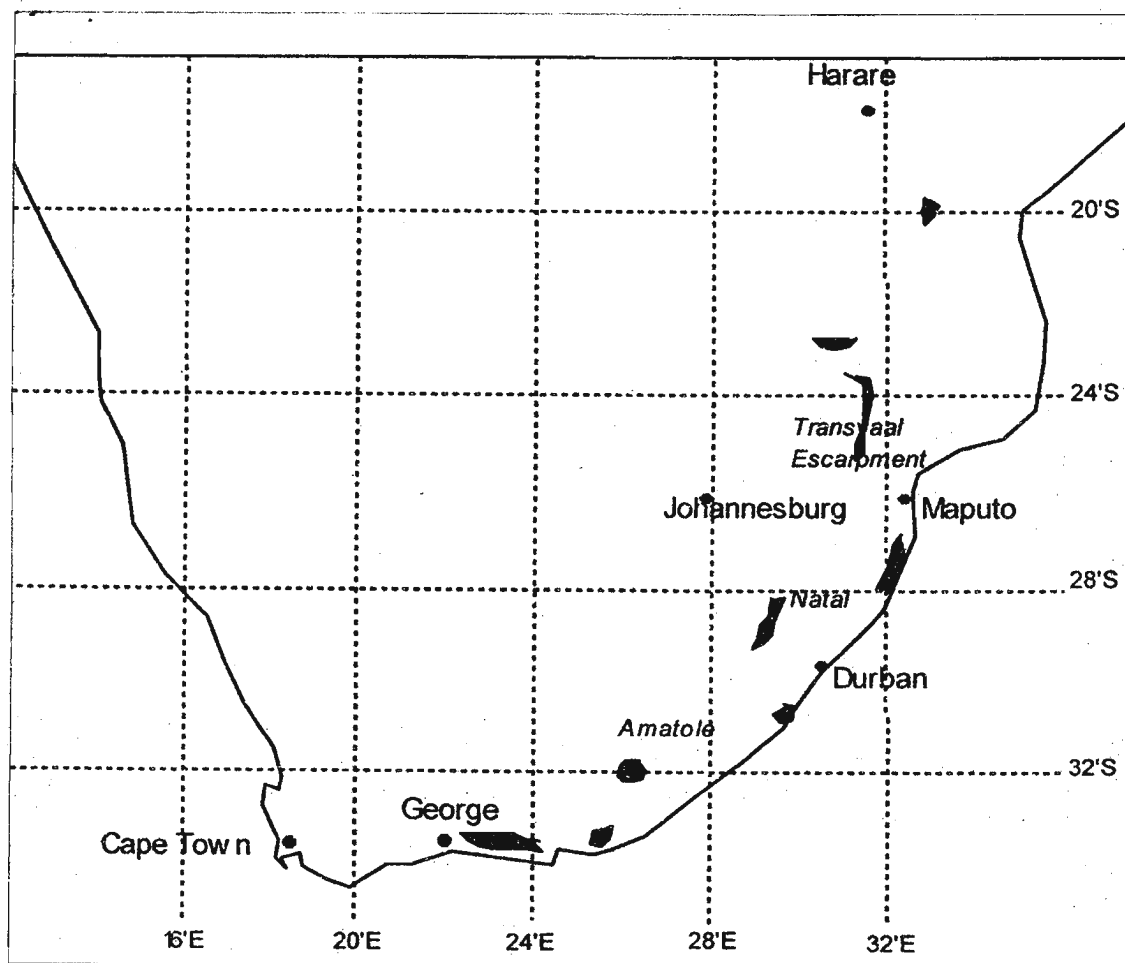


Figure 1: Distribution of mixed evergreen forest in southern Africa. The shaded areas indicate forest complexes. Scattered small forest patches occur in the area between the larger concentrations of forest.



Geldenhuys (1994a) demonstrated that environmental factors (rainfall and substrate) determine the potential limits of forest distribution, but that the actual forest location pattern is determined by the fire pattern, which in turn is determined by the interaction between the prevailing winds during dry periods and terrain physiography. His study showed that forests on the coastal platform persisted in topographic shadow areas of the gusty, hot, desiccating northwesterly fohnlike bergwinds which are common during autumn and winter. Bergwind direction is locally changed due to barriers posed by the position and form of the mountain ridge to the windward (northern) side of the forests, and is channeled through valleys running from the mountains. Lightning and human-induced fires (Deacon *et al* 1983) associated with the bergwinds would burn with higher frequency in zones in the landscape where forest is currently absent. The wind-fire pattern would furthermore cause calm conditions and a lower frequency of fire in localities where the forests have survived. Feely (1980, 1986) indicated that most of the present southern African grassland existed throughout the Holocene and was not induced by forest clearing over the last 100 to 300 years. For example, Iron Age farmers in Transkei settled in high density in preferred sites in presently wooded areas for at least the last 1400 years. Forest and scrub forest have been continuously cleared and exploited for timber, plant foods and medicines during this period and still persist today in complex mosaics in the same areas.

The fragmentation had been aggravated by current landuse practices, such as clearing for agriculture, forestry and subsistence utilization, and veld burning practices for grazing and improved water runoff in catchments (Phillips 1963; Cooper 1985; McKenzie 1988; Geldenhuys *et al* 1986, 1988a; Geldenhuys 1991 a). Commercial forestry plantations of pine and eucalyptus were established in the grasslands and shrublands surrounding the forests, and rarely in areas where evergreen forests were cleared. The plantations aided the rehabilitation of the forests, and expansion in places, released pressure on the forests for timber, fibre and firewood needs, and protected forest margins against frequent fires (Geldenhuys *et al* 1986).

## COMPOSITION, BIODIVERSITY AND BIOGEOGRAPHY

### Forest composition

Two main forest types occur whose floras have strong affinities to the tropical forest flora of Africa (Moll & White 1978; White 1978, 1983): forests of the Afromontane Region along the escarpment; and forests of the Tongaland-Pondoland Regional Mosaic along the coastal dunes and lowlands.

The major forest complexes and many of the smaller forests have been described in qualitative, descriptive or quantitative, multivariate studies (Muir 1929; Phillips 1931; King 1940; Rycroft 1944; Story 1952; Taylor 1955; Killick 1963; Edwards 1967; Moll 1969, 1978a,b, 1980a,b; Morris 1969; Van der Schijff & Schoonraad 1971; Venter 1972; Campbell & Moll 1977; McKenzie *et al* 1977; Boucher 1978; McKenzie 1978; Scheepers 1978; Weisser 1980; Cowling 1984; Von Breitenbach 1984, 1990; Deall 1985; Burns 1986; Cawe 1986; Everard 1987; Lubke & Strong 1988; Everard & Hardy 1993:

Midgley 1993; Geldenhuys 1993b; Geldenhuys & Murray 1993; Geldenhuys & Pieterse 1993; Butt *et al.* 1994). In addition, checklists are available for several other forests or regions (Moll 1981; Weisser & Drews 1980; Nicholson 1982; Von Breitenbach & Von Breitenbach 1983; Abbott 1985; Johnson & Cawe 1987; Philipson 1987; Geldenhuys 1993c). These studies provided a better understanding of the association of species in different forest complexes, the biogeography of the forests, individual species and species groups, and historical and ecological factors which govern the present distribution and composition of the forests.

### Patterns of species richness

Geldenhuys (1992a) listed 1 438 species which had been recorded for 14 forests or forest complexes representing the geographic range of the mixed evergreen forests in southern Africa. These included 155 families and 661 genera. The forests cover only 0.08% of the area and 7.1% of the vascular species, but have a relatively rich 0.58 species/km<sup>2</sup>. Gibbs Russell (1987) indicated a ratio of 0.0079 plant species/km<sup>2</sup> overall for southern Africa with 20,227 indigenous vascular taxa. Only fynbos exceeds the forest value with 1.36 species/km<sup>2</sup> (7316 species). The third richest biome is grassland with 0.25 species/km<sup>2</sup> (3 788 species).

Species richness remains relatively constant along the tropical-temperate gradient of southern Africa except for the south-western extreme (Geldenhuys & Macdevette 1989; Geldenhuys 1992a). Forest of the east coast (Natal north coast and southern Natal/Pondoland Umtamvuna sandstone complex with a large proportion of endemic plants (Van Wyk 1981) have the highest number of woody species (254 and 338 species respectively) and the south-western Cape and Cape Peninsula forests and a high-altitude escarpment forest have the lowest number (78, 48 and 76 species respectively). The number of woody species in the other forests, which varied largely in size, varied between 113 and 196. In the southern Cape, the mountain and coastal forests are continuous in places (Geldenhuys 1991a) and contain elements of both the coastal and montane zones of further north and of the southern temperate element (Geldenhuys 1993b, c). Size and species richness of the forests vary greatly. The number of species of both woody and herbaceous plants showed a significant log species - log area relationship, but explained only 30% and 38% respectively of the variation in size of the flora (Geldenhuys 1992a). In a multiple regression analysis for woody plants, proximity to other forests, the number of dispersal corridors and mean altitude of a forest together explained 82% of the variation in species richness. The number of landscape types included in the forest area and number of dispersal corridors explained 75% of the observed variation in the number of herbaceous plant species.

The mean percentage woody plants for the forests is 49% (Geldenhuys 1992a). However, the ratio of woody plant species varied greatly between individual forests. In general, coastal forests have a woody ratio in excess of 60%, whereas in the montane forests the ratio varied between 39 and 53%.

Geldenhuys & Macdevette (1989) list very few studies, mainly ongoing, of species richness of higher plants in 0.1 ha plots. The Natal forests represent an increasing richness from the cool montane *Podocarpus* forests (46-68 species) through mist-belt mixed *Podocarpus* forests (62-91) to the hot and humid lowlands, coastal and dune forests (57-100). Richness declines from the Natal to the southern Cape forests (52-53).

Species richness varied more within a forest than between forests (Geldenhuys & Macdevette 1989). Montane forests, in general, have fewer species than lowland, coastal and dune forests, both in Natal and the southern Cape. Furthermore, drier (or warmer?) forests are richer in species than wetter (or cooler?) forests. The different growth forms also show clear patterns amongst the different forest types. Relative richness of herbaceous plant species is greater in the moister areas, and of woody plant species is greater in the drier areas. Species richness for woody plants increases more sharply than for herbaceous plants from montane to platform (lowland) forests. Fern species richness declines, and richness of vines, graminoids, geophytes and forbs increases from the mountain to the coastal forests, whereas epiphyte richness is highest in the Natal mist-belt or southern Cape platform and river scarp forests (more mature forests).

Taxa shared between forests show at least three patterns (Geldenhuys 1992a). Firstly, forests share many more of their species with forests to their north and east than with forests to their south and west. This indicates the erosion of species from the two tropical source areas (in East Africa), as was evident in several parts of southern Africa (McKenzie 1978; Tinley 1985; Cawe 1986; Geldenhuys 1992b). For example, in the southern Cape forests 206 of the 470 species of all growth forms reach their geographic distribution limit in the area, or have disjunct distributions within the area and wider distributions outside (Geldenhuys 1992b). Of these, 1958 species reach their western limit and only 23 species reach their eastern limit in the area. Secondly, forests share many more species with their nearest neighbours than with forests further away. Thirdly, the Afromontane forests (including those near the coast in the south) share relatively fewer species with the forests of the subtropical coastal areas. A large proportion of the species is unique to individual forests: 33% of the woody and 42% of the herbaceous species (Geldenhuys 1992a). Canopy trees and ferns have the lowest proportions of unique species, whereas these proportions are 40% for the shrubs, geophytes and forbs.

Direction and rate of change in species richness also vary with type, intensity and frequency of disturbance. The major disturbances of the forests which relate to future conservation requirements are of three types:

- Several papers indicate the selective nature of the harvesting of forest products (King 1938; Phillips 1963; Scheepers 1978; Geldenhuys 1980; Cunningham 1985). These disturbances cause different types of vertical and horizontal gaps in the forest by removing large canopy trees, layer communities or particular growth forms and must have long-term consequences on forest dynamics. Moil (1972) suggested that species regenerating in the Natal mistbelt forests are those capable of a drier climate. However, Geldenhuys (1993d) recorded prolific regeneration of *Podocarpus latifolius* in the southern Cape forests after excessive preferential utilization of this species at the turn of the century (Phillips 1963).

- Fire is mentioned by many as the major cause for the rapid decline of the forests (Edwards 1967; McKenzie *et al.* 1977; Westfall *et al.* 1983; Granger 1984; Cooper 1985; Everard 1986). Dune forest along the Zululand coast regrows rapidly following protection of the dune cordon from fire and grazing (Weisser 1978; Weisser & Marques 1979; Weisser *et al.* 1982; Van Daalen *et al.* 1986). Plantation forestry requires protection against fire and as such contributed to forest spread with the exclusion of fire (Huntley 1965; Geldenhuys *et al.* 1986; Knight *et al.* 1987).
- Clearing of forest for agriculture, development of infrastructure and dune mining causes the loss of species and fragments gene flow. Riverine and rare swamp forest in Natal and Kwazulu which contain many rare species have been cleared for sugar cane and other purposes (Cooper 1985).

The general patterns suggest that undisturbed forest is somewhat richer than disturbed forest and that mature forest is richer than regrowth or seral forest. Furthermore, along the seral stages from scrub, through bush clumps and forest margin to mature forest, the floristic and structural composition continually changes and species richness increases (Van Daalen *et al.* 1986; Geldenhuys 1993b).

### Phytogeography

As indicated before, two main forest zones occur whose flora have strong affinities to the tropical forest flora (White 1978, 1983; Moll & White 1978). Forests of the Afromontane Region occur along the Drakensberg escarpment, the Natal and eastern Cape midlands and the southern Cape mountains and coastal plateau. Forests of the Tongaland-Pondoland Regional Mosaic occur along the coastal dunes and lowlands. Scrub forest includes Kaffrarian Subtropical Transitional Thicket (Cowling 1984; Everard 1987). Three studies attempted to reconstruct the phytogeography of the forests in southern Africa.

Geldenhuys (1992a) showed the floristic relationships between widely separated forests in South Africa. He argued that the present patterns of composition and interrelationships of the different forests suggest that their high degree of similarity may have been established before major fragmentation of the forests since the late Pliocene (about 2.5 million years ago) due to geological uplift and increasing aridity. During this period of fragmentation, forests and forest biota survived in areas which we now consider as dispersal corridors. The number of dispersal corridors (mountain chains, escarpments, river valleys, coastal dune systems) meeting in a particular forest was shown in the study to be one of the strongest variables determining the number of woody plants in a forest.

Geldenhuys (in press a) reconstructed the changes in species composition as a result of forest contraction and expansion due to landscape and climatic changes. The relic temperate flora of the small, isolated forests of the inland mountains of the southern Cape had been enriched from the large forest complex on the coast along specific migration routes and during specific waves of forest expansion.

The distribution ranges of taxa of the southern Cape forests were used to establish generalized tracks of the flora in order to test hypotheses about the speciation and development of the forest floras (Geldenhuys 1994b). The results indicated that the ecological characteristics of the species of each geographical species group reflected the environmental conditions and disturbance regimes which prevail in each source area. The southern Cape forest flora is therefore made up of the following elements: species adapted to a narrow, cool humid Afromontane area; species of a transition zone between the montane zone and the humid, warm subtropical coastal areas; species adapted to more frequent and extreme droughts and drier conditions of the lowlands between the coast and mountains; species adapted to the southern temperate cool, moist mountain areas; species adapted to frequent grassland and shrubland fires on the forest margin; and local endemic species. These characteristics have to be considered in the management of each of the geographical zones and of the species.

## CONSERVATION STATUS

Conservation status implies the extent to which populations, species or communities have been modified by the influences of man and the degree to which they might be expected to maintain their genetic diversity and ecological processes in the medium term (10 to 100 years). Conservation of the forests and forest biota has two major components: maintenance of the components and critical processes within a forest ecosystem through appropriate systems for sustained utilization of forest products and values, and maintenance of gene flow between the different forests through management of land surrounding the forest and forest corridors.

Ownership determines the type and quality of forest management and possible impacts on the vegetation (Phillips 1963; Cooper 1985; Cawe 1986; McKenzie 1988; Cooper & Swart 1992). The National and Provincial Governments and statutory bodies manage and control a very large proportion of the forests and the largest forests, and only a small portion is privately owned (Cooper 1985; Geldenhus 1991a).

Conserved forests in southern Africa range from forests in private and tribal ownership that are in good condition, to forests in conservancies and natural heritage sites, through to forests in nature reserves and wilderness areas proclaimed under the Forest Act. There are many forests outside the proclaimed areas which are well conserved but with insecure conservation status. Geldenhuys & Macdevette (1989) defined conserved forests as those forests in the custody of government authorities, including National Parks Board and City Councils. The forest types and forest complexes in southern Africa are generally well conserved (Geldenhuys & MacDevette 1989). Along the entire South African coast the seaward slopes of the coastal dunes and the dunes within a 1 km restricted area are proclaimed under the Environmental Conservation Act. In Natal where many forests are on private land, the Conservancy system and the Natural Heritage System hold out hope for conservation. It is noteworthy that controlled utilization of reserved trees and ferns on private land through a permit system, contributed to forest conservation in many areas. A series of nature reserves provides for the conservation of large areas of forest.

Various sources still exert pressures on indigenous forests (Geldenhuys & Macdevette 1989):

- Growing human needs in rural tribal areas.
- High intensity farming interests such as in the eastern Cape lowlands cause the clearing of scrub forest and riverine forest for agriculture.
- Economic pressures cause uncontrolled exploitation, grazing and burning of forests on farms.
- Mining of forested dunes continue along the Natal north coast.
- Development of infrastructure (roads, powerlines, dams) and township and resort developments (Geldenhuys *et al.* 1988; Geldenhuys 1993e).

## DISTURBANCE AND RECOVERY

Many studies of forest composition and dynamics, of forest recruitment, growth and mortality, and of disturbance, recovery and restoration processes, have provided a basis for sustainable resource utilization. The rationale of the research programme on the ecology and management of the evergreen forests was that the demography of forest populations provides a basis for sustained use management, in particular the harvesting of forest products and management of the forest ecosystem in the forest/other vegetation complexes. The programme investigated how site and community processes and interactions determine the size, class distribution and growth of a population. It consisted of both short and long term studies, partly dictated by management requirements and partly by theoretical requirements for understanding the system. It provided for descriptive studies (composition and biogeography - see section above, and of bird populations e.g. Koen & Crowe 1987; Koen 1988, 1992), investigation of natural dynamic processes such as nutrient cycling and phenology (Koen 1992; Geldenhuys & Theron 1994), seed production, predation, dispersal and germination (Koen 1991; Geldenhuys 1993d, 1996), regeneration and establishment (Lubbe & Geldenhuys 1991), growth, competition and mortality (Van Daalen & Shugart 1989; Van Daalen 1991, 1993a,b,c; Geldenhuys *in press*) and of impacts of natural disturbances and management systems (Geldenhuys & Maliepaard 1983; Geldenhuys *et al.* 1988; Geldenhuys 1980, 1993f, 1994c; Van Wyk *et al.* 1995). Various studies were conducted to sustain production of important commercial species (Geldenhuys & Van der Merwe 1988, 1994; Geldenhuys & Lübke 1991; Lübke 1990, 1991; Lübke & Geldenhuys 1991)

The forest interior is subject to regular small-scale disturbances causing gaps about 0.005 to 0.1 ha in size (Geldenhuys & Maliepaard 1983). Lightning and man-induced fires, flooding and landslides on steep slopes during heavy rainstorms (Bosch & Hewlett 1980; Anonymous 1985; Pammenter *et al.* 1985; Geldenhuys 1994a,c ) occasionally expose larger areas in the forests. Various studies have been conducted to understand the

processes of recovery from these disturbances and to apply them in practice (Geldenhuys *et al.* 1988; Geldenhuys 1994c, d, 1995; Van Wyk *et al.* 1995).

## MANAGEMENT OF THE FORESTS

### Uses and values

The recognition of the values of forests is one of the basic requirements in order to reduce conflicts in land use options. McKenzie (1988) recognized many direct uses and indirect values of the southern African forests.

### Direct uses

With the settlement of the Europeans in Southern Africa since 1652, large diameter trees of selected species were harvested for building and furniture timber such as *Podocarpus* species (Podocarpaceae) and *Ocotea bullata* (Lauraceae), and for railway sleepers such as *Ptaeroxylon obliquum* (Ptaeroxylaceae) (King 1938, 1941; Phillips 1963; McKenzie *et al.* 1977; Scheepers 1978; Cawe 1986). Today plantations of pines, eucalyptus and wattles provide the structural timber needs of the region (Geldenhuys *et al.* 1986). Furniture timber is provided mainly from the relatively large southern Cape forests (Geldenhuys 1982, 1986b, 1992c) where this industry has an annual turnover of 15 million Rand (about US\$4 million) and employs about 650 people.

Forests have long been a source of building material to African people. Today provision of low cost housing is a growing problem in southern Africa and in rural areas indigenous plants are available at low cost (McKenzie 1988). Climbers (*Abrus precatorius*, *Flagellaria guineensis*, *Hippocratea delagoensis*, *Landolphia kirkii*, *Monanthotaxis caffra*, *Uvaria caffra*, *U. lucida*), leaves (*Sansvieria hyacinthoides*, *S. guineensis*), leaf petioles (*Strelitzia nicolai*) to tree bark (*Ficus trichopoda*) are sources of binding materials (Cunningham & Gwala 1986). Wood use for building varies with building style and availability of materials but a variety of species has been recorded (Johnson 1982, 1983; Cunningham 1985; McKenzie 1988). Livewood is cut for tall straight poles and laths. Selection for durable, termite resistant species results in cutting of species with low annual increment.

Fuelwood accounts for 51% of domestic energy use in South Africa (Basson 1987) and represents the highest volume of forest products used by rural people. Le Roux (1981) estimated that 6.6 million people in rural areas use wood as an energy source. Fuelwood gathering focuses on forests which are not surrounded by woodland or exotic plantations and woodlots have not been developed. Where wood resources are abundant, hardwoods from the native evergreen forest, producing little smoke are selected such as *Cleistanthus schlechteri*, *Dialium schlechteri*, *Hymenocardia ulmoides*, *Newtonia hildebrandtii* and *Pteleopsis myrtifolia* from Sand Forest. When fuelwood resources are depleted, people either travel greater distances to collect preferred wood, or cut less preferred species and livewood from the same area, or reduce firewood consumption by using alternative but expensive fuels (McKenzie 1988).



Traditional medicines are important to rural communities for medical, psychosomatic and economic reasons (Johnson 1983; McKenzie 1988). Traditional medicinal forest plants include trees, shrubs, climbers, epiphytes and parasites. Some popular forest species are *Cassipourea malosana*, *Erythrophleum lasianthum*, *Ocotea bullata* and *Warburgia salutaris*. Some of the characteristic faunal elements of forests are also important for this purpose, particularly pill millipedes, baboons, genets, pythons, mambas and cobras. The traditional medicines remain important to the rapidly growing urban black population. This has generated a local and countrywide multimillion Rand annual trade between rural source areas and urban markets and shops (Cunningham 1986).

Edible fruits, wild spinach, honey and edible fungi provide important dietary supplements to rural people in less developed areas of southern Africa, providing nutrients deficient in the starchy staple diet. This role is increased during drought periods, particularly in marginal agricultural potential areas (Grivetti 1979). Forests are a poor source of wild spinach but the vine *Pyrenacantha scandens* is the most popular forest spinach along the northeast coast (Cunningham 1985). Fruits are primarily a source of vitamin C and are poor sources of Ca and nicotinic acid (Cunningham 1985). Afromontane forest is generally poor in edible fruit bearing species but those species may occur at high density such as *Eugenia capensis* in Transkei (Cawe 1986). Coastal Forest and Dune Forest have more species whereas Sand Forest has the highest diversity of fruit-bearing species. Important species which are commonly collected along the northeast coast are *Annona senegalensis*, *Dialium schlechteri*, *Landolphia kirkii*, *Manilkara concolor*, *M. discolor*, *Syzygium cordatum*, *Trichilia emetica* (Cunningham 1985).

Several home crafts are based on sources from the forest (McKenzie 1988). In Port St. John's, Transkei, climbers are the basis of a craft industry, mainly baskets and mats, which forms an important part of the local economy and traditions of the Pondo people. The industry is worth about R 100 000 per annum (US\$25.000) and grows rapidly with organized marketing methods. Each basket uses *Oncinotis inandensis* for the basic framework. *Monanthotaxis caffra* for the ribs, and *Flagellaria quineensis* for the weave. Forest hardwoods are used for sticks, grinding mortars and domestic items such as meat dishes.

Commercial sale of wooden items probably accounts for higher localized use of wood than minor use for utilitarian purposes. Examples of this are commercial sale of wooden meat dishes of *Balanites maughamii* and *Spirostachys africana*, sticks (in demand from tourists and in urban areas) particularly from *Cleistanthus schlechteri*, *Ochna arborea*, *O. natalitia*, *Drypetes gerrardii* and *Strychnos henningsii*, and *Oncinotis inandensis* stems for basket frames and handles.

Fronds of the fern *Rumohra adiantiformis* are used extensively in the florist trade, both locally and abroad. The development of the export market for the fern since 1981 has developed into a lucrative local industry employing 200-300 people (Milton 1987 a,b; Geldenhuys & Van der Merwe 1988). During 1994/5 2.2 million fronds were harvested from the forest over a total area of 15000 ha and sold for a value of almost R 500,000 (US\$125,000). The industry expanded to shade cloth nurseries and planting under pine



stands. Epiphytic mosses have been harvested from Transvaal forests as packing material for flowers, for floral arrangements and exhibition purposes (Jacobsen 1978).

Forests provide habitat for animal species which are valued targets of trophy, communal and recreational hunting. Due to their aesthetic value there is an increasing demand for rare birds, butterflies and moths some of which occur in forests (McKenzie 1988).

Forests play an increasingly important role in providing for the recreation and aesthetics of the growing urbanized and industrialized societies of southern Africa. Many picnic sites, view points, camping sites, forest walks and hiking trails in forests offer unique experiences (Levy 1987; Van Dijk 1987). The revenue from entry fees to one view point with a big tree of *Podocarpus falcatus* in the southern Cape was R 110,000 (US\$27,500) during 1994/95. The availability of such trails are also important in the tourist industry and in conservation education.

Forests also have cultural importance as burial sites such as Thathe forest of the Vhavenda (Netshiungani *et al.* 1981) and the burial site of the Zulu chief Dingaan in Hlatikulu Forest (McKenzie 1988). Undisturbed forest and wooded copses persist around major grave sites in many parts of southern Africa due to the acknowledged importance of the role that ancestral spirits play in daily life and the value of ensuring them peace (Parker 1982).

### Indirect values

Anecdotal evidence suggests that a protective forest cover ensures a sustained flow of water from catchments more evenly throughout the year (Cooper 1985). The forest cover prevents soil erosion and driftsand formation in coastal and inland areas (Bosch & Hewlett 1980; Tinley 1985). Faunistically and floristically forests are amongst the richest biomes known and are thus extremely important in terms of conservation of genetic diversity. Preservation of plants which may still have important utility is also important in order to allow experimentation and research. *Inhambanella henriquesii*, *Manilkara discolor*, *Manilkara concolor* and *Landolphia kirkii* for example, are forest tree species which have been identified as potential crop plants on the basis of their palatability, nutritional value and appearance (Cunningham 1985). Similarly, plants which have great potential to modern pharmaceutical medicine may be restricted to forests.

Forests are often affected by alternative land uses. They are used as winter shelter and grazing for livestock. Grazing by cattle causes soil erosion in upland areas in the eastern Cape and Natal midlands, destroy understorey vegetation to a larger degree than the natural browsers in many areas and open up the forest interior, and render them more prone to fire damage and invasion by alien invaders (Taylor 1962; Phillips 1963; Moll 1972; Geldenhuys *et al.* 1986). Agriculture, forestry, power-lines, road-building and township development do cause some loss of forest cover (Cooper 1985; Geldenhuys & Macdevette 1989; Geldenhuys *et al.* 1988a; Geldenhuys 1991a, 1993e).

### Forest management practices

Management of the forests range from the sophisticated multiple-use management system (timber, minor forest products, ecotourism) applied in the State Forests, to a low income subsistence utilization of the headmen's forests applied in rural areas for building material, fuelwood and household goods. Two systems for the removal of marketable timbers are in use in the single-tree selection system applied in State Forests: optimal productivity harvesting of trees selected from a stand on the basis of species growth and mortality rates; and harvesting of dead and dying trees of commercially valuable species. Critical elements of the management system are: timber is harvested by the State forestry personnel to control impacts on the forest; large utilizable trees are topped before felling to reduce canopy damage and minimize gap size; special extraction equipment is used to minimize soil compaction and drainage disturbances; and timber is sold on auction to realize the best timber prices through the supply-demand mechanism on the price. Through this system high quality silvicultural management can be practised and the scarcity value of the timber is acknowledged.

### Multiple-use management system of the southern Cape

The initial timber exploitation and destruction of forests was followed by forest protection and the development of management systems (King 1938; Phillips 1963; Geldenhuys 1980, 1982a). Today timber and other minor but important forest products are utilized conservatively from ecologically suitable but small areas of State Forest in the southern and eastern Cape (Van Dijk 1987; Geldenhuys & Van der Merwe 1988, 1994; McKenzie 1988; Milton 1987a, b; Seydack *et al.* 1990; Van Daalen 1991; Vermeulen 1993; Seydack 1995). Scientific and multiple use management principles are applied in order to sustain utilization of forest products, recreation, and conservation. Five management classes determine the management objectives (indicated as proportion of the total area): production of timber and ferns (19.7%); protection of ecologically fragile areas (55.8%); nature reserves with enhanced conservation status to maintain ecological diversity and genetic resources (23.0%); recreation facilities for intensive public use (0.4%); and ecological and silvicultural research (1.1%).

In the optimal productivity harvesting system, single trees are selected from a stand for removal proportional to the relative density of species in diameter classes above 300 mm. Large utilizable trees are topped before felling to reduce damage to the canopy, immature boles and regeneration and to keep gaps in accordance with the average gap size (Geldenhuys & Maliepaard 1983). Special care is taken to minimize soil compaction and drainage disturbance during extraction of the timber. Large non-utilizable trees are girdled to die standing and gradually release shade (Geldenhuys 1982b). In the mortality retrieval harvesting system, dead and dying trees of commercially valuable species such as *Ocotea bullata* (Lauraceae) and *Podocarpus latifolius* (Podocarpaceae) are utilized. This method is also applied in the Amatole forests in the eastern Cape.

Forest inventory data are used as a basis of yield regulation for sustained-use of the forests (Geldenhuys 1991b). The data are recorded on 400m<sup>2</sup> plots sampled on a grid of 100 m x 80 m which cover the areas identified for timber harvesting in the single-tree

selection system. All trees  $\geq 10$  cm DBH are recorded per plot by species and DBH. The sampling data are used to assess at least four components of the forests: (i) Forest communities and the importance of different species in the different communities (e.g. Everard & Hardy 1993; Geldenhuys 1993b; Geldenhuys & Murray 1993; Geldenhuys & Pieterse 1993); (ii) Grain, i.e. the relationship between composition of canopy species in the regeneration and in the canopy of the same stand to gain some understanding of the scale of forest disturbance processes (Midgley *et al.* 1990; Geldenhuys 1993b, in press c; Everard *et al.* 1995); (iii) shape of diameter distributions within species over different communities, which provide useful insights into the resource status and recruitment requirements of constraints for the specific species (Geldenhuys 1992c, 1993b, d, g; Geldenhuys & Murray 1993); and (iv) standing growing stock (stand basal area/ha, volume/ha) of useful species. The form of the diameter distribution indicates the ecological behaviour of a species in relation to the typical disturbance regime of each forest community as indicated by the analysis of grain (Geldenhuys 1993b, in press c; Everard *et al.* 1995). For example, the inverse J-shaped curve in evergreen forest is typical of the shade-tolerant species of the small-gap forest, whereas the bell-shaped curve is typical of dominant species of forest with regular large - scale disturbances.

A small set of long-term study sites was expanded since 1987 to provide data on recruitment, growth and mortality for the South African indigenous forests to improve the yield regulation for sustainable timber harvesting (Seydack *et al.* 1990; Van Daalen 1991, 1993a,b,c; Vermeulen 1993; Geldenhuys 1996). Currently the main objectives for the long-term research plots are (i) to develop an understanding of forest dynamics for practical application, such as comparative growth rate and mortality of individual species over diameter classes in different areas, and of the potential sizes of species in different areas; (ii) to enable modelling of forest change; and (iii) to develop scenarios on the impacts on the forest of different resource management systems (Geldenhuys 1996). In general the mean stand basal area of the growth study sites is relatively high, ranging from 32 to 61 m<sup>2</sup>/ha. The range and frequency distribution in basal area in the sites showed different patterns. The regrowth stands had a relatively narrow range with a general bell-shaped frequency distribution. The old-growth stands have a wide range with some very high values due to some large trees, and the frequency distributions are rather flat with a number of low peaks, and many plots with very low or no basal area, and a high frequency for subplots with  $>80$  m<sup>2</sup>/ha. Nett growth of a stand is the end result of the growth of individual trees, the ingrowth into the lowest diameter class of stems from below the lower limit (in this case 5 cm DBH), and mortality of trees in stems above 5 cm DBH (Geldenhuys 1996; Van Daalen 1991, 1993 a,b,c). Ingrowth is generally low and included only a fraction of the species present in the sites, i.e. from 11% to 64%, and of these only a few were canopy trees. Mortality occurred in all stem diameter classes. In several stands mortality due to windfalls and trees dying standing, in particular of only a few large trees, resulted in a negative net change in basal area. Nett stand growth was generally very low, i.e. between - 0.2% and 4.4% of the original stand basal area per year. Basal area growth showed a significant relationship with initial stand basal area. The growth, ingrowth and mortality information are used together with the diameter class distributions obtained through the forest inventory data and community classification (Everard & Hardy 1993; Geldenhuys 1993b) to develop scenarios of stand development in relation to harvesting intensity. A start has been made, using the data

from these sites, to model the growth of the stands and individual species which are well represented, in order to assess the trends in stand development and potential species changes over time (Geldenhuys *et al.* in prep). The fronds of *Rumohra* fern are marketed by tender. Picking of fronds from the forest, restricted by ecological constraints, is done by the private tenderer and is controlled through regular inspection and a monitoring system (Milton 1987 a,b; Geldenhuys & Van der Merwe 1988, 1994; Geldenhuys 1994e). The demand from the market exceeds the production capacity of the forest, but is supplied through growing the fern under nurse stands of pine or Australian blackwood, or under shade-cloth nurseries with irrigation.

### Controlled subsistence management

In Transkei and Ciskei commercial timber species are periodically utilized to salvage timber of dying trees as a result of crown break, fires, construction of roads and illegal ringbarking of trees. Harvesting of unreserved forest products from government forests for domestic purposes is controlled by forest guards (McKenzie 1988). However, no sustained yield principles apply and mostly pole and smaller sized trees are utilized. This results in progressive alteration of forest structure and composition. A possible solution is to educate the people in rural areas as to the value to them of controlled utilization of the resources. This should be achieved through negotiation between conservation managers, planners, researchers and the local people (McKenzie 1988). Woodlots should be established after consultation with the end-users as to *their* needs.

In most cases uncontrolled use of private forests is minimal except where forests are being removed for farming or industrial purposes. Protected trees can be utilized under permit. In Transkei undemarcated forests under control of the tribal authorities, i.e. the headmen's forests, are often completely destroyed due to lack of control. These forests are generally of small size and in early regrowth stages.

### Forest Rehabilitation and Reconstruction

The large ratio of forest margin to forest area accentuates the importance of forest margins in forest survival. The frequent fires occurring in fire-adapted shrublands and grasslands prevented the development of forest margin communities (Everard 1986) and limited the few indigenous pioneer forest trees such as *Virgilia* spp (Phillips 1926), *Trema orientalis* (Scheepers *et al.* 1968; Scheepers 1978) and *Acacia karroo* (Weisser & Marques 1979). Regrowth of forest is low in tall, dense fynbos shrublands (Van Daalen 1981). Many introduced tree species were planted as commercial timber plantations in forest gaps, and in grassland and shrubland along the forest margins, since the late nineteenth century. Today commercial timber plantations, mainly pines and eucalyptus, but also acacias, cover 1.34 million ha. The species selected were generally easily raised, fast-growing, light-demanding species from rainforest or other sources. They provided for timber, fibre, and firewood needs, and protected forest margins against frequent fires (because of the plantation fire protection practices). In the areas surrounding the forest, pine and eucalyptus plantation rotations for structural timber vary between 30 and 50 years. They also aided the rehabilitation of the forests and the expansion of forest into former grassland or shrubland adjacent to forest (Geldenhuys *et al.* 1986). This nursing role of alien invader plants was shown to be similar to that of the indigenous pioneer

trees. The initial pure stand of the indigenous or alien pioneer tree is gradually colonized and enriched by the shade-tolerant species of middle to late seral stages (Phillips 1926; Huntley 1965; Seagrief 1965; Scheepers *et al.* 1968; Scheepers 1978; Weisser & Marques 1979; Geldenhuys *et al.* 1986; Knight *et al.* 1987; Geldenhuys 1992c, 1995; Van Wyk *et al.* 1995). Litter accumulation in the seral stages after disturbance restores the nutrient cycling and determines the rate of colonization and recovery (Scheepers 1978; Scheepers *et al.* 1968; Van Daalen *et al.* 1986; Masson & Moll 1987).

It is common practice in the warm-temperate southern Cape forests to convert stands of introduced timber trees on the forest margin to mixed-species stands of indigenous canopy species, by ringbarking and handpulling of the alien species, i.e. manipulating the overhead alien stand to increase the establishment rate of the shade-tolerant native forest tree species without stimulating the establishment of the light-demanding alien pioneer tree species (Geldenhuys *et al.* 1986; Van Wyk *et al.* 1995). Where necessary, native pioneer or early secondary species are planted in scattered mixed groups of five plants throughout the area to establish bush clumps to facilitate the development process (Van Daalen 1989).

Plantation forestry could be used to restore the forest margins and migration corridors of forest species (Geldenhuys 1993h, 1994d, in press d), and this approach is being further investigated (Geldenhuys 1995).

### **Conclusion: Challenges for the Future**

After maltreatment for nearly two centuries, the remaining forests are at present in a relatively good condition, and are expanding in many areas (Geldenhuys *et al.* 1986; Knight *et al.* 1987). Sustained use management forms the basis of resource utilization from the largest forest complexes (Vermeulen 1993) and efforts are coordinated to expand this approach to different levels of forest size and management expertise (McKenzie 1988). Disturbance is a key factor in the maintenance of viable populations of many of the early and mid-seral forest species (Geldenhuys & Macdevette 1989). At present such species are well represented in rural and other regularly disturbed areas (Feely 1986). They could become rare in many areas following protection and the progression of succession as suggested by existing anecdotal information (Feely 1986; Geldenhuys & Macdevette 1989). It is a challenge to reserve managers to maintain a balance between areas of early, middle and late forest seral stages to maintain the existing species diversity.

The resource harvesting systems in State owned forests are sophisticated. Suitable systems will have to be developed for subsistence use of forests by rural communities.

The large forest complexes are well conserved. However, the isolated, scattered and biogeographically important small forest patches on farmland require better conservation of the dispersal corridors for gene flow maintenance.

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## **CONSERVATION OF TROPICAL HUMID FORESTS**

## CONSERVATION AND SUSTAINABLE MANAGEMENT OF FOREST RESOURCES IN SRI LANKA

*H.M. Bandaratillake*

### BACKGROUND

Sri Lanka is one of Asia's most densely populated countries, with a land area of about 6.5 million ha. and 17.5 million people. Topographically the country consists of a highland area in the south central part of the island which rises to about 2500 m. and lowland plains surrounding it. The climate is tropical and maritime. Three major climatic zones can be recognized based on the rainfall pattern; the wet zone (over 2500 mm/year) intermediate zone (1900-2500 mm/year) and the dry zone (below 1900 mm/year). The natural vegetation follows the pattern of the country's climatic zonation. In the wet zone Lowland Rain Forest forms the climax vegetation type. At elevations 1000-1500 meters, the natural vegetation is classified as Sub Montane Forests and at still higher elevations (over 1500 m) montane. The characteristic natural vegetation of the dry zone is the Dry Monsoon Forest and the natural vegetation in the intermediate zone represents Moist Monsoon Forests.

Sri Lanka was almost entirely covered by natural forest until the turn of the century. Since that time, the closed canopy natural forest cover has dwindled rapidly from about 80% , to 23.9% of the land area of the country in 1992 (1.5 million ha). In view of the increasing demands placed upon the forestry sector, its diminished capacity to meet the various needs of the people sustainably has become a major problem, which is being felt both at the national and local level. Despite past and continuing forestry activities, there is still net deforestation, with severe implications for the environment, the welfare of the rural people, agriculture and other allied sectors, and the entire economy of the country. The forest area *per capita* has declined from about 1.3 ha in 1900 to less than 0.1 ha in 1992. The remaining natural forests are under increasing pressure as the population keeps on growing and the resource base diminishing.

### FORESTRY IN THE NATIONAL ECONOMY

According to the official statistics, the contribution of the forestry sector to the national economy in 1993 was 1.4% of the total gross domestic product. Employment in the sector is estimated at about 170,000. (Sri Lanka Forestry Sector Master Plan, 1995). The true contribution to the economy is, however much greater. The official statistics fail to account for the large number of non-market oriented activities, they only concentrate on market oriented activities. The forestry sector's contribution to the energy sector is also poorly recognized. The share of bio-energy in the total energy consumption is about 67%. Of this about 66% is fuelwood, which means that fuelwood provides about 44% of the country's energy supply. Forestry also provides other tangible and intangible benefits such as

biodiversity, protection of soil and water resources, recreation and aesthetic value and impact on the greenhouse effect etc. Taking all the tangible benefits into account the Sri Lanka Forestry Sector Master Plan (1995) has estimated the sector's true contribution to the national economy to be in the region of 6% (excluding all the intangible benefits).

## **HISTORICAL PERSPECTIVES OF FOREST MANAGEMENT**

Prior to 1880s Sri Lanka was a well forested land and opening of forests was accelerated during Dutch and British periods for its timber and land. Exploitation and clearing of forests were heavy during 1830 to 1840 to export valuable timbers such as satin wood and ebony and the development of coffee and tea industries. The need for forest protection and regulation of felling was felt during this period and the Forest Ordinance was promulgated in 1840 which led to the declaration of Forest Reserves from 1850s, onwards. Forest management in Sri Lanka can be said to have started from this time. Since then, forest management began to be organized, based on scientific directions and with the emphasis on yield control which was introduced in 1882 and preparation of working plans. At around this time forest plantations of various species such as teak, mahogany and eucalyptus etc. were started. In 1929, the first forest policy was drawn up which emphasized the need for protection and self sufficiency in timber.

The national forest inventory of 1956 was the basis for selecting areas that should be kept for "perpetual" timber production. A resource assessment in 1965-67 concluded that with correct management, the country could enjoy an adequate supply of timber and protective environment of forest cover for all times. This led to the establishment of forest industries in the country and the State Timber Corporation. By the early 1980s however, it became clear that forest management based on the "commercial selection system" could not be sustained. The dense forest cover which was 44% of the total land area in 1956 dropped to about 27% in 1983 and 23% by 1992. Most of the deforestation had occurred in the dry zone, mainly as a result of planned and unplanned agricultural expansion.

### **Long Term Planning**

The first Forestry Master Plan for Sri Lanka was prepared in 1986 and a subsequent five year investment programme was launched in 1990 as the Forestry Sector Development Project. To overcome the criticisms levelled against this Master Plan due to inadequate attention paid to conservation issues, the Environmental Management Component was introduced to the Forestry Sector Development Project. The Environmental Management Division was established in the Forest Department in 1990 with the National Conservation Review (ecological assessment of all the natural vegetation types) in its agenda. A moratorium on logging operations in all the natural forests in the country was introduced in the same year. The Forestry Sector Development Project co-financed by the World Bank, FINNIDA, ODA,

and UNDP/FAO which is being implemented since 1990 and due to be completed in 1996 consists of the following components:

- (a) Forest Management
- (b) Forest Plantation Establishment
- (c) Forestry Research
- (d) Forestry Education
- (e) Environmental Management
- (f) Institutional Support

Further, a "Participatory Forestry Project" which covers participatory tree planting and forestry extension commenced in 1993 with financial assistance from the Asian Development Bank (ADB). The Forestry Master Plan (1986) was reformulated and the new Sri Lanka Forestry Sector Master Plan was developed in 1995.

### PRESENT CONDITIONS AND POTENTIAL OF THE FORESTS

The most recent forest cover mapping was done in 1994 based on the Landsat Thematic Mapper Imagery acquired in 1992. An indicative forest inventory was carried out in 1993 for the forest areas which are to be managed for sustainable production of timber and other forest products. National Conservation Review (ecological assessment) based on the biodiversity (flora and fauna) and hydrological characteristics was carried out during 1992-1995.

According to the forest map prepared in 1994 the dense natural forest cover of Sri Lanka was 1.5 million hectares representing 23.9% of the land area of the country. The total natural forest cover including sparse forests (less than 70% crown closure) was 2 million ha which represented 30.8% of the land area. Table 1 shows the area of natural forest cover in 1992.

Table 1 : Area of natural forest cover in 1992 ('000ha)

|                          | Area (ha)     | % of forest  | % of land   |
|--------------------------|---------------|--------------|-------------|
| Montane forest           | 3.1           | 0.2          | 0.1         |
| Sub montane forest       | 68.8          | 3.4          | 1.0         |
| Lowland rain forest      | 141.5         | 6.9          | 2.1         |
| Moist monsoon forest     | 243.9         | 11.9         | 3.7         |
| Dry monsoon forest       | 1094.3        | 53.5         | 16.5        |
| Dry zone riverine forest | 22.4          | 1.1          | 0.3         |
| Mangrove                 | 8.7           | 0.4          | 0.1         |
| Sparse                   | 463.8         | 22.6         | 7.0         |
| <b>Total</b>             | <b>2046.5</b> | <b>100.0</b> | <b>30.8</b> |

Over 98% of the forest land is controlled by state agencies. The Forest Department (FD) has management authority over 56% of the natural forests in the country and the Department of Wild life Conservation (DWLC) has authority over 40% of the forest land. A small proportion of the forest land is managed by the Local Administrators (about 3%). All forest areas under the management of the DWLC are categorized as protected areas. These are of 5 types, i.e. Strict Natural Reserves, Nature Reserves, National Parks, Jungle corridors and Sanctuaries. Those under the FD were all formerly identified as production forests, but lately some have been classified as Conservation Forests, National Heritage and Wilderness Area and Man and Biosphere Reserves (Protected forests) based on their biodiversity and other environmental significance. The forests under the Local Administrators are basically intended for the benefit of local people and for development purposes.

Table 2 shows the current extents of production and protected forests in Sri Lanka under the management of three state agencies.

**Table 2 : Production and protected forests in Sri Lanka ('000 ha)**

| Management                             | Production<br>(ha) | Protection<br>(ha) | Total<br>(ha) |
|----------------------------------------|--------------------|--------------------|---------------|
| Forest Department                      | 1039.4             | 111.1              | 1150.5        |
| Department of Wildlife<br>Conservation | 0.0                | 821.9              | 821.9         |
| Local Administration and private       | 74.1               | 0.0                | 74.1          |
| <b>Total</b>                           | <b>1113.5</b>      | <b>933.0</b>       | <b>2046.5</b> |
| Percentage of the total forest area    | 54.4%              | 45.6%              | 100.0%        |

Source : Forestry Sector Master Plan, 1995

The most common management system used at the time when logging of natural forests was still allowed (upto 1900) was the "commercial selection system", which was characterized by the removal of all trees of commercial species of over 60 cm DBH. at the end of each cutting cycle of 20-30 years. The results of the indicative inventory carried out in 1993 confirmed that this management system is a poor one and has resulted in the degradation of the forests in both stand structure and species composition. It was clear that in these forests, logging did not simulate the regeneration needed. Many of the valuable species have become rare or have disappeared altogether. Currently a moratorium has been imposed on all commercial logging operations in the natural forests in Sri Lanka.

Most of the forest plantation establishment took place after the 1950s and about 127,000 ha of forest plantations have been established up to 1994. (Administration Report of the

Conservator of Forests, 1994). Of this about 95% belongs to the Forest Department (FD) and the rest (about 5000-6000 ha) mainly fuelwood plantations belong to the tea estates and a tobacco company. The most common species planted are Teak (*Tectona grandis*), Eucalyptus (*E. grandis*, *E. microcorys*, *E. camaldulensis* and *E. tereticornis*), Pine (*Pinus caribaea*) and Mahogany (*Swietenia macrophylla*).

## **STRATEGIES ADOPTED FOR CONSERVATION AND SUSTAINABLE FOREST MANAGEMENT**

### **National Forestry Policy**

The first National Forest Policy was formulated in 1929 and since then the policy was amended and reformulated several times until 1980. The Current National Forestry Policy was formulated in 1994 and approved by the government in 1995. The main objectives are:

To conserve forests for posterity, with particular regard to biodiversity, soils, water and historical, cultural, religious and aesthetic values.

To increase the tree cover and productivity of the forests to meet the needs of present and future generations for forest products and services.

To enhance the contribution of forestry to the welfare of the rural population, and strengthen the national economy, with special attention paid to equity in economic development.

In order to meet the above policy objectives the following management strategy has been drawn up.

### **Revision of Forest Legislation**

A national task force has been appointed with the approval of the Cabinet of Ministers in order to make proposals to revise or reformulate the existing forest legislation. The objective of this is to make positive changes in legislation for effective implementation of the National Forest Policy.

### **Long Term Planning**

The forestry sector is characterized by the long growing periods of the trees and the long gestation periods for investments. Planned action is necessary in the forestry sector to curb deforestation and forest degradation in order to ensure the ability of our forests to provide much needed services and products for the people. Long term planning is also important because many decisions may have irreversible consequences.

**Table 3 : National forest policy objectives matrix**

| Objectives                                                                               | Protected areas                                                                             | Multiple use natural forests                                                                                                             | Home gardens & other non-forest land                                                                            | Forest Plantations                                                                                                                              | Industrial Production                                                                                                                       |
|------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| To conserve forests, biodiversity, and soils and water                                   | Priority in land allocation.<br>Managed by the state.<br>Rehabilitation of important areas. | Management by state, rural people, communities and state activities defined in management plans. Some logged over forests rehabilitated. | Priority over monocultural plantations, for the sake of biodiversity and wide range of products.                | Conservation of water and soils                                                                                                                 |                                                                                                                                             |
| To provide forest products and services                                                  | Protection of biodiversity, soil and water.<br>Non-wood forest products.                    | Products for subsistence and market.<br>Harvesting of forest products by state, local people and others in private sector.               | Subsistence and market needs.<br>Owner managed.<br>Promoted by state.<br>Relaxation in harvesting and transport | One or more products.<br>Emphasis on private sector and lease holds.<br>Owner managed.<br>Promoted by state. Wood for local users and industry. | Better use of wood and non-wood products.<br>Liberalized transport and trade. Self sufficiency in major products.<br>Competitive industries |
| To contribute to the welfare of the rural people and to strengthen the national economy. | Support for agricultural production.<br>Ecotourism.                                         | Subsistence needs.<br>Development of local economy.                                                                                      | Development of household and rural economies.<br>Main source of bio-energy and industrial wood.                 | Development of rural and national economies.                                                                                                    | Emphasis on private production.<br>Promotion of rural industries.<br>Development of rural and national economies.                           |

Source : Sri Lanka Forestry Sector Master Plan (1995)

The Forestry Sector Master Plan was reformulated in 1995, in order to ensure effective implementation of the National Forest Policy through addressing the complex issues faced by the forestry sector at present. The Forestry Sector Master Plan identifies development programmes required for sustainable development of the sector (Table 3)



### Intersectoral and Multidisciplinary Approach and Application of Land Use Planning

Intersectoral linkages will be strengthened particularly in the area of land allocation for forestry. A multi-disciplinary committee is to be appointed to carry out macro-level zoning of forest lands following approved criteria based on land use plans.

### Forest Conservation

The main objectives of this component cover conservation of biodiversity and protection of endemic and threatened species in forests and conservation of soil and water resources. This is one of the most important components in the forestry sector. Around 966,00 ha of natural forests representing over 45% of the natural forests in the country have been currently identified as protected areas (Table 4) to be managed for biodiversity and soil and water conservation. This current protected areas network in Sri Lanka is one of the most extensive in Asia and covers about 14% of the total land area of the country.

However, until the recent past, protected areas system did not include representative samples of biodiversity, particularly in the wet zone. A biodiversity survey (National Conservation Review) of all natural forests in the country is under way to fill this gap by establishing an optimal system of protected areas for the country. Based on the results of this National Conservation Review, 30 forests covering around 55,000 ha. have been identified in the wet zone to be managed as protected areas. This survey in the dry zone has been completed and the results are yet to be analysed.

**Table 4 : Extent of protected area in Sri Lanka**  
(managed by the FD and DWLC)

| Designation/Agency                | No.        | Area (ha)      |
|-----------------------------------|------------|----------------|
| <b>DWLC</b>                       |            |                |
| Jungle Corridors                  | 01         | 10,360         |
| National Parks                    | 12         | 462,448        |
| Nature Reserves                   | 03         | 33,372         |
| Sanctuaries                       | 52         | 284,117        |
| Strict Natural Reserves           | 03         | 31,574         |
| <b>Sub Total</b>                  | <b>71</b>  | <b>821,871</b> |
| <b>Forest Department</b>          |            |                |
| National Heritage Wilderness Area | 01         | 11,187         |
| Conservation Forests (Proposed)   | 31         | 71,000         |
| International Biosphere Reserves  | 02         | 9,376          |
| National Biosphere Reserves       | 39         | 63,384         |
| <b>Sub Total</b>                  | <b>73</b>  | <b>154,947</b> |
| <b>Sub Total Corrected</b>        | <b>73</b>  | <b>144,384</b> |
| <b>Total</b>                      | <b>144</b> | <b>966,255</b> |

\* Corrected for the International and National Biosphere Reserves which are located within National Heritage and Wilderness Areas and Conservation Forests. (Proposed new protected areas are not included in Table 2).

Sri Lanka Forestry Sector Master Plan prepared in 1995 has identified the following programmes of activities in order to address the major issues in this sector:

- I. Development of an adequate knowledge base and monitoring system. (Biodiversity and Socio-Economic Surveys, Applied and Basic Research, Biodiversity Monitoring System)
11. Integration and rationalization of comprehensive system of protected areas (*In-situ* Conservation and *Ex-situ* Conservation)
111. Effective management of protected areas to conserve biodiversity and provide benefits to local people (Management Planning, Participatory Management, Public Awareness)
- 1V. Conservation of Biodiversity outside Protected areas (Assessment of Biodiversity and Management Planning in Production forests, Research and Monitoring to assess the impacts on selective logging)

#### **Multiple Use Management of Forests**

There will be approximately 1 million ha (around 50% of the natural forest cover) of natural forests to be managed for sustainable production of timber and non-wood forest products. Increased emphasis will be given to Non-Wood Forest Products in the management of these forests. Planning and management of these forests should be carried out in collaboration with local communities. These forests are highly degraded at present due to over exploitation in the past and the current moratorium on commercial logging operations in these forests will continue for a further period of time until the forests are ready for harvesting. This category of forests consists of two types:

- \* Forests to be managed by the state with the participation of local people. (Extensive forest areas usually over 500 ha)
- \* Forests to be managed by the communities or user groups for the benefit of communities. These forests are mostly a few hundred hectares in extent and rarely over 500 ha (Initially this is to be practised on a pilot scale)

Long term objectives of the management of multiple use forests are:

1. These forests will be productively managed jointly with the rural people, and yielding a sustained flow of products and services that they and the rest of the society need.
- 11 The management of these forests will ensure maintenance of biodiversity and conservation of soil and water resources.

- 111 The management of multiple-use forests will contribute substantially to raising incomes and living standards of rural people.
- IV State agencies and non-state agencies (NGOs) will work with the rural people ensuring that no further deforestation and degradation will occur.

### **Home Gardens and Other Non-Forest Tree Resources**

At present home gardens, plantation crops and other farm lands provide about 70% of the industrial and construction wood supply and 80% of the bio-energy consumed in the country. The demand is increasing, while the capacity of natural forests and forest plantations is limited. Therefore this is one of the main programmes aimed at meeting the basic needs of the people for wood and bio-energy. Land for agroforestry (homegardens etc.) has been designated along with the other categories of forests as part of a permanent forest state. Now, various programmes are being developed to encourage establishment and maintenance of home gardens and other agro-forestry systems, i.e. leasing out state lands for home garden development, introduction of incentives for home gardens, providing institution support etc.

### **Forest Plantations**

The importance of forest plantations in providing a significant proportion of goods and also services has been well recognized. The current established total forest plantation area is around 127,000 ha. in 1994. (Administration Report of the Conservator of Forests, 1994). These forest plantations which have been established by the Forest Department in the past, provide an important source of wood for the country. It has been observed that both forest plantation establishment and management in the past had not been very efficient due to various limitations. Therefore long term objectives of the current programme are:

- \* To establish efficient forest management systems *and*
- \* Establishment of new forest plantations with the involvement of rural communities and the private sector.

Various monetary and non-monetary incentives have been proposed in order to promote private sector involvement in tree planting. Leasing of state lands to the non-state sector has been identified as one of the major incentives for future forest plantation establishment.

### **Support Programmes**

The support programmes that are being identified to ensure effective implementation of the sustainable forest management strategies are:

Supporting the development of an enhanced role for communities in forest protection, management and utilization.

Strengthening the training of forestry professionals.

Training of communities by the Forest Department, NGOs and the private sector relevant to their needs.

Strengthening the involvement of NGOs and community based organizations in forestry activities.

Strengthening the research capabilities in the forestry sector.

Utilization of latest developments in technology including computer databases, remote sensing etc.

Development of public awareness in all aspects of forestry.

Promoting initiatives to reduce the wood demand by increasing efficiency in utilization and introducing substitutes.

Practising environmental guidelines in logging operations and environmental and social impact assessments with reference to the forestry sector.

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# LONG TERM RESEARCH SITES IN TROPICAL FORESTS OF INDIA

S.N. Rai

## ABSTRACT

*Some of the oldest Long Term Research Sites (LTRS) in the tropical forests of the world, perhaps, exist in India. The earliest Increment plot which was established in India is in the West Coast region for *Hopea parviflora*. Subsequent to this, during the 1930s, there were concerted efforts for establishing Long Term Research Sites (called Linear Tree Increment plots (LTI), Linear Sample Plots and Linear Increment Plots). During this period plots were established in 2 main regions: in northern India in *Shorea robusta* forests of Uttar Pradesh, Bihar and West Bengal States and in southern India in Tropical Rain forests of Western Ghats in Karnataka, Tamil Nadu and Kerala States. Subsequently during the early 1950s in parts of Karnataka and in early 1980s in parts of Maharashtra there were renewed efforts for the creation of LTI plots in Moist Deciduous and Dry Deciduous teak bearing forests, respectively. At present nearly 100 such LTSRS exist in India and the majority of them are well maintained, with the exception of Sandalwood plots, which have been practically destroyed beyond recognition, in the three southern states of Andhra Pradesh, Karnataka and Tamilnadu, due to anthropogenic factors.*

*Over the past 20 years, the rate of diameter growth, basal area increment and pattern of mortality in the LTSRS in the Tropical Rain forests and moist deciduous teak and non-teak forests of Karnataka were studied. Similarly the rate of diameter increment of Sandalwood from the existing old records was also estimated. The average increment of Basal Area in the Tropical Rain forests is around 2% per year. The average rate of diameter increment for species in the Western Ghat ranges between 0.3 to 0.35 cm per year. The pattern of mortality as expected is very high for pioneer species and low for the typical climax species of the Rain forests.*

## INTRODUCTION

Long Term Research Sites (LTRS) in India have three different names: Linear Tree Increment Plots, Linear Increment Plots and Linear Sample Plots. In addition to this, they have also been called sometimes Permanent Preservation Plots. The common feature of all these plots has been their linear shape and formation with the object of recording diameter/girth measurements periodically. Sometimes only the commercially important species received attention while at other times most tree species were numbered and tagged for periodic measurements. In certain cases these plots were also used for studying the phenology and to serve as an area for the identification of various species. Some of these sites had detailed descriptions regarding crown sizes (distinguished as Large, Medium and Small), besides the trees being categorized into the dominance class. The dominance class was recorded as Dominant, Co-dominant, Dominated and Suppressed. These characteristics are important for studying the differential rate of diameter increment dependant upon dominance class or size of the crown.

## LOCATION OF LONG TERM STUDY SITES

The Long Term study sites are concentrated in Northern Uttar Pradesh, parts of West Bengal, parts of Bihar, Maharashtra, Karnataka, Tamilnadu and Kerala. The largest number of sites is in the forests of *Shorea robusta* (43) followed by those in *Tectona grandis* (23) and in Tropical Rain forests (20). The largest number of sites for *Shorea robusta* is in Uttar Pradesh followed by West Bengal and Bihar. Similarly, the largest number of sites for *Tectona grandis* is in Karnataka, followed by Maharashtra and Kerala. In respect of Tropical Rain forests also, the maximum number of sites is in Karnataka followed by Kerala, Assam and Tamil Nadu. There are sites for Montane Hill forests in Tamilnadu and Maharashtra. There are Preservation Plots in some of the oldest teak plantations of 1844 and 1872 in Kerala and Tamilnadu, respectively. Similarly there are sites (although not in good shape) for Sandalwood forests and in Red sanders plantations.

## LONG TERM RESEARCH SITES (LTRS) IN TROPICAL RAIN FORESTS

The majority of these sites is in the tropical rain forests of Karnataka, Kerala, Tamilnadu, Assam and Andaman Islands. They represent the characteristic vegetation of the area. The earliest among them was started during the 1930s in the Western Ghats and some of them have been very well maintained and periodically measured at 5 year intervals. Besides giving an indication regarding the rate of growth of individual species, some of the sites have also given very good information about the pattern of mortality for various species (Rai 1981).

The rate of Basal Area increment for 95 species and for the forest as a whole has been estimated as a percentage increase per year (Rai 1983). As expected the pioneer species have quick turn over and over a period of 35 years there was 47% mortality among them. The species which form the top canopy and which characterize this type of vegetation, have a much longer life span; the rate of mortality among them was only 25% over a period of 36 years. As opposed to this, the rate of diameter growth and consequently the rate of basal area increment for the pioneer species were highest (52%) and it was relatively low for the top canopy species (1.87%).

Besides the sites in Tropical Rain Forests there is a large number of increment plots for *Hopea parviflora* in the South Kanara district of Karnataka. This district is said to be the home of the species. It can also be claimed to have the oldest increment plots (established in 1911) for this species. Several of these plots have been continuously maintained and they are reasonably in good shape. A detailed analysis of the entire data available has given an annual diameter increment of 0.21 to 0.66 cm for the species (Rai, 1979).

The rate of growth of 47 species has been reported (Rai, 1979).

## SITES IN MOIST DECIDUOUS FORESTS

Such sites can be broadly grouped into three main categories as given below:

1. Increment plots in *Shorea robusta* forests
2. Increment plots in Teak bearing Moist deciduous forests
3. Increment plots in Non-teak Moist deciduous forests.

They are described below.

### Sites in *Shorea Robusta* Forests

The earliest increment plots of *Shorea robusta* were laid in parts of Uttar Pradesh and Bengal during the 1920s and 1930s. The largest number of plots are in and around Haldwani and Ramnagar in North-West Uttar Pradesh. The peculiarity of these plots is that only 3 important species namely *Shorea robusta*, *Adina cordifolia* and *Terminalia tomentosa* received attention in the beginning. Trees of only these species were measured and tagged, while the trees of other species although measured, were not tagged. However, in some of the sites in West Bengal trees of all the species have been measured and tagged.

The periodicity of measurement although intended to be every 5 years has not always been regular. There is a wealth of information which is available for detailed analysis. During the past, the pattern of mortality in these forests was studied and on certain occasions the rate of growth in various diameter classes has also been studied for these forests (Mathauda 1958). The real purpose of these study sites would be served, if they can be carefully studied to assess the impact of anthropogenic pressure and relative changes that have taken place in the species composition in these forests. As expected, on certain sites, where there were recurrent fires, thorny species like *Lantana* and others have invaded. Similarly in parts of West Bengal (where there is better distribution of rainfall), a process of succession has been observed wherein several of the pioneer species such as *Macaranga peltata*, *Callicarpa lanata*, *Erythrina* spp. etc. got replaced by more mesophytic species within a span of 20 - 25 years. These sites can be an excellent example for studying the rate of succession. In these forests, the succession process that has been observed has 7 stages.

The **first** seral stage is a grassland and in the **second** seral stage species like *Acacia catechu* and *Dalbergia sissoo* are generally found in pure patches. They are occasionally mixed with *Erythrina* spp, *Trewia nudiflora* and *Albizia* spp. The **third** seral stage has species like *Bombax cieba*, *Albizia odoratissima*, *Trewia nudiflora*, *Erythrina* spp, *Adina cordifolia*, *Ficus glomerata* and lots of climbers. The **fourth** seral stage has species like *Toona ciliata*, *Adina cordifolia*, *Sterculia villosa*, *Gmelina arborea*, *Bombax cieba*, *Wrightia tinctoria*. There is a scanty undergrowth of herbs and shrubs. Climbers are also common. The **fifth** seral stage has dry mixed forests with sporadic *Shorea robusta* mixed with *Dillenia pentegyna*, *Cereya arborea*, *Terminalia crenulata*, *Acrocarpus fraxinifolius* and *Lagerstroemia parviflora*. The undergrowth has *Coffea bengalensis*, *Clerodendron viscosum*, *Leea* spp. and others. The **sixth** stage is mainly dominated by *Shorea robusta* and

its other associates are *Schima wallichii*, *Lagerstroemia parviflora*, *Terminalia belerica*, *Chukrassia tabularis* etc. The ground cover has *Leea* spp, *Eupatorium* spp. and grasses. This can be called as a climax stage. However, there is a post climax stage which is too moist for *Shorea*. The species that are found in this evergreen type are *Artocarpus chaplasi*, *Michelia champaca*, *Machilus* spp. *Amoora wallichii* etc. The undergrowth has canes, ferns, *Leea* spp. and *Alpinia* spp.

### Sites in Teak forests

The majority of the LTRS on teak are in the moist deciduous forests of Karnataka State. Some of them are in Maharashtra, and one in Kerala. Teak is a dominant species in these sites and other associates generally are *Lagerstroemia lanceolata*, *Terminalia paniculata*, *Xylia xylocarpa* and bamboos. The majority of the sites was started in the 1950s and they have been measured regularly. The information on rate of growth of sites of Karnataka has been reported (Rai 1978, 1979, 1980, 1987, Rai & Sarma (1990). In some cases even the relative rate of growth for three dominance classes namely Dominant, Co-dominant and Suppressed has also been studied. The sites in Kerala and Tamilnadu are interesting from a different point of view as both are teak plantations of 1844 and 1872, respectively. They have been maintained as Permanent Preservation Plots with a view to observe the rate of diameter growth of the trees beyond rotation age. However, these sites also offer an excellent example for studying succession pattern under these climatic conditions e.g. the site in Kerala now has species of *Schleichera loeosa* *Dalbergia latifolia*, *Strychnos nuxvomica* etc, which is the natural succession on these sites.

### Sites in non-teak moist deciduous forests

Some of the oldest LTRS of this type were set up in parts of Maharashtra. These forests do not have teak although they fall in the same zone. The dominant species is *Pterocarpus marsupium* and other associates are *Lagerstroemia parviflora*, *Dalbergia latifolia*, *Saccopetalum tomentosum*, *Xylia xylocarpa* etc. The rate of growth of several species from these forests has been reported (Mathauda, 1955). Similar sites are also found in parts of Karnataka and they offer an interesting comparison with predominantly teak bearing sites. Some of the species which can be called as elements of semi-evergreen forests have much faster rates of growth under similar climatic conditions. The examples are *Vitex altissima* and *Lannea grandis*. However, it must be borne in mind that these sites have become more moist over a period of time and consequently they bring in these elements of semi-evergreen vegetation and over a long period of time have excluded *Tectona grandis* from them.

### SITES IN DRY DECIDUOUS FORESTS

Such sites have been set up during the 1980s in Maharashtra and in Tamilnadu. The majority of them have *Tectona grandis* as the main species and the other associates are *Grewia*



*tilaefolia*, *Lagerstroemia parviflora*, *Anogiessus latifolia*, *Diospyros melanoxylon* etc. One of them is being studied very intensively and is being maintained on a 50 ha plot. Some of the important observations are:

- (a) The dominant canopy tree species *Lagerstroemia microcarpa*, *Terminalia crenulata*, *Anogiessus latifolia* and *Tectona grandis* have undergone relatively minor changes in their population sizes.
- (b) There was a reduction in the population of the understorey tree *Kydia calycina* and the shrub *Helicteres isora* due to the pushing over and debarking of stems by elephants and by fire.
- (c) The majority of the other species (both the common and rarer ones) show marginal declines in their populations.
- (d) Though there was a decrease in the total number of individuals in the plot during 1988-93, there was a small increase in the Basal Area of the plot. The present average Basal Area of the plot is 24.98 sq m per ha.

The plot had 25929 living woody plants of 1 cm DBH and above, belonging to 71 species in 1988. The four most common species constituted 55.9% and the eight most common species constituted 83.2% of the population.

## RESULTS AND DISCUSSION

From the analysis so far the following results are reported. The study sites in moist teak zones can be distinguished in 3 different categories: Teak as a pre-dominant association, teak as an associate, teak absent or rare. In order to assess any differential rate of growth, the first two categories were examined. There was no perceptible difference between the rate of growth under the first two categories. However, variation in the rate of growth depending upon the location of the plots is seen as expected. Average annual diameter increment of *Dalbergia latifolia* ranged between 0.20 to 0.30 cm while that of *Xylia xylocarpa* ranged between 0.21 to 0.31 cm (Rai 1978). Basal area increment of these two species was also considered over a period of 25 years and the percentage increase for *Dalbergia latifolia* was 1.11% (range 0.57 to 1.59% for 8 sites) and for *Xylia xylocarpa* it was 1.27%.

The rate of growth of *Hopea parviflora* in the western coast of India on alluvial soil was higher (1.25 cm per year) in the tree of 11 to 20 cm diameter class, however, the general rate of growth ranged between 0.29 to 0.57 cm per year (Rai 1979). The rate of diameter growth of the 2 species which are representative of semi-evergreen forests but also occur sometimes in moist sites on deciduous forests was studied (Rai 1979). The average rate of increment for *Vitex altissima* ranged between 0.27 to 0.46 cm and that of *Lannea coromandelica* ranged between 0.21 to 0.31 cm. However the average increase in basal area over a 25 year period was 3.37% for the former and 2.33% for the latter. The trees below 30 cm DBH generally

had a higher rate of Basal Area increment although the maximum diameter increment is in the middle diameter range of 40 - 55 cm. In the earlier studies the rates of growth were on the higher side e.g. a study by Kadambi (1956) on the rate of growth of *Terminalia paniculata* gave an estimate of 120 and 145 years to reach a DBH of 60 cm, however, the study by Rai (1980) based on 385 trees over a period of 25 years revealed that *Terminalia paniculata* on an average requires 203 years to grow to a diameter of 60 cm. Similarly *Lagerstroemia lanceolata* requires 201 years to reach a DBH of 60 cm. The maximum annual diameter increment for the former was 0.33 cm and for the latter it was 0.34 cm.

## PATTERN OF SURVIVAL IN TROPICAL RAIN FORESTS

Data from 3 study sites were examined for a period of 36 years in order to study the pattern of survival in the Tropical rain forests. The overall survival percent for 87 species (2966 trees above 10 cm DBH) was 63.67%. The canopy species such as *Dipterocarpus indicus*, *Calophyllum elatum*, *Lophopetalum wightianum*, *Aglaia roxburghii*, *Diospyros oocarpa* etc., had an overall survival of nearly 75% during 36 years of observation. Similarly the species which constitute the typical underwood such as *Garcinia cambogia*, *G. monrlla*, *Knema attenuata*, *Myristica beddomei*, *M. malabarica*, *Olea dioica* etc. had 78% survival. The higher survival of these species is an indication of the ecological resilience which permits them to grow under shade and eventually become more tolerant, as their requirement of light and possibly of nutrients is lower than the canopy species. The species that came up in the gaps which can be called as Gap Phase species e.g. *Macranga peltata*, *Pterospermum reticulatum*, *Euophoria longena* etc. had a lower survival percentage of around 53% only. Similarly the *Caryota* palm had a survival of 50% only. An analysis of this type can give an indication regarding the average rate of turnover of these species.

In another study the Mean Annual Girth Increment of several species was studied in Tropical Rain forests over a period of 35 years (Rai 1981). The range of five yearly girth Increment for various species was 0.85 cm for *Poeciloneuron indicum*, 1.38 cm for *Dipterocarpus indicus*, 0.32 for *Diospyros paniculata*, 0.36 for *Garcinia* spp., 0.88 for *Palaquium ellipticum*, 0.94 for *Mesua ferrea* and 1.32 for *Litsea wightiana*.

Processing of data sometimes has been done in a transition matrix and sometimes a second degree quadratic equation of the form  $Y=a+bx+cx^2$  has been fitted to the data. However as measurements are not available for diameters of upto 10 cm, the regression equation has certain limitations. In many cases the graphical method of manually fitting the curve is as good if not better, than the regression method. However, in certain cases both methods have given comparable results.

Basal Area Increment of 95 species occurring in four sites in the Tropical Rain forests of Western Ghats was studied, based on measurements available for these sites (Rai 1983) for 36 years. Based on the habit of growth the species were classified into four categories namely, Pioneers, Canopy, Middle storey and Understorey species. The rate of Basal Area

increment for the Pioneer species was 5.3% per year, while that for the Canopy species was 3.22%, for the Middle storey species 2.02% and for the understorey species 1.87% per year in these forests. The overall rate of Basal area increment for the 4 sites was 2.06 per year and in terms of real increase it was 0.505 square metre per ha/year.

Average Basal area increase of *Terminalia tomentosa* in 5 study sites of the Moist deciduous forests was 1.64% per year over a period of 25 years. Similarly for *Careya arborea* on 7 study sites it was 2.21% (Rai 1985). The rate of diameter increment of Sandalwood computed from the old data gave an increment of around 0.27 cm/year (Rai & Sarma 1986).

## BASAL AREA

The estimate of Basal Area for 93 LTRS are given (Rai In press). The Basal Area in Tropical Rain forests of Assam was 41.9 sq m/ha (average of 2 sites) and it was 44.5 sq m/ha (average of 8 sites) in the rain forests of Karnataka. In Kerala, in the Salient valley area, the Basal Area measured in 10 plots ranged between 40-80 sq m/ha. In a typical forest in Wynad, Kerala, the basal area was 42.8 sq m/ha.

In the Montane Hill forests in Karian *Shola* at Top slip in Coimbatore Division of Tamilnadu, the Basal Area was 44.8 sq m/ha. In a similar kind of vegetation near Pune in Maharashtra, the basal area was 50.3 sq m/ha. In a semi-evergreen forest of Karnataka, it was 35.5 sq m/ha.

In another *Shola* forest in Oooty, the basal area was 34.8 sq m/ha.

In Dry Deciduous *Shorea* forests in parts of Bihar, the average Basal Area was 27.0 sq m/ha. However, in the moist deciduous *Shorea* forests in Uttar Pradesh, the average of 27 sites gave a basal area of 34.5 sq m/ha and the range was from 20.2 to 67.6 sq m/ha.

In parts of West Bengal, the average Basal Area of 7 sites was 58.7 sq m/ha and the range was from 27.1 to 75.7 sq m/ha.

In the Moist deciduous Teak forests of Karnataka, the average Basal Area was 29.7 sq m/ha and the range was 21.6 to 47.8 sq m/ha for 15 sites.

In a Non-teak Moist deciduous forest in Maharashtra, the Basal Area was 27.3 sq m/ha for 6 study sites in Dry Deciduous teak forests of Maharashtra the average Basal Area was 12.4 sq m/ha.



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**TREE POPULATION DYNAMICS OF A RIVERINE MIXED FOREST IN  
KETAMBE RESEARCH STATION, G. LEUSER BIOSPHERE RESERVE,  
SUMATRA, INDONESIA**

*Rochadi Abdulhadi, Razaly Yusuf & Suhardjono*

**ABSTRACT**

*A 1.6 hectare permanent plot of a lowland forest of Ketambe Research Station in G. Leuser National Park, Sumatra was established in 1980. All trees with the DBH greater than 10 cm were initially enumerated and marked. This forest was described as a Riverine mixed forest. A total of 736 trees, of 129 species, 86 genera and 50 families were recorded. The Euphorbiaceae and Meliaceae were the most dominant families which comprised 15 and 14 species, representing 28.4% (216 trees) and 18.9% (139 trees) of the stand respectively. The most leading species were *Dendrocnide sinuata* (IV. 18.00), *Parashorea lucida* (IV. 17.30), *Rinorea sclerocarpa* (IV. 16.50), *Aglaia cauliflora* (IV. 13.60) and *Paranephelium nitidum* (IV. 11.90).*

*In 1995, all trees were reinvestigated. In 15 years 167 (22.81%) trees of 62 species were no longer present. More than 20% of dead trees in the plot were light demanding. Secondary species included *Dendrocnide sinuata* (20), *Croton argyratus* (7), *Macaranga diepenhorstii* (4), and *Macaranga triloba* (3). The other dead trees were mostly the prevalent species such as *Paranephelium nitidum* (15), *Aglaia cauliflora* (7), and *Rinorea sclerocarpa* (6). In contrast, 215 new trees in 65 species were present. The most abundant were *Aglaia cauliflora* (18), *Paranephelium nitidum* (17), *Pseudouvaria rugosa* (13), *Rinorea sclerocarpa* (11), and *Parashorea lucida* (10). Changes in population size of the species and forest structure over 15 years are further discussed.*

**INTRODUCTION**

A tremendous effort in the compiling of a forest inventory and carrying out ecological studies in Indonesia, has been made by the National Biological Institute (now called the Research and Development Center for Biology) and the Forest Research Institute (now known as the Forest Research and Development Center) during the last two decades (Kartawinata 1990). Many of them were descriptive, short term and have focused on vegetation types of the lowland forest in Sumatra and Kalimantan (Kartawinata 1990; Laumonier 1992). More recently, the Indonesian Institute of Sciences has been doing several integrated baseline environmental studies and comprehensive ecological researches in various conservation areas.

Comprehensive research in Indonesia, however, is relatively new and is urgently needed

before the natural forests disappear. Long term ecological research with large permanent plots is still lacking. There are only several permanent plots in Gunung Leuser Biosphere Reserve, Sumatra; Cibodas Biosphere Reserve, West Java ; Lempake and Wanariset, East Kalimantan. The present paper reports a study of population changes in a riverine mixed forest plot in Ketambe Research and Conservational Education Station, G. Leuser Biosphere Reserve, Sumatra.

## STUDY AREA

The study was carried out in the study site of Ketambe Research and Conservational Education Station (3° 4" North and 97° 37" West). This station is located within the Gunung Leuser Biosphere Reserve, which is well known as G. Leuser National Park, 32 km north of Kutacane, the Capital city of South Aceh, Sumatra.

The area is around 150 ha, lies just below the confluence of the fast flowing and rocky Alas and the Ketambe river (Fig. 1), and is surrounded by Gunung Mamas, Gunung Kemiri and Gunung Bandahara. The topography is flat to hilly at an altitude of 350 -450 m above sea level (Rijksen 1978).

According to the exploratory soil map of Aceh (Dai 1974), the soil in the area consists of alluvial and yellow red podzolic complex, with lithosol and latosol occurring in the hilly and ridge area.

The climate belongs to the rainfall type A with Q value of 0.8 (Schmidt & Ferguson 1951). The annual rainfall is about 4000 mm with the highest precipitation during October- January and driest months occurring in April - May (Rijksen 1978). Kartawinata (1973) is classified as an "ever wet" climate, with the driest month having never less than 100 mm.

## METHODS

In 1980, a permanent plot of 100 x 160 m was established near the confluence of the Alas and Ketambe rivers (Fig. 1), within the low-canopy forest type (Abdulhadi *et al.* 1990, Abdulhadi & Yusuf 1991). The plot was divided into 160 sub plots, each 10 x 10 m. Each plot was marked with four red-painted PVC pipe stakes. Every tree with the DBH > 10 cm in the 160 sub plots was recorded and numbered using an aluminium tag. The diameter at breast height (1.3 m above the ground) was measured, and marked using red paint marker.

In 1995, re-enumeration and re-measurement of coloured trees in the plot were carried out. Voucher specimens for all trees were collected to verify field identification. The results of re-investigation of this 1.6 hectare plot are reported in this paper.



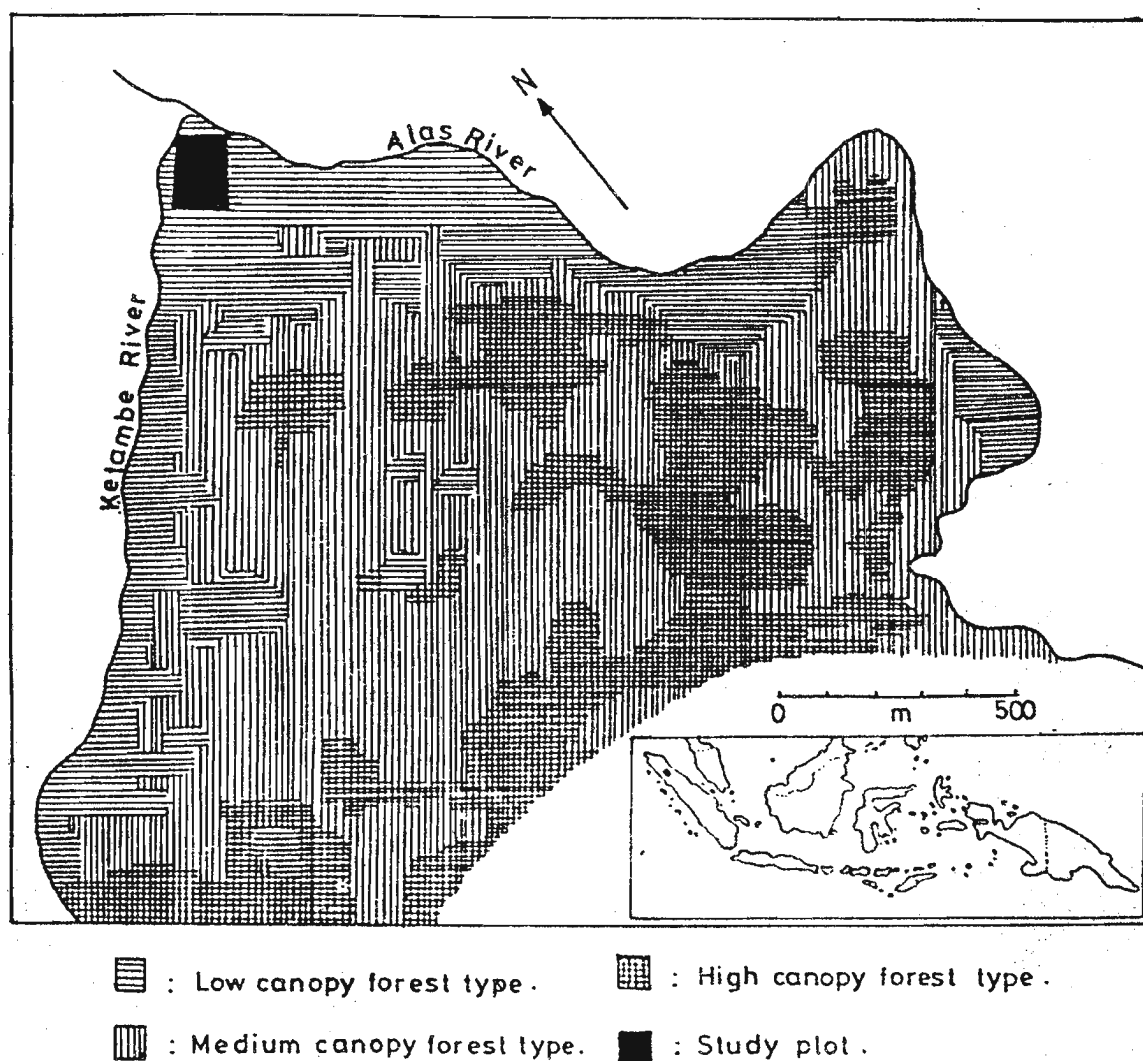


Figure 1 : Location of the Study Site

## RESULTS AND DISCUSSION.

### Floristic Composition

In 1980, a total number of 129 species belonging to 86 genera and 50 families were recorded within the 1.6 ha plot. The number of species, genera and families recorded in 1995 were slightly higher (Table 1). The full list of species enumerated in the plot are presented in Appendix 1.

**Table 1: Number of species, genera and families in 1.6 ha Riverine Mixed Forest plot at Ketambe Research Station, G. Leuser Biosphere Reserve.**

| Description                  | 1980 | 1995 |
|------------------------------|------|------|
| No. of species               | 129  | 132  |
| No. of genera                | 86   | 90   |
| No. of families              | 50   | 51   |
| Dipterocarpaceae:            |      |      |
| No. of species               | 2    | 2    |
| No. of trees                 | 27   | 33   |
| Basal area (m <sup>2</sup> ) | 4.1  | 2.9  |

**Table 2: Number of trees per ha (D), frequency (F) and the important values (IV) of the prevalent species within 1.6 ha plot of Riverine Mixed Forest in Ketambe Research Station, G. Leuser Biosphere Reserve, Sumatra, Indonesia**

| Species                      | Family           | D  | F    | IV   |
|------------------------------|------------------|----|------|------|
| <u>1980</u>                  |                  |    |      |      |
| <i>Dendrocnide sinuata</i>   | Urticaceae       | 36 | 29.3 | 18.0 |
| <i>Parashorea lucida</i>     | Dipterocarpaceae | 16 | 11.3 | 17.3 |
| <i>Rinorea sclerocarpa</i>   | Violaceae        | 33 | 24.0 | 16.5 |
| <i>Strombosia zeylanica</i>  | Olacaceae        | 21 | 17.5 | 14.5 |
| <i>Aglaia cauliflora</i>     | Meliaceae        | 25 | 13.7 | 13.6 |
| <i>Paranephelium nitidum</i> | Sapindaceae      | 32 | 21.4 | 11.9 |
| <i>Pseudouvaria rugosa</i>   | Annonaceae       | 19 | 15.6 | 10.3 |
| <u>1995</u>                  |                  |    |      |      |
| <i>Aglaia cauliflora</i>     | Meliaceae        | 29 | 21.8 | 17.7 |
| <i>Paranephelium nitidum</i> | Sapindaceae      | 31 | 25   | 17.5 |
| <i>Rinorea sclerocarpa</i>   | Violaceae        | 37 | 26.9 | 16.4 |
| <i>Strombosia zeylanica</i>  | Alocaceae        | 20 | 17.5 | 14.7 |
| <i>Dendrocnide sinuata</i>   | Urticaceae       | 26 | 20.6 | 13.3 |
| <i>Parashorea lucida</i>     | Dipterocarpaceae | 20 | 11.9 | 12.8 |
| <i>Pseudouvaria rugosa</i>   | Annonaceae       | 16 | 19.4 | 12.4 |

Table 1 also shows that the number of Dipterocarp trees was slightly higher. However, the basal area of these species was less. Three big *Parashorea lucida* trees (DBH > 90 cm) recorded in 1980 were no longer found in 1995. In contrast, nine new small trees of this species were present.

Table 2 shows the density, frequency and the importance values of the most prevalent species that occurred in the plot, recorded in 1980 and 1995. The seven most important species in 1980 in descending order of importance values were *Dendrocnide sinuata*, *Parashorea lucida*, *Rinorea sclerocarpa*, *Strombosia zeylanica*, *Aglaia cauliflora*, *Paranephelium nitidum* and *Pseudouvaria rugosa*. Their importance values accounted for 34% of all species. A light demanding tree species *Dendrocnide sinuata* had the highest IV in 1980, which accounted for 6% of the total. The abundance of this secondary species indicated that the disturbance had occurred in this forest. Abdulhadi & Yusuf (1991) noted that the forest in this plot was in development phase. Seventy percent of the forest canopy comprised the gap (15%) and building phase (55%)

After 15 years, the most important species were still similar, but there were changes in the IV order. The rank of *Dendrocnide sinuata*, the short lived, light demanding species, dropped to the fifth order, following *Aglaia cauliflora*, *Paranephelium nitidum*, *Rinorea sclerocarpa* and *Strombosia ceylanica*.

Out of the 50 families, five families were observed as the most common families in the plot, in terms of number of species, genera and trees (Table 3). Euphorbiaceae and Meliaceae were the most common in both 1980 and 1995, representing 28.4% and 18.9% of the tree stand respectively. From 1980 to 1995, both families showed an increasing number of species. Three species of Euphorbiaceae i.e., *Baccaurea* sp., *Macaranga tanarius*, and *Mallotus* sp., and five of Meliaceae species i.e., *Aglaia maingayi*, *Chisocheton* sp., *Didymocheton nutans*, *Dysoxylum caulostachyum* and *Dysoxylum cyrtobrachium* were new.

However, the last two common families, i.e., Lauraceae showed a decrease in the number of species, and the number of Sapindaceae species was stable.

**Table 3 :** Five common families recorded in 1.6 ha plot of Mixed Riverine Forest of Ketambe Research Station, G. Leuser Biosphere Reserve, Sumatra, Indonesia.

| Family        | 1980 |     |       | 1995 |     |       |
|---------------|------|-----|-------|------|-----|-------|
|               | Spec | Gen | Trees | Spec | Gen | Trees |
| Euphorbiaceae | 11   | 10  | 140   | 13   | 10  | 129   |
| Meliaceae     | 13   | 4   | 90    | 18   | 5   | 114   |
| Annonaceae    | 10   | 7   | 53    | 10   | 7   | 65    |
| Lauraceae     | 8    | 7   | 36    | 7    | 6   | 46    |
| Sapindaceae   | 3    | 3   | 64    | 3    | 3   | 66    |

## Forest Structure

In 1980, there were 736 trees with DBH > 10 cm. Fifty four species (40%) were represented by a single individual, 55 species (47%) by 2 -10 individuals, 18 species (13%) by more than 11 individuals. The density of trees in 1.6 ha plot averaged 474 per ha over the period 1980 - 1995, and Table 4 shows a general increase of about 2.6 %. In 1995, 786 trees of 133 species were recorded. Out of 133 species, 42% (56 species) were represented by a single individual, 49 % ( 65 species) by 2-10 individuals and 9% (12 species) by more than 10 individuals.

The basal area also increased by about 9.3% with the average basal area of 26.15 cm<sup>2</sup>. The increase of basal area was a result of the increasing tree density, and it was also reflected in the growth of individual trees of the study plot. As shown in Table 4, the average basal area of trees was slightly increased by 0.04 square metres. In other words, the average of tree DBH showed a slight increase of about 0.5 cm a year. The diameter class distribution in 1980 and 1995 indeed, was similar (Fig. 2).

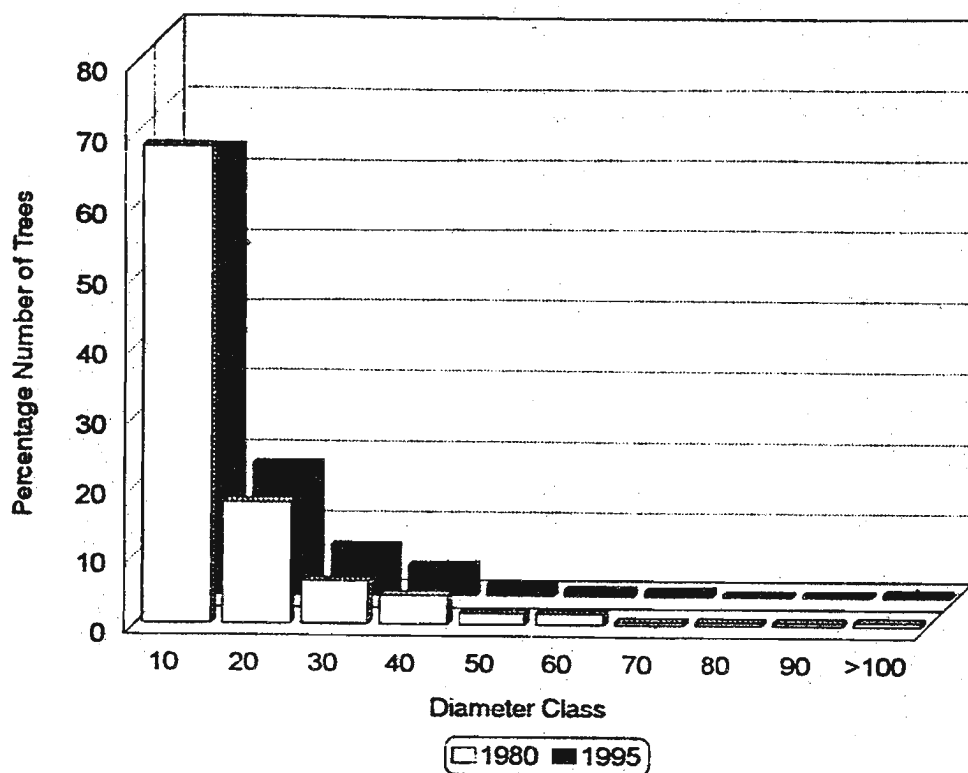


Figure 2: Diameter Class Distribution of trees in 1980 and 1995

**Table 4 :** Density and basal area of trees DBH >10 cm in 1.6 ha sample plot in Ketambe Research Station, G. Leuser Biosphere Reserve, Sumatra, Indonesia.

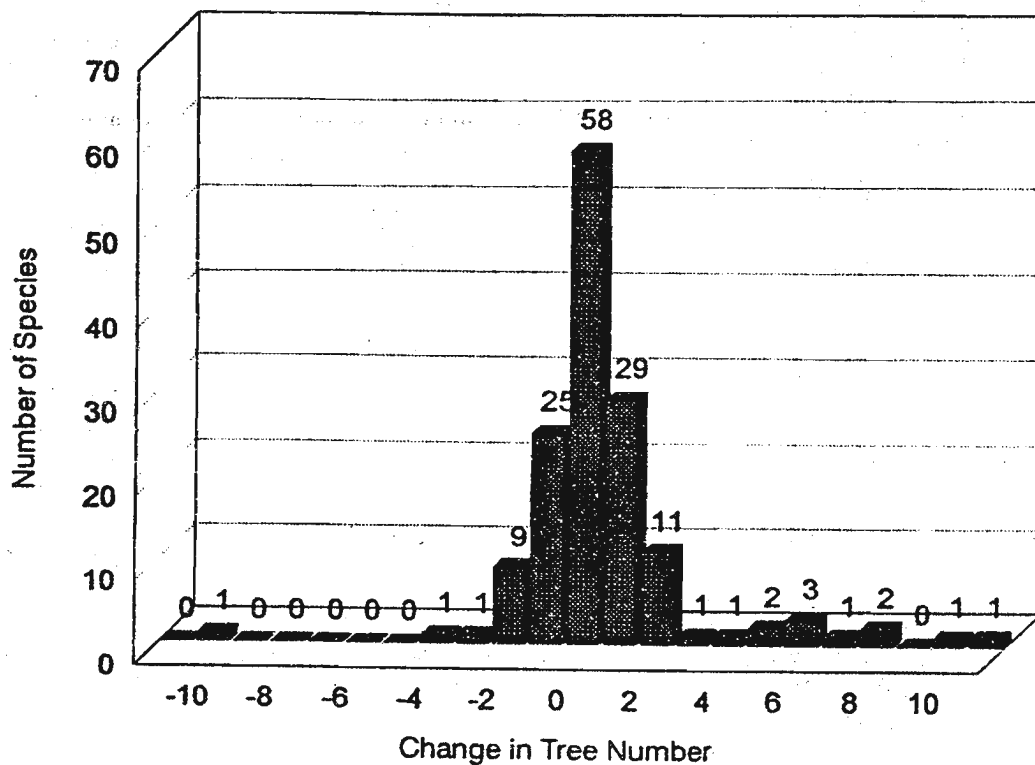
|                                               | 1980  | 1995  |
|-----------------------------------------------|-------|-------|
| Tree density (ha <sup>-1</sup> )              | 468   | 480   |
| Basal area (m <sup>2</sup> ha <sup>-1</sup> ) | 24.98 | 27.31 |
| Basal area per tree (m <sup>2</sup> )         | 0.053 | 0.057 |

### Mortality and Recruitment

During the period between 1980 and 1995, both number of trees (Table 4) and species richness (Table 1) tended to increase, indicating the development and changes of population within the period of 15 years. Out of 736 trees recorded in 1980, 167 individual trees were not found in 1995, giving the mortality value of 22.8% over the 15 year period, or an annual mortality rate of 1.52%. This rate was apparently in the range of other tropical forests studied. Swaine *et al.* (1987) reviewed that annual mortality rates were mostly in the range of one or two percent. However, Abdulhadi *et al.* (1995) reported that the annual mortality rate in a montane forest in Cibodas Biosphere Reserve, West Java was 2.3%. The mortality rates varied to a similar degree within local sites (Lieberman & Lieberman 1987), and successive periods (Manokaran *et al.* 1987).

Of 127 species recorded in 1980, 64 species had zero mortality while the remaining had a mortality rate ranging from 7% to 100%. Most of these species were the rare species in the plot, i.e., the species with a single tree (23 species), two individual (2 species) and only one species with three individual trees. More than 85% of the dead trees were the small trees with the DBH less than 30 cm; and 31% of it were the light demanding trees, *Dendrocnide sinuata* (20 trees), *Croton argyratus* (7 trees), *Macaranga diepenhorstii* (4) and *Macaranga triloba* (3 trees). A similar trend was also noted by Manokaran & Kochumem (1987).

Death and recruitment of trees resulted in the changes in population size of the species. As shown in Figure 3, 76% of the species recorded showed the net change in density by one or no change. Significant changes in density of species are difficult to test, because most species have few trees. However, population of the important light demanding species *Dendrocnide sinuata* decreased by 17 trees. The population of the other important species *Parashorea lucida*, *Aglaia cauliflora* and *Pseudouvaria rugosa* increased from nine to 11 trees respectively. These population changes were apparently related to the direction of forest development; i.e., replacement of light demanding species by shade tolerant species.



**Figure 3 :** Distribution of change in number of trees over 15 years for 145 species in 1.6 hectare plot of a riverine mixed forest in Ketambe Research Station, G. Leuser Biosphere Reserve, Sumatra, Indonesia.

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**Appendix 1 : List of tree species recorded in 1.6 ha plot of Riverine Mixed Forest in Ketambe Research Sation, G. Leuser Biosphere Reseve, Sumatra, Indonesia**

| NO | SPECIES                          | FAMILY        | TOTAL<br>1980 | NUMBER<br>DIED | %<br>MORTALITY | NEW<br>RECRUIT | TOTAL<br>1995 |
|----|----------------------------------|---------------|---------------|----------------|----------------|----------------|---------------|
| 1  | <i>Saurauia</i> sp.              | Actinidaceae  | 3             | 2              | 66.67          | 0              | 1             |
| 2  | <i>Saurauia tristyla</i>         | Actinidaceae  | 2             | 1              | 50.00          | 0              | 1             |
| 3  | <i>Mangifera</i> sp.             | Anacardiaceae | 1             | 1              | 100.00         | 0              | 0             |
| 4  | <i>Spondias</i> sp.              | Anacardiaceae | 1             | 0              | 0.00           | 0              | 1             |
| 5  | <i>Cananga odorata</i>           | Annonaceae    | 5             | 1              | 20.00          | 0              | 4             |
| 6  | <i>Cyathocalyx sumatranus</i>    | Annonaceae    | 2             | 0              | 0.00           | 0              | 2             |
| 7  | <i>Griffithianthus merrillii</i> | Annonaceae    | 5             | 2              | 40.00          | 1              | 4             |
| 8  | <i>Mitrephora</i> sp             | Annonaceae    | 2             | 0              | 0.00           | 0              | 2             |
| 9  | <i>Polyalthia celebica</i>       | Annonaceae    | 2             | 0              | 0.00           | 0              | 2             |
| 10 | <i>Polyalthia lateriflora</i>    | Annonaceae    | 1             | 0              | 0.00           | 1              | 2             |
| 11 | <i>Polyalthia</i> sp.            | Annonaceae    | 2             | 0              | 0.00           | 2              | 4             |
| 12 | <i>Popowia</i> sp.               | Annonaceae    | 1             | 0              | 0.00           | 0              | 1             |
| 13 | <i>Pseudouvaria reticulata</i>   | Annonaceae    | 3             | 0              | 0.00           | 2              | 5             |
| 14 | <i>Pseudouvaria rugosa</i>       | Annonaceae    | 31            | 3              | 9.68           | 13             | 41            |
| 15 | <i>Alstonia scholaris</i>        | Apocynaceae   | 1             | 0              | 0.00           | 0              | 1             |
| 16 | <i>Trevesia sundaica</i>         | Araliaceae    | 3             | 3              | 100.00         | 1              | 1             |
| 17 | <i>Gossampinus valetonii</i>     | Bombacaceae   | 2             | 0              | 0.00           | 0              | 2             |
| 18 | <i>Canarium apertum</i>          | Burseraceae   | 2             | 1              | 50.00          | 1              | 2             |
| 19 | <i>Canarium denticulatum</i>     | Burseraceae   | 4             | 0              | 0.00           | 0              | 4             |
| 20 | <i>Canarium</i> sp.              | Burseraceae   | 3             | 0              | 0.00           | 1              | 4             |
| 21 | <i>Santiria</i> sp.              | Burseraceae   | 2             | 1              | 50.00          | 2              | 3             |
| 22 | <i>Stixis parviflora</i>         | Capparaceae   | 1             | 0              | 0.00           | 0              | 1             |
| 23 | <i>Lophopetalum javanicum</i>    | Celastraceae  | 1             | 0              | 0.00           | 1              | 2             |
| 24 | <i>Calophyllum soulattri</i>     | Clusiaceae    | 3             | 2              | 66.67          | 2              | 3             |
| 25 | <i>Garcinia parviflora</i>       | Clusiaceae    | 2             | 0              | 0.00           | 1              | 3             |
| 26 | <i>Terminalia bellirica</i>      | Combretaceae  | 2             | 0              | 0.00           | 0              | 2             |
| 27 | <i>Mastixia trichotoma</i>       | Cornaraceae   | 1             | 0              | 0.00           | 0              | 1             |
| 28 | <i>Tetrameles nudiflora</i>      | Datiscaceae   | 2             | 0              | 0.00           | 0              | 2             |



## Appendix 1 : Contd.

| NO | SPECIES                         | FAMILY           | TOTAL<br>1980 | NUMBER<br>DIED | %<br>MORTALITY | NEW<br>RECRUIT | TOTAL<br>1995 |
|----|---------------------------------|------------------|---------------|----------------|----------------|----------------|---------------|
| 29 | <i>Dillenia castaneaefolia</i>  | Dilleniaceae     | 10            | 0              | 0.00           | 0              | 10            |
| 30 | <i>Dillenia excelsa</i>         | Dilleniaceae     | 2             | 1              | 50.00          | 0              | 1             |
| 31 | <i>Parashorea lucida</i>        | Dipterocarpaceae | 26            | 3              | 11.54          | 9              | 32            |
| 32 | <i>Shorea leprosula</i>         | Dipterocarpaceae | 1             | 0              | 0.00           | 0              | 1             |
| 33 | <i>Disopyros capreaefolia</i>   | Ebenaceae        | 2             | 2              | 100.00         | 0              | 0             |
| 34 | <i>Elaeocarpus</i> sp.          | Elaeocarpaceae   | 1             | 1              | 100.00         | 0              | 0             |
| 35 | <i>Sloanea javanica</i>         | Elaeocarpaceae   | 1             | 0              | 0.00           | 0              | 1             |
| 36 | <i>Aporosa frutescens</i>       | Euphorbiaceae    | 18            | 10             | 55.56          | 0              | 8             |
| 37 | <i>Baccaurea racemosa</i>       | Euphorbiaceae    | 24            | 4              | 16.67          | 6              | 26            |
| 38 | <i>Baccaurea</i> sp.            | Euphorbiaceae    | 0             | 0              | 0.00           | 1              | 1             |
| 39 | <i>Blumeodendron tokbrai</i>    | Euphorbiaceae    | 12            | 3              | 25.00          | 3              | 12            |
| 40 | <i>Bridelia minutiflora</i>     | Euphorbiaceae    | 1             | 0              | 0.00           | 0              | 1             |
| 41 | <i>Cleidion speciflorum</i>     | Euphorbiaceae    | 1             | 0              | 0.00           | 3              | 4             |
| 42 | <i>Croton argyratus</i>         | Euphorbiaceae    | 21            | 7              | 33.33          | 4              | 18            |
| 43 | <i>Drypetes longifolia</i>      | Euphorbiaceae    | 23            | 7              | 30.43          | 3              | 19            |
| 44 | <i>Macaranga tanarius</i>       | Euphorbiaceae    | 0             | 0              | 0.00           | 1              | 1             |
| 45 | <i>Macaranga diepenhorstii</i>  | Euphorbiaceae    | 5             | 4              | 80.00          | 6              | 7             |
| 46 | <i>Macaranga triloba</i>        | Euphorbiaceae    | 4             | 3              | 75.00          | 0              | 1             |
| 47 | <i>Mallotus philippensis</i>    | Euphorbiaceae    | 3             | 1              | 33.33          | 0              | 2             |
| 48 | <i>Mallotus sphaerocarpus</i>   | Euphorbiaceae    | 14            | 1              | 7.14           | 11             | 24            |
| 49 | <i>Neoscortechinia kingii</i>   | Euphorbiaceae    | 9             | 2              | 22.22          | 1              | 8             |
| 50 | <i>Adenanthera</i> sp.          | Fabaceae         | 1             | 0              | 0.00           | 0              | 1             |
| 51 | <i>Lithocarpus sundaicus</i>    | Fagaceae         | 2             | 1              | 50.00          | 1              | 2             |
| 52 | <i>Hydnocarpus heterophylla</i> | Flacourtiaceae   | 3             | 0              | 0.00           | 0              | 3             |
| 53 | <i>Hydnocarpus</i> sp.          | Flacourtiaceae   | 0             | 0              | 0.00           | 2              | 2             |

## Appendix I : Contd.

| NO | SPECIES                          | FAMILY         | TOTAL<br>1980 | NUMBER<br>DIED | %<br>MORTALITY | NEW<br>RECRUIT | TOTAL<br>1995 |
|----|----------------------------------|----------------|---------------|----------------|----------------|----------------|---------------|
| 54 | <i>Osmelia philippina</i>        | Flacourtiaceae | 2             | 0              | 0.00           | 1              | 3             |
| 55 | <i>Cratoxylum clandestinum</i>   | Hypericaceae   | 3             | 2              | 66.67          | 0              | 1             |
| 56 | <i>Nothapodytes montana</i>      | Icacinaneae    | 11            | 2              | 18.18          | 4              | 13            |
| 57 | <i>Alseodaphne montana</i>       | Lauraceae      | 2             | 2              | 100.00         | 0              | 0             |
| 58 | <i>Beilschmiedia</i> sp.         | Lauraceae      | 4             | 1              | 25.00          | 1              | 4             |
| 59 | <i>Cinnamomum</i> sp.            | Lauraceae      | 2             | 0              | 0.00           | 1              | 3             |
| 60 | <i>Cryptocarya</i> sp.           | Lauraceae      | 6             | 1              | 16.67          | 0              | 5             |
| 61 | <i>Dehaasia tomentosa</i>        | Lauraceae      | 8             | 1              | 12.50          | 0              | 7             |
| 62 | <i>Endiandra</i> sp.             | Lauraceae      | 1             | 0              | 0.00           | 0              | 1             |
| 63 | <i>Litsea</i> sp.                | Lauraceae      | 10            | 2              | 20.00          | 8              | 16            |
| 64 | <i>Leea</i> sp.                  | Leeaceae       | 1             | 1              | 100.00         | 0              | 0             |
| 65 | <i>Strychnos axillaris</i>       | Loganiaceae    | 1             | 0              | 0.00           | 0              | 1             |
| 66 | <i>Strychnos</i> sp.             | Loganiaceae    | 1             | 1              | 100.00         | 0              | 0             |
| 67 | <i>Lagerstroemia ovalifolia</i>  | Lythraceae     | 1             | 0              | 0.00           | 0              | 1             |
| 68 | <i>Aglaia argentea</i>           | Meliaceae      | 6             | 1              | 16.67          | 7              | 12            |
| 69 | <i>Aglaia cauliflora</i>         | Meliaceae      | 40            | 7              | 17.50          | 18             | 51            |
| 70 | <i>Aglaia glabriflora</i>        | Meliaceae      | 1             | 0              | 0.00           | 0              | 1             |
| 71 | <i>Aglaia maingayi</i>           | Meliaceae      | 0             | 0              | 0.00           | 2              | 2             |
| 72 | <i>Chisocheton lasiogynus</i>    | Meliaceae      | 1             | 0              | 0.00           | 0              | 1             |
| 73 | <i>Chisocheton multijugus</i>    | Meliaceae      | 4             | 1              | 25.00          | 0              | 3             |
| 74 | <i>Chisocheton sandoricarpus</i> | Meliaceae      | 2             | 0              | 0.00           | 1              | 3             |
| 75 | <i>Chisocheton</i> sp.           | Meliaceae      | 0             | 0              | 0.00           | 1              | 1             |
| 76 | <i>Didymocheton nutans</i>       | Meliaceae      | 0             | 0              | 0.00           | 2              | 2             |
| 77 | <i>Dysoxylum macrocarpum</i>     | Meliaceae      | 1             | 0              | 0.00           | 1              | 2             |
| 78 | <i>Dysoxylum arborescens</i>     | Meliaceae      | 2             | 0              | 0.00           | 0              | 2             |

## Appendix 1 : Contd.

| NO  | SPECIES                            | FAMILY        | TOTAL<br>1980 | NUMBER<br>DIED | %<br>MORTALITY | NEW<br>RECRUIT | TOTAL<br>1995 |
|-----|------------------------------------|---------------|---------------|----------------|----------------|----------------|---------------|
| 79  | <i>Dysoxylum<br/>caulostachyum</i> | Meliaceae     | 0             | 0              | 0.00           | 1              | 1             |
| 80  | <i>Dysoxylum<br/>cyrtobotryum</i>  | Meliaceae     | 2             | 0              | 0.00           | 1              | 3             |
| 81  | <i>Dysoxylum<br/>pachyrhache</i>   | Meliaceae     | 4             | 0              | 0.00           | 1              | 5             |
| 82  | <i>Dysoxylum</i> sp.               | Meliaceae     | 20            | 3              | 15.00          | 8              | 25            |
| 83  | <i>Dysoxylum</i> sp. A.81.         | Meliaceae     | 1             | 0              | 0.00           | 0              | 1             |
| 84  | <i>Dysoxylum</i> sp.2.             | Meliaceae     | 0             | 0              | 0.00           | 1              | 1             |
| 85  | <i>Lansium domesticum</i>          | Meliaceae     | 3             | 0              | 0.00           | 0              | 3             |
| 86  | <i>Antiaris toxicaria</i>          | Moraceae      | 1             | 0              | 0.00           | 0              | 1             |
| 87  | <i>Ficus ampelas</i>               | Moraceae      | 0             | 0              | 0.00           | 1              | 1             |
| 88  | <i>Ficus annulata</i>              | Moraceae      | 2             | 0              | 0.00           | 0              | 2             |
| 89  | <i>Ficus cordatula</i>             | Moraceae      | 1             | 0              | 0.00           | 0              | 1             |
| 90  | <i>Ficus magnoliaefolia</i>        | Moraceae      | 2             | 0              | 0.00           | 0              | 2             |
| 91  | <i>Ficus miquelii</i>              | Moraceae      | 1             | 0              | 0.00           | 1              | 2             |
| 92  | <i>Ficus</i> sp.                   | Moraceae      | 8             | 1              | 12.50          | 1              | 8             |
| 93  | <i>Ficus variegata</i>             | Moraceae      | 1             | 1              | 100.00         | 0              | 0             |
| 94  | <i>Horsfieldia</i> sp.             | Myristicaceae | 1             | 0              | 0.00           | 0              | 1             |
| 95  | <i>Knema laurina</i>               | Myristicaceae | 1             | 0              | 0.00           | 0              | 1             |
| 96  | <i>Ardisia humilis</i>             | Myrsinaceae   | 1             | 1              | 100.00         | 0              | 0             |
| 97  | <i>Eugenia</i> sp. A3              | Myrtaceae     | 3             | 0              | 0.00           | 0              | 3             |
| 98  | <i>Eugenia racemosum</i>           | Myrtaceae     | 3             | 0              | 0.00           | 0              | 3             |
| 99  | <i>Eugenia</i> sp.                 | Myrtaceae     | 7             | 1              | 14.29          | 3              | 9             |
| 100 | <i>Eugenia</i> sp.K.               | Myrtaceae     | 0             | 0              | 0.00           | 1              | 1             |
| 101 | <i>Eugenia</i> sp.2                | Myrtaceae     | 0             | 0              | 0.00           | 1              | 1             |
| 102 | <i>Eugenia</i> sp.3                | Myrtaceae     | 0             | 0              | 0.00           | 1              | 1             |
| 103 | <i>Pisonia umbellifera</i>         | Nyctaginaceae | 1             | 0              | 0.00           | 1              | 2             |
| 104 | <i>Strombosia javanica</i>         | Olacaceae     | 4             | 1              | 25.00          | 0              | 3             |
| 105 | <i>Strombosia ceylanica</i>        | Olacaceae     | 34            | 3              | 8.82           | 1              | 32            |
| 106 | <i>Linociera montana</i>           | Oleaceae      | 6             | 2              | 33.33          | 0              | 4             |
| 107 | <i>Linociera</i> sp.               | Oleaceae      | 3             | 1              | 33.33          | 0              | 2             |

## Appendix 1 : Contd.

| NO  | SPECIES                               | FAMILY        | TOTAL<br>1980 | NUMBER<br>DIED | %<br>MORTALITY | NEW<br>RECRUIT | TOTAL<br>1995 |
|-----|---------------------------------------|---------------|---------------|----------------|----------------|----------------|---------------|
| 108 | <i>Piper aduncum</i>                  | Piperaceae    | 0             | 0              | 0.00           | 1              | 1             |
| 109 | <i>Helicia serrata</i>                | Proteaceae    | 1             | 1              | 100.00         | 2              | 2             |
| 110 | <i>Nauclea</i> sp.                    | Rubiaceae     | 0             | 0              | 0.00           | 1              | 1             |
| 111 | <i>Citrus</i> sp.                     | Rutaceae      | 1             | 1              | 100.00         | 0              | 0             |
| 112 | <i>Euodia</i> sp.                     | Rutaceae      | 2             | 0              | 0.00           | 0              | 2             |
| 113 | <i>Scleropyrum<br/>wallichianum</i>   | Santalaceae   | 2             | 0              | 0.00           | 0              | 2             |
| 114 | <i>Mischocarpus<br/>fuscescens</i>    | Sapindaceae   | 2             | 1              | 50.00          | 0              | 1             |
| 115 | <i>Elattostachys</i> sp.              | Sapindaceae   | 12            | 1              | 8.33           | 7              | 18            |
| 116 | <i>Paranephelium nitidum</i>          | Sapindaceae   | 51            | 15             | 29.41          | 17             | 52            |
| 117 | <i>Madhuca</i> sp.                    | Sapotaceae    | 1             | 0              | 0.00           | 0              | 1             |
| 118 | <i>Palaquium</i> sp.                  | Sapotaceae    | 3             | 0              | 0.00           | 0              | 3             |
| 119 | <i>Payena sericea</i>                 | Sapotaceae    | 1             | 0              | 0.00           | 0              | 1             |
| 120 | <i>Planchonella nitida</i>            | Sapotaceae    | 1             | 0              | 0.00           | 0              | 1             |
| 121 | <i>Polyosma intergrifolia</i>         | Saxifragaceae | 1             | 1              | 100.00         | 0              | 0             |
| 122 | <i>Turpinia sphaerocarpa</i>          | Staphyleaceae | 2             | 0              | 0.00           | 2              | 4             |
| 123 | <i>Turpinia</i> sp.                   | Staphyleaceae | 4             | 2              | 50.00          | 2              | 4             |
| 124 | <i>Pterocymbium<br/>javanicum</i>     | Sterculiaceae | 0             | 0              | 0.00           | 1              | 1             |
| 125 | <i>Pterospermum<br/>diversifolium</i> | Sterculiaceae | 1             | 1              | 100.00         | 0              | 0             |
| 126 | <i>Pterospermum<br/>javanicum</i>     | Sterculiaceae | 10            | 2              | 20.00          | 5              | 13            |
| 127 | <i>Scaphium macropodum</i>            | Sterculiaceae | 1             | 0              | 0.00           | 0              | 1             |
| 128 | <i>Sterculia insularis</i>            | Sterculiaceae | 1             | 0              | 0.00           | 0              | 1             |
| 129 | <i>Sterculia oblongata</i>            | Sterculiaceae | 3             | 2              | 66.67          | 0              | 1             |
| 130 | <i>Styrax perkinsae</i>               | Styracaceae   | 3             | 1              | 33.33          | 0              | 2             |
| 131 | <i>Symplocos<br/>odoratissima</i>     | Symplocaceae  | 1             | 0              | 0.00           | 0              | 1             |
| 132 | <i>Symplocos</i> sp.                  | Symplocaceae  | 2             | 1              | 50.00          | 0              | 1             |

## Appendix 1 : Contd.

| NO  | SPECIES                          | FAMILY      | TOTAL<br>1980 | NUMBER<br>DIED | %<br>MORTALITY | NEW<br>RECRUIT | TOTAL<br>1995 |
|-----|----------------------------------|-------------|---------------|----------------|----------------|----------------|---------------|
| 133 | <i>Pyrenaria serrata</i>         | Theaceae    | 7             | 1              | 14.29          | 1              | 7             |
| 134 | <i>Celtis nigrescens</i>         | Ulmaceae    | 1             | 0              | 0.00           | 0              | 1             |
| 135 | <i>Celtis platanthes</i>         | Ulmaceae    | 2             | 1              | 50.00          | 0              | 1             |
| 136 | <i>Dendrocnide sinuata</i>       | Urticaceae  | 59            | 20             | 33.90          | 3              | 42            |
| 137 | <i>Laportea</i> sp.              | Urticaceae  | 0             | 0              | 0.00           | 4              | 4             |
| 138 | <i>Laportea stimulans</i>        | Urticaceae  | 2             | 0              | 0.00           | 0              | 2             |
| 139 | <i>Villebrunea<br/>rubescens</i> | Urticaceae  | 1             | 0              | 0.00           | 0              | 1             |
| 140 | <i>Premna tomentosa</i>          | Verbenaceae | 2             | 0              | 0.00           | 0              | 2             |
| 141 | <i>Rinorea sclerocarpa</i>       | Violaceae   | 53            | 6              | 11.32          | 11             | 58            |
| 142 | Unidentified                     |             | 9             | 6              | 66.67          | 9              | 12            |
|     | <b>Total</b>                     |             | <b>736</b>    | <b>167</b>     |                | <b>215</b>     | <b>783</b>    |

# SPATIAL DYNAMICS OF CANOPY BREAKDOWN AND RECOVERY IN FOREST ECOSYSTEMS

Dieter Mueller-Dombois

## ABSTRACT

*Spatial patterns of tree mortality in forest ecosystems have, so far, received little attention in ecological research. In contrast, recovery patterns following gap formation in tropical rain forests and successional processes following larger-area disturbances have traditionally received primary attention in vegetation research. However, in addition to the building factors operating during recovery in forest ecosystems, disturbance processes are equally important in long-term ecosystem development.*

*At a recent Workshop of DIWPA (Diversitas Western Pacific and Asia) in Singapore (December 1995), I suggested this knowledge gap as a new focus for cooperative international/interdisciplinary research on the function of biodiversity. The research hypothesis states that, "Spatial dynamics of forest canopy breakdown and recovery is a function of disturbance regime and biodiversity".*

*This paper elaborates on this new hypothesis by discussing examples from Pacific forests, which may also apply to differences in the disturbance dynamics of Sri Lanka's lowland and montane rain forests.*

## INTRODUCTION

At the recent Singapore Workshop of DIWPA (Diversitas Western Pacific and Asia), a spatial dynamics hypothesis was suggested by Mueller-Dombois & Kitayama (1996) as an international/interdisciplinary research task on the function of biodiversity in an ecosystem context. The hypothesis states that the "spatial dynamics of forest canopy breakdown and recovery is a function of disturbance regime and biodiversity". My intention in this paper is to explain and justify the spatial dynamics hypothesis as a new and worthwhile research focus under DIWPA for rain forest ecology and biological conservation.

Spatial dynamics relates to the change of spatial patterns over time and to the processes that are involved in these changes (Mueller-Dombois 1992). The research approach to spatial dynamics involves a landscape perspective. The term landscape refers to a segment of land with its biological and structural components, as for example, those dominated by forest vegetation. The term landscape is therefore the geographical equivalent to the term ecosystem.

Perhaps the most familiar pattern of canopy breakdown in forest ecosystems is gap formation. There is also a general consensus among forest ecologists that gap formation is the key process by which multi-species tropical rain forests regenerate and maintain their high species diversity (Platt & Strong 1989). However, when many tree individuals die synchronously, the general consensus is usually that such mortality patterns indicate a forest health problem (Manion 1981). Thus, the study of forest decline or canopy dieback is left, at least initially, to forest pathologists and pest entomologists. In the indigenous Hawaiian rain forest, decline and canopy dieback was recognized also as a broader ecological problem (Mueller-Dombois *et al.* 1983). This led to new study approaches and unexpected results.

In this paper I focus on (1) spatial concepts of forest dynamics, (2) the role of disturbance regime in ecosystem development, and (3) the role of stand structure and species diversity in canopy breakdown and natural growth cycles by reproducing, regenerating, growing, and dying (Jones 1945, Watt 1947, Whittaker 1953).

In most natural mature forests, some individual canopy trees can be found in a declining or dieback state, others may be dead and still standing and still others are broken down or have fallen to the ground. In all these cases, an opening or gap is created in the forest canopy. The most commonly observed canopy opening is a tree-fall gap, caused by the breakdown of an individual tree. Depending on the size of the fallen tree, a tree-fall gap can be small or large, but tree-fall gaps are usually not much larger than 100m<sup>2</sup>. Larger tree-fall gaps can occur during wind storms, when groups of neighbouring trees are toppled together. However, the spatial concept, without precise definition of gap size, can be called "gap formation," because the openings are small relative to the area of closed green canopy.

Another spatial concept arises when canopy trees are dying synchronously in larger numbers. When tree mortality occurs at the stand level, rather than individual tree level, this is called "canopy dieback or forest decline". Such larger spatial mortality patterns are often visualized at the landscape level. Depending on the overall spatial extent, such dieback or forest decline patterns, can show up as an "unhealthy patch mosaic" in an otherwise healthy looking forested landscape.

To clarify this further, forest decline here is not understood as a lateral shrinkage in areas occupied by trees, but instead, as a significant loss of tree vigour, which is noticeable in a large number of trees of a forest ecosystem. Such loss in vigour may be indicated by the stagnation of diameter increments or by unseasonal yellowing and necrosis of otherwise evergreen crown foliage among many trees. Leaf necrosis associated with unseasonal loss of crown foliage of many trees may be recognized as the beginning of canopy dieback. The term canopy dieback refers to forest stands or forest segments with an assortment of dead standing trees, some that have died recently, others earlier, and still others in the process of dying. Tree mortality may be rapid or very slow. In the latter

case, trees become stagheaded with foliage remaining on their lower branches, or often with new adventitious branches appearing on their lower trunks.

The terms forest decline and canopy dieback are often used alternatively as synonyms for the same structural phenomenon (Manion & Lachance 1992, Huettl & Mueller-Dombois 1993), but the size concept differs from that of gap formation by referring, in the case of dieback, usually to larger areas of canopy breakdown. Therefore, in terms of area-size, we may distinguish between gap dynamics and dieback dynamics and ask the question of how they differ functionally. This leads to a consideration of disturbance regimes.

## **DISTURBANCE IN ECOSYSTEM DEVELOPMENT**

Along with the spatial distinction between tree fall gaps and forest decline or canopy dieback are assumed causes and consequences, which, so far have not been analysed in a sufficiently complete and comparative way. However, disturbance has been widely recognized as a factor in ecosystem development (Pickett & White 1985, Remmert 1991). Clearly, gap formation and canopy dieback are respectively smaller and larger disturbances of forest canopy, and disturbances as such can be visualized as breakdowns or set-backs.

Disturbance regimes, a concept relating to recurring patterns of disturbances (Mueller-Dombois 1995), differ among forest ecosystems and even distinguish certain ecosystems from others functionally. For example, the boreal forest in Canada can be said to be regulated by a disturbance regime of recurring fires (Heinselman 1981), while that is certainly not true for tropical rain forests (Mueller-Dombois 1981).

Large-area disturbances, such as landscape-level diebacks are usually thought of as caused by catastrophic or violent disturbance factors such as fire, volcanism, hurricanes, insect outbreaks, epidemic diseases, or air pollution and acid rain. The latter were, until recently, assumed to be the primary cause of forest decline in the industrial areas of Europe and North America (Huettl & Mueller-Dombois 1993).

However, if only the canopy trees are affected and the undergrowth of the forest remains unscarred and vigorous as in many canopy diebacks or forest declines (Ciesla & Donaubauer 1994), the immediate causes cannot be considered violent or catastrophic. Instead, a more subtle cause may be expected. In fact, recent advances in forest decline and dieback research have resulted in the unanimous conclusion that there is no single principal cause of canopy dieback, but that instead there are two principal cause complexes, which can be called (1) predisposing causes and (2) inciting or trigger causes (Mueller-Dombois 1988).

Disturbance regimes are often understood as recurring patterns of violent abiotic or biotic disturbances. This is an incomplete concept, because disturbance regimes regularly also



include more subtle perturbations such as unseasonal droughts, floods, and storms. The latter are still subtle when they remove substantial amounts of canopy foliage without toppling the trees. In fact, every hurricane affects a much larger area of forest in this less catastrophic way, and often trees with substantial loss of crown foliage recover rapidly (Bellingham *et al.* 1992, Harrington & Fownes 1996). This leads to another consideration, namely that of biodiversity and its role in disturbance regimes.

## THE FUNCTION OF BIODIVERSITY IN CANOPY BREAKDOWN AND RECOVERY

Biodiversity is a wide ranging concept. It started with species richness per area in communities and later became quantified by indices that incorporate richness with species abundance. It now extends above the community level to the landscape level, and below that to the population and genetic/molecular levels of biodiversity.

For plant ecological purposes, it is necessary to consider biodiversity in at least two additional ways with regard to: (a) the differential survival and growth strategies of the species in an ecosystem, and (b) the various population structures which are associated with the species that make up the community or vegetation type of an ecosystem. For example, a rain forest containing canopy emergents and trees in many size classes, each with several growth and survival strategies, is much more diverse than a forest containing the same number of tree species in only a few size classes, each with only one or two growth and survival strategies. The most simplified extreme of biodiversity is represented by a plantation forest in one size or age class.

In some areas of the humid tropics, there are natural forests with very low canopy species diversities. This applies, for example, to some isolated archipelagoes in the Pacific such as the Galapagos and the Hawaiian Islands.

In the most humid zone at mid-elevation on Santa Cruz Island in the Galapagos, occurs a near mono-specific forest comprising the fast-growing tree species *Scalesia pedunculata*. This species has a short life span of 12 to 15 years and dies in synchrony during maturation (Lawesson 1988, Itow & Mueller-Dombois 1988). *Scalesia pedunculata* is, however, not a monocarpic species, like some of the Sri Lankan Acanthaceae which are programmed to die after flowering. Instead, *Scalesia pedunculata* is a polycarpic member of the Asteraceae that apparently evolved from a herbaceous weed. The *Scalesia* genus radiated in the Galapagos Island into more than a dozen woody species, three of which attained tree stature (Itow 1995). Following stand-level dieback, new cohort stands regenerate in synchrony in the course of a few years.

Much the same phenomenon of stand-level or canopy dieback occurs in the Hawaiian *Metrosideros polymorpha* dominated rain forest (Mueller-Dombois 1988). However, the growth cycle is taking much more time on account of the approximately 200 to 400 year life span of the leading species (*M. polymorpha*). Moreover, the process of dieback and

recovery is more complicated by the spectrum of soil substrates underlying Hawaii's *Metrosideros* rain forest. Substrates range from well-drained lava flows to soils from recent volcanic ash and deeply weathered clay soils to poorly drained oxisols and bogs. Across this spectrum of substrates, we recognized different types of dieback/recovery types. These include (1) "replacement diebacks" which occur on lava flows and nutritionally poor soils, on which *M. polymorpha* regenerates abundantly and grows into a next generation forest without much interference from competition; (2) "displacement diebacks" which occur on nutrient-rich soils, where the next generation of *M. polymorpha* is quantitatively displaced by the vigorous undergrowth of tree ferns (*Cibotium* spp.); and (3) "stand-reduction diebacks" in boggy sites, where increasingly poor drainage is stunting the regeneration of *M. polymorpha* by arresting its growth capacity in the shrub stage (Mueller-Dombois 1986, 1991). New forms of displacement dieback are occurring through encroachment of alien tree species (Jacobi *et al.* 1988).

It must be emphasized that low-biodiversity rain forests are not restricted to isolated islands. The "Shimagare" dieback in the subalpine forest of Japan (Kohyama 1988, Sato & Iwasa 1993) relates to two *Abies* species and is functionally similar to the replacement dieback in the Hawaiian rain forest and the replacement dieback in the *Scalesia* forest of the Galapagos. The same applies to the *Nothofagus pullei* dieback in the montane tropical rain forests of Papua New Guinea (Arentz 1983, 1988, Ash 1988). But stand-level dieback of the emergent *Araucaria hunsteinii* has also been reported for a multi-species lowland forest in Papua New Guinea by Enright (1993).

This brings up the question of whether there is really a fundamental difference between gap dynamics and dieback dynamics other than the spatial difference. Answering this question requires an analysis of the causal factors that are involved in small-area canopy failure.

## FOREST STAND DEMOGRAPHY AND THE COHORT SENESCENCE THEORY

All tree species comprising the canopy of a forest have a specific life history. Studies of species growth cycles reveal some aspects of their life history in the form of significant demographic events and processes. Such significant demographic events include the life stages, recognizable as germination, seedling, sapling, mature, and old age or senescing stages and also the spatial distribution of such life stages. During each life stage, the growth forms undergo changes and, with this, the trees' physiology changes in form of carbon allocation patterns. The population demography of a dominant canopy tree species may influence or control the demography of whole forest stand and, depending on its area coverage, that of a whole forested landscape.

The most significant and unified outcome of forest decline studies in recent years is the finding that there is no single principal cause of such canopy breakdowns. Instead, there

are, as already pointed out above, two principal cause complexes. These include (a) predisposing causes and (b) precipitating (or trigger) causes.

Predisposing causes arise during the history of a stand's demography. A stand's demography may be synchronized initially through a violent disturbance creating an open area. What happens thereafter depends very much on the biodiversity of the surrounding area as well as on what may be left in the violently disturbed area.

An example from Sri Lanka's black patana in the Horton Plains area is the tree *Rhododendron zeylanicum* (Ekanayake 1962). It appears to be the only species of Sri Lanka's montane rain forest that can survive in the periodically reburned grassland of the black patana because of its underground lignotubers (Mueller-Dombois & Perera 1971). It may also be the only tree that can act as a natural nurse tree for reinvasion of other montane forest tree species under a policy of fire exclusion. While the *R. zeylanicum* example may provide a clue to the recovery dynamics of montane rain forest after conversion to grassland, it does not provide an answer to the canopy dieback that was observed in the montane rain forest of Sri Lanka in the late 1970s (Perera 1978 cited by Werner 1988).



Figure 1 : Section of Horton Plains "wet black patana" with scattered *Rhododendron zeylanicum* trees. The trees appear to be remnants of formerly closed montane rain forest. They survive in a less frequently burned section of the grassland. Alternatively, they may also reinvade the grassland from seeds. (D. Mueller-Dombois photo Sept. 1968.)





Figure 2 : Canopy dieback at entrance sign to Horton Plains Nature Reserve. (D. Mueller-Dombois photo Sept. 1981.)



Figure 3 : Native forest dieback next to exotic healthy looking pine sapling with sign saying "Panoramic View of Department Plantations of Eucalyptus, Cypress and Pinus Species" at roadside before entering Horton Plains Nature Reserve. (D. Mueller-Dombois photo Sept. 1981.)





Figure 4 : Continuation of view to right of Fig. 3 showing more native canopy dieback with healthy looking dense undergrowth of monocarpic *Strobilanthes* shrubs. Most of the dying trees appear to be *Calophyllum* spp. (D. Mueller-Dombois photo Sept. 1981.)



Figure 5 : Broader view of native forest canopy dieback down-slope on Pattipola side. Note reservoir at left in valley and planted vigorously green pine forest on opposite slope. These landmarks should allow re-photographing the same scene. (D. Mueller-Dombois photo Sept. 1981.)





**Figure 6 :** Diagonal view up-slope on Pattipola side of Horton Plains; the latter begins at horizon. Note the vigorous undergrowth persisting under the opened tree canopy. (D. Mueller-Dombois photo Sept. 1981, taken from same location at mountain road as Fig. 5.)



**Figure 7 :** Close-up view of canopy dieback with vigorous *Strobilanthes* shrub undergrowth and tree fern on upper left of entrance sign to Horton Plains Nature Reserve, a view that could be re-photographed now after 15 years. (D. Mueller-Dombois photo Sept. 1981.)

The Hawaiian montane rain forest dieback, however, may provide an answer through the cohort senescence theory, which was the outcome of intensive forest decline and dieback research. This theory is based on the forest stand demography concept as follows:

1. A violent disturbance gives rise to an open area which in turn is invaded by a dominant tree species more or less synchronously (*Metrosideros polymorpha*).
2. The seedlings develop into a young forest which undergoes self-thinning and becomes invaded by a blanket of undergrowth fern (*Dicranopteris linearis*), which effectively stops further recruitment of *Metrosideros* seedlings.
3. The *Metrosideros* trees develop into a mature cohort or one-generation forest, which is vigorous and productive for about 100 years or more.
4. Meanwhile, the forest is exposed to non-violent disturbances (perturbations) perhaps twice per decade, but a violent disturbance, such as occurred originally, does not return.
5. Gradually this first-generation forest declines in vigour due to loss of energy associated with advanced ageing or senescence, often associated with cumulative environmental stresses, and dieback becomes initiated through another non-violent disturbance.
6. Recovery by tree regeneration starts more or less synchronously with the dieback of the first generation stand, and the stand demographic sequence is repeated over several generations until the dieback becomes desynchronized by a change in disturbance regime.

This 6-step sequence is not limited by the area-size concept. It can also be applied to smaller cohorts, or to cohort trees more widely dispersed in a multi-species forest. It may also apply to the dieback that affected the montane rain forest in Sri Lanka. The monocarpic undergrowth shrub of *Strobilanthes* may here act as an additional synchronizing factor in forest tree recovery.

The ecology of the Sri Lankan dieback should receive serious investigation in collaboration with the new international research programme under DIWPA for the purpose of understanding what happened and is now happening there in succession to provide the best information for conservation management of this valuable indigenous forest watershed (Mueller-Dombois 1972). The principal difference to the usual disease or abiotic stress concept of dieback is the realization that mature trees do not die easily until they are ready to die (Franklin *et al.* 1987, Waring 1987, Mueller-Dombois 1987) and that the search for a single principal cause has eluded researchers in nearly all serious investigations of forest decline and canopy dieback (Huettl & Mueller-Dombois 1993).

## CONCLUSIONS

In addition to the conventional biodiversity and vegetation research, patterns of canopy breakdown should be mapped at a landscape level from periodically retaken aerial photographs. For this, computer technology provided by GIS (geographic information system) can be usefully employed for spatial statistical analysis and the display of dynamic vegetation maps (Akashi & Mueller-Dombois 1995). Such analyses would reveal, for example, whether canopy gap formation is a regular or irregular phenomenon and whether gaps oscillate throughout a forest ecosystem or tend to recur at the same places. Moreover, gap size distribution and gap enlargement into canopy dieback at the landscape level, could be documented and studied in relation to forest demographic factors and successional development. With this, the forest health status could also be evaluated in relation to its biodiversity functions and disturbance factors. Moreover, the question posed by the spatial dynamics hypothesis could be resolved. To recall this question; it asks whether or not biodiversity plays a role in the disturbance regime of a forest ecosystem, and whether biodiversity is an important functional component in the recovery process.

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**SUSTAINABLE UTILIZATION OF TROPICAL HUMID  
FOREST RESOURCES**

**THE EFFECT OF INCOME AMONG THE COMMUNITIES OF SINHARAJA  
ON THE EXTRACTION OF NON-TIMBER FOREST PRODUCTS:  
A PRELIMINARY STUDY**

*Dayananda Kariyawasam*

**BACKGROUND**

Protected areas, such as biosphere reserves, have been established in many parts of Asia to conserve important natural resources systems for the benefit of the human community. However, the consequences of the protection strategy have often been to deny people access to their traditional rights. Sinharaja forest is the sole lowland rain forest in Sri Lanka that is big enough to have a reasonable chance to conserve the unique, notably diverse flora and fauna of the island. The outstanding qualities of the Sinharaja forest have been recognized by UNESCO which in 1978 proclaimed it an International Man and the Biosphere Reserve, and ten years later a World Heritage Site. These designations reflect not only the great species richness and exceptionally high degree of endemism found in Sinharaja, but also its status as the last remaining significant representative of the Sri Lankan lowland evergreen rain forest.

Sinharaja forest is surrounded by some thirty villages, located along the southern, north-eastern, northern and the north-western sections of the forest. The total population in these villages can be estimated at about 5000 (IUCN 1993). Some of them have a long history dating back to the ancient kings of Sri Lanka. The villages are isolated, without road access in most cases, and the small populations have been little influenced by the outside world. A large number of these peripheral communities depend on the forest for many of their subsistence needs.

Under the present management policy, all uses of the Sinharaja forest resources other than conservation, research, education and recreation are illegal. However, non-timber resources of this species-rich forest have always been of critical importance in meeting the basic needs of the rural people. The villagers use the resource for both subsistence and income. Forest clearing to plant agricultural crops is the base for almost all subsistence or income generating activity, except for the extraction of forest products. As the non-agricultural economic sector and the existing agricultural land do not have the capacity to absorb the growing rural work force, many rural poor have appropriated forest land for plantation agriculture. As in the colonial period, tea remains Sri Lanka's highest net foreign exchange earner and principal agricultural product. During the last two decades it has become the only important source of smallholder income and economic development in the Sinharaja region. Even the most isolated and remote villages are now dedicated to tea and it has become an important source of income for them. Villagers

have even neglected their traditional home gardens and crop diversification practices in the rush to grow as much tea as possible.

## PROBLEM STATEMENT

The protection of wildlife and the assurance of plant and animal diversity are seen as essentials for sustaining human life. Scientists and conservationists have increasingly emphasized the importance of biodiversity conservation to support various forms of life, including human life (Wells *et al.* 1992; Braatz *et al.* 1992). The most politically appealing and economically attractive argument is that it provides enormous direct economic benefits in the form of food, medicines and industrial raw materials, and has the potential for generating many more (McNeely 1988; de Beer & McDermott 1989). The conservation community has acknowledged that communities which live next to protected area boundaries frequently bear substantial costs as a result of lost access, while receiving little in return. As people in the communities around protected areas tend to be poor, politically powerless, and lacking in government services, a large part of conserving biological diversity is being borne by those least able to pay. There is enough literature arguing that unless local people are integrated in the management of protected areas, there is little likelihood that effective long-term protected area conservation can be achieved (Poore & Sayer 1991; Wells *et al.* 1992). In an effort to link the conservation of biodiversity in protected areas with local and economic development, most programmes try to stabilize land use outside protected areas and to increase local incomes, with the ultimate objective of reducing the pressure for further exploitation of natural resources within the protected areas (Kariyawasam 1992).

This study investigates the relations between peripheral communities of the Sinharaja reserve and the environment. It focuses on the interaction of local population processes, practices and patterns with the biophysical environment, and examines the ways by which they have responded to changes in their economies. The specific objectives are to:

- estimate the current household needs met by the biosphere reserve;
- examine what happens to people's use of tropical rain-forest resources when economic development takes place;
- analyse the differences in changes in forest use in response to economic development, that are due to significant distinctions in social structure.

Although biological research has been carried out on the plants and animals in the wet evergreen forests of Sri Lanka, little attention has been paid to the socio-economic aspects of village communities and their dependency on the forest (Kariyawasam 1991). Detailed case studies of the economic and ecological interrelations of the Sinharaja protected area and local people can provide a basis for intervention aimed at resolving conflicts in Sinharaja. By taking into consideration the past, present and future forestry sector developments elsewhere in Sri Lanka, management initiatives in Sinharaja, based

on integrative biophysical and socio-economic assessments, can serve as a model to extend the conservation concept to other wet-zone forests in the country.

## DATA COLLECTION AND METHODS

The objective is to identify the different uses of the Sinharaja forest resource by the peripheral communities, and to understand the changing social structure resulting from the cultivation of tea, which in turn affects resource use. Field research was conducted in three villages adjacent to the reserve boundary to examine the wants and needs of the local people. I have attempted to explore the relative dependence of different sections of the population on the forest resources and to use comparative methods to determine the effects of socio-economic differentiation due to the tea economy on resource-use practices. Research techniques have included participatory rural appraisal (PRA), household socio-economic survey, direct observation, and semi-structured interviews in the selected villages. The research forms part of a larger study on the complexities of resource use and allocation in the communities surrounding the Sinharaja protected area.

Participatory rural appraisal, as an inclusive research process, has helped to include the perspectives of all interest groups. It was through PRA that I was able to speak directly to individuals and groups about their priorities and concerns. It created opportunities for dialogue between the interest groups in which they could voice their concerns. Because the participation of the rural villagers living in the case study area was solicited throughout the process, they assisted in verifying the research, and this has resulted in more accurate information. Through this method, information on the relative wealth of each community member was determined by participants revealing their wealth in relation to other members. To begin with, a census was conducted of the population in each village. A master list of houses was prepared and then, through discussion with the villagers, the criteria for wealth and poverty were determined. Villagers were asked to sort the houses according to wealth categories. Within each strata I used a simple random sample technique to select households for the questionnaire survey. As the substantive issues being studied are relevant to the relative wealth of the community members, and since the separate categories are more homogeneous than the general population, this type of stratified sampling reduces variance. It also ensures that there is an adequate number of cases from each category. Qualitative data obtained through the PRA, by using a semi-structured interview guide, helped in the interpretation of quantitative data and in the identification of issues.

A formal household questionnaire was used to quantify variation in economic, social and agro-ecological characteristics in the sampled population. It was mainly involved with the collection of quantitative data on variables such as household production, consumption, expenditure, sources and uses of income, and farm size. Quantitative information was also collected on non-timber forest products (NTFPs) extracted and consumed, and on time spent in the forest. Wherever possible, these data were confirmed

by direct observation. This survey has been designed to provide information on high and low incomes from tea and NTFPs, and on expenditure patterns, that was then used to assess whether or not the social dynamics due to the tea economy have a significant impact on income from forest products, as well as on the nature of relationships between the rich and the poor.

## RESULTS AND DATA ANALYSIS

The three villages were selected from the northern side of Sinharaja and are typical of villages found in the region. Table 1 contains demographic information. The total population of the three villages is 1010 ; the greatest population, of 625 is found in Illumbakanda. The average household size is about 5.5 but in Pelawatta it is about 6.0 . A considerable proportion of the people in these traditional old villages depends mainly on agriculture. The villagers, as is generally the case, have a high literacy rate. The traditional characteristics of an old village still persist in these villages, but the recent cash flow coming from the flourishing tea cultivation has begun to alter the simple life style of the villagers.

**Table 1 : Population data and wealth categories**

|                          | Village      |              |           |
|--------------------------|--------------|--------------|-----------|
|                          | Illumbakande | Denuwankande | Pelawatta |
| No. of households        | 108          | 35           | 42        |
| Household size           | 5.8          | 5.6          | 6.0       |
| Population               | 625          | 135          | 250       |
| <b>Wealth categories</b> |              |              |           |
| Low income               | 55           | 9            | 9         |
| Medium income            | 24           | 9            | 10        |
| High income              | 29           | 17           | 23        |

Most of the land in the villages is family owned, passed on from generation to generation. However, the social structure of the villages is not egalitarian. Fifty per cent of the households own less than one hectare of land (Table 2).

**Table 2 : Land distribution among the communities**  
(Numbers of households)

|               | Village      |              |           | Total    |
|---------------|--------------|--------------|-----------|----------|
|               | Illumbakande | Denuwankande | Pelawatta |          |
| Sample        | 33           | 15           | 15        | 63       |
| <0.50 ha      | 7            | 1            | 2         | 10 (15%) |
| 0.50 - 1.0 ha | 9            | 7            | 6         | 22 (35%) |
| 1.0 - 1.5 ha  | 9            | 6            | 4         | 19 (30%) |
| > 1.5 ha      | 8            | 1            | 3         | 12 (19%) |



The wealth of the villagers in the study was categorized as low, medium, and high, by a participatory approach. Several determinants were taken into consideration in identifying wealth status, including income derived from occupations or from household resources, the condition of housing, and household property. The numbers of households falling into each of these three categories vary by community, as is summarized in Table 1.

Tea is the predominant crop. All those who own land, farm tea to some extent. The study has shown that 75% of the households own tea land. Cinnamon is also grown (41% of total households) in small areas. Although 62% of households possess paddy land, income from paddy is very low. While the household average annual income from paddy ranges from Rs. 500 to 3000, it is about Rs. 5000 to 30,000 for tea. Villagers also get income from their homesteads, the main crops being bananas, coffee, cloves, and arecanuts. The average household annual income is about Rs. 52,210; the shares from farm and non-farm activities are shown in Figure 1.

I have ranked the households by income in Figure 2. The results suggest that as income rises the importance of NTFPs in the household economy falls. Non-timber forest goods account for 32% of the household income of the low income group, but only about 3.5% of that of the high income group. On the other hand, the share of tea in household income rises from 10% in the poor income group to 47% for wealthier villagers. Non-farm income, chiefly from labour, is more important in the low income category. The share of household income from other activities such as paddy and homestead crops remains the same in all three categories. As expected, the high income group has a better share from employment.

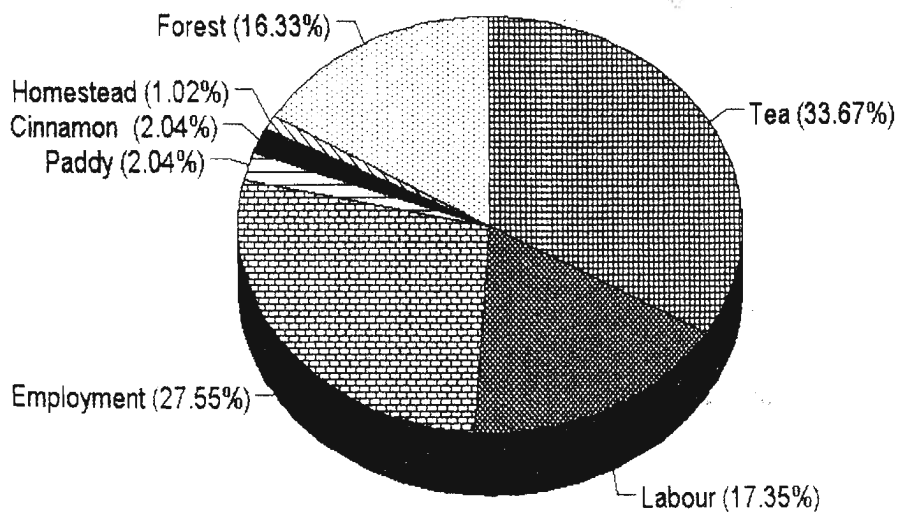


Figure 1 : Household income sources

The selected villages are situated very close to Sinharaja forest. Being isolated, and away from the Forest Department base camp at Kudawa, they were considered to be dependent on the forest for additional income. Nevertheless, the study reveals that 25 households out of a total of 63, representing 40% of the population, do not extract forest products as an income generating activity. Table 3 indicates the continuing dependence on the forest resource. It lists the different purposes for which Sinharaja is used by the people. It is interesting to note that the main income from the forest comes from the collection and sale of mushrooms, cardamoms, rattans, and jaggery made from kitul sap. It also reveals that households in the low income category are the groups most dependent on collecting saleable items.

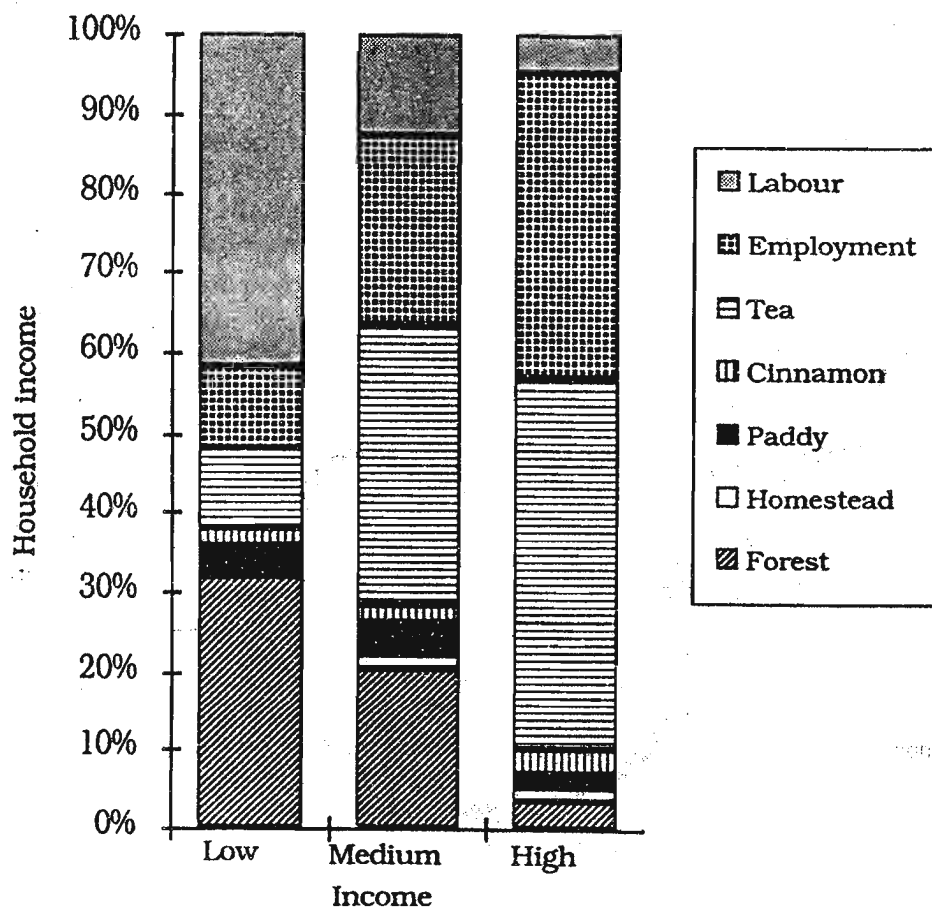
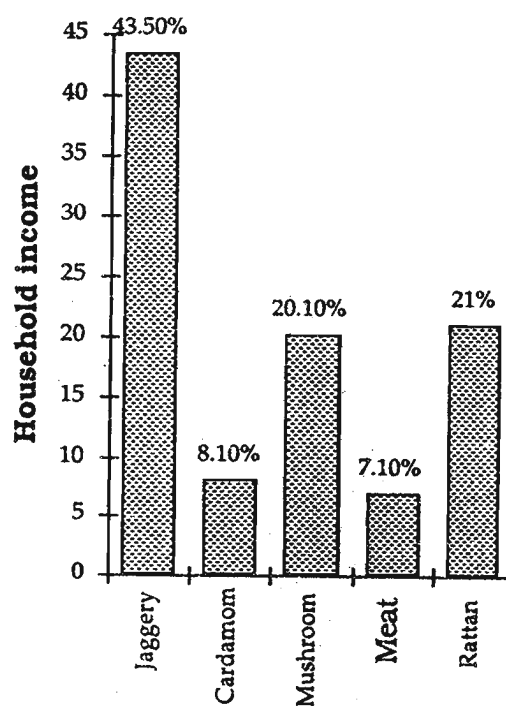


Figure 2 : Income structure

**Table 3 :** Number of households that collect products from Sinharaja forest, categorized by wealth, and by their role in the village economy

| Products           | High income | Medium income | Low income | No. of respondents | % of total (63) |
|--------------------|-------------|---------------|------------|--------------------|-----------------|
| <b>Market</b>      |             |               |            |                    |                 |
| Mushrooms          | 1           | 13            | 19         | 33                 | 52              |
| Cardamoms          | 2           | 5             | 14         | 21                 | 33              |
| Rattans            | 2           | 3             | 12         | 17                 | 26              |
| Jaggery            | 2           | 6             | 5          | 13                 | 20              |
| Meat               | 1           | 2             | 3          | 6                  | 9               |
| <b>Subsistence</b> |             |               |            |                    |                 |
| Food               | 6           | 7             | 6          | 19                 | 30              |
| Medicine           | 3           | 7             | 12         | 22                 | 35              |



**Figure 3 :** Income from forest products

Figure 3 contains information about the share of the forest income that comes from different products extracted from the Sinharaja forest by the villagers. Income from jaggery ranks first, but only 20 percent (Table 3 ) of the households are involved in kitul tapping. Table 3 suggests that 33% of the households extract both rattans and cardamoms from the forest for sale. However, the share of the forest income from cardamoms is only 8% whereas for rattan it is 21%.

The cross tabulation in Table 4 contains information on forest dependence by the wealth rank of the communities. The table suggests that 79% of the wealthier population do not depend on the forest for additional income. However, 69% of poor villagers have a high dependence on the forest, and almost all the poor (92%) go to the forest to extract products for sale.

In keeping with the above results, 76% of the people who do not use the forest for additional income belong to the high income category, while 8% belong to the low income category. Again, among the high dependence group, the rich villagers' representation is only 11% while that of the poor is 61%.

The covariation as suggested in the cross tabulation was tested using the Pearson chi-squared test of association. The low probability value confirms that there is a strong association between wealth and dependency.

**Table 4 :** Dependence on Sinharaja Forest by wealth (The figures in brackets show the percentage by row and column respectively)

| Wealth rank   | Dependency    |            |            | Row total |
|---------------|---------------|------------|------------|-----------|
|               | No dependency | < Rs. 5000 | > Rs. 5000 |           |
| Low income    | 2 (8/8)       | 5 (22/42)  | 16 (69/61) | 23        |
| Medium income | 4 (25/16)     | 5 (31/42)  | 7 (30/26)  | 16        |
| High income   | 19 (79/76)    | 2 (8/17)   | 3 (12/11)  | 24        |
| Column total  | 25            | 12         | 26         | 63        |

$$\chi^2 = 29.8$$

$$p < 0.0001$$

## DISCUSSION

The results of the study suggest that the amount of resources utilized by peripheral communities in Sinharaja varies according to their relative social and economic status. I argue that identifying differentiation within rural communities can contribute to an understanding of the dependency of the rural communities. People of different ranks in a community have differential access to various community resources. Differential access to control and benefits determines the land-use systems and social structures, which reflect people's responses to the biophysical environment. The extent to which socially based differences in access coincide with differences in income and wealth depends on the history of production and accumulation by different groups within a local economy.

As hypothesized, the results suggest that, as household income rises, the share of it that comes from forest produce declines, overshadowed by the income from tea. The tea

economy has led to higher incomes, which in the long run have reduced dependence on forest products. Furthermore, people replace many forest goods (which are often expensive to find, process and transport) by cheaper substitutes. Therefore the dependence on forest products in the household's economy is inversely related to its total income.

It can also be seen that at least in the short run, the tea economy (cash economy) leads to an increased demand for capital to set up holdings and this can lead to increased marketing of forest products by the poor. The study has shown that 71% of the population produces tea for the market. However, access to this option depends on the availability of disposable income for buying seedlings, fertilizer, etc., and most importantly, land. The traditional rich get a disproportionate share of the benefits, since they are the ones who can get more land and capital to plant tea, hire labour, and use better technology. With stringent regulations, villagers may tend to restrict their extraction activities to limited areas and more importantly, with the coming of the cash economy, extraction has been limited to a few species. People extract products that are in demand by the outside world. The main income from the forest comes from the collection and sale of mushrooms, cardamoms and rattans. The villagers have been exposed to a market economy by the commercialization of their rural economic activities. This process has led to changes in life styles and as a result, villagers may increasingly find a need for cash. In this type of cash economy, people remove fewer goods from a smaller area, know less about the forest plants and animals, and are more likely to deplete the stock of selected forest products.

## CONCLUSIONS

Three conclusions that can be drawn from this preliminary study are:

- First, the study reveals that a significant part of the rural poor are dependent on the forest as a source of income.
- Second, the importance of NTFPs in a household's economy is inversely related to its total income. As economies modernize, NTFPs do not play a significant role in rural households because agriculture becomes more important. Therefore, we need to rethink our strategies of intensifying the use of NTFPs as a means of raising rural income. These interventions may be useful until poor economies get moving.
- Third, the shift of emphasis in rural development in favour of agriculture rather than forest extraction might lead to a situation in which forests have more value for farming than for foraging, a trend which would endanger the concept of conserving the forest as a source of goods and services to local people.

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# FLORISTICS OF SOIL SEED BANKS IN RELATION TO LIGHT AND TOPOGRAPHIC POSITION IN A SRI LANKAN RAIN FOREST

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## ABSTRACT

Soil seed banks have been reported to play an important role in the regeneration of tropical moist forest after disturbance. We examined this phenomenon for mixed-dipterocarp forest of southwestern Sri Lanka. Experiments were conducted at the Sinharaja World Heritage site that compared soil exposed to different amounts of light (full sun; partial shade about 35% of full sun) and taken from two topographic positions (valley; ridge). In all instances, plots from which soil was collected, were located beneath late-successional closed-canopied forest stands. For each plot the surface litter layer was scraped away and mineral soil was collected up to 5cm in depth. The soil from each plot was placed in wooden trays within shelters at the field station. All treatments were watered periodically to maintain field capacity. Seeds that germinated were tagged and recorded every five days for a period of eight months.

A total of 41 species germinated during the period of study. Results showed that germination was significantly affected by light. Soils exposed to partial shade exhibited greater seed germination than soils placed in full sun. In all treatments pioneer herbs (*Emilia exserta*, *Eupatorium* spp.), grasses (*Eragrostis japonica*, *Panicum gardenri*, *Frimbristylis manticola*) and shrubs (*Clidemia hirta*, *Osbeckia octandra*) represented a far greater proportion of germinants than pioneer trees (*Macaranga peltata*, *Trema orientalis*). Late-successional trees, or herbs and shrubs of the forest understorey were negligible. There were also differences between sites. Some species were recorded solely from soils of ridges (4 spp.), while others were associated only with soils of valleys (14 spp). However, most species were common to soils from both valleys and ridges. The total number of germinants was significantly less on soils taken from ridges than those from valleys. Results suggest that within the mixed-dipterocarp forest type in Sri Lanka the buried seed phenomenon plays a varied role in the regenerative capacity of the forest after severe disturbance. This capacity depends in part on topographic location and exposure to sun. Findings also suggest that the kind and severity of disturbance that releases the soil seed bank within mixed-dipterocarp forest will promote pioneer vegetation that is of a very different composition, structure and successional status than that of the original forest.

## INTRODUCTION

Soil seed banks consist of all seeds buried in the mineral soil. Seeds in the litter or humus layer can often be included. The length of time seeds reside in the soil seed bank

will be determined by their physiological properties (Leck *et al.* 1989). This includes (i) germination, dormancy and viability; (ii) the environmental conditions where they land and subsequent microenvironmental changes and (iii) presence of seed predators and pathogens. Seed densities and number of species present in the soil seed bank varies with the types and maturity of vegetation. Soil seed banks have been reported to be dynamic with changes in seed density, species composition and number of species with successional status of the forest (Leck *et al.* 1989).

Seed banks can be considered ecologically important because of several factors. Firstly, they partially reflect the history of the vegetation, and are also likely to contribute to its future, through changing species composition (Major & Pyott 1966). Also in frequently disturbed habitats the species composition of the seed bank and the vegetation are often similar, but as the vegetation matures the disparity between the two increases (Hall & Swaine 1980; Major & Pyott 1966; Van der Valk 1986; Pratt *et al.* 1984). Lastly, seed banks can play an important role in the rehabilitation of degraded land (Johnson & Bradshaw 1979), and in the regeneration of felled forests or abandoned agricultural lands (Leck *et al.* 1989).

However, much more research is needed on soil seed banks in order to understand their importance and role in forest regeneration. For example few soil seed bank studies have examined spatial heterogeneity or degree of disturbance required to promote their germination. There has also been no investigation on the seed banks of wet tropical forests in Sri Lanka. The main objective of this study was to document the soil seed bank of late successional mixed-Dipterocarp forest in relation to topography and exposure to light.

## METHODS AND MATERIALS

### Site description

The study was done at the field station of the Sinharaja forest in the southwest lowlands of Sri Lanka. The topography of this forest is undulating, approximately 600m above mean sea level with differences between valley and ridge generally less than 100m. Annual precipitation is between 3.75 and 5 m . Mean monthly temperature ranges between 25 and 27°C. The forest topography is steeply dissected, with parallel ridges and valleys aligned east-west that range in elevation from 90 m to 1170m. The bedrock consists of khondolites and graniferous charnokites with recent gravels, sands, and clays (Wijepala 1958), overlain by red-yellow podzolic soils (Moorman & Panabokke 1961).

Ten sites within the Sinharaja forest were selected for the study. Five of them were from valleys and the other five from ridgetops. These sites were located in widely separated locations (> 4 km) and within different floristic associations. All ten sites were located



beneath closed canopied late successional forest that was classified as the *Mesua-Doona* type (de Rozayro 1942).

### Experimental design

Three soil samples were collected from different locations at each site. All were within a 10 x 10 m<sup>2</sup> plot but were more than one metre apart from each other. The litter layer was scraped away and surface mineral soil was collected up to 5 cm depth. All roots and larger particles were removed as far as possible. The three samples were pooled and well mixed in a polythene bag, labelled, and then taken to the Field Research Station at Sinharaja. Ten such bags were collected from ten sites.

Soil from each site had six trays constructed of plywood, dimensions 30 cm x 30 cm with 5 cm depth. Trays were first half filled with sterilized sand (sand was sterilized at 210<sup>o</sup> C for 48 hours). Soil from a site was then divided into six equal parts by volume (1000 cm<sup>3</sup>). Each part was spread over the sand of a single tray. This procedure was followed for soil from all ten sites. Seeds in the soils were allowed to germinate under two different light conditions: (i) full sunlight and (ii) partial shade providing 35% of full sunlight (as recorded by a Licor radiation Senso, Lincoln NE, at noon on a sunny day). Half of the six trays of soil collected from each site were placed under full sunlight and the other half under partial shade. All soil was maintained at field capacity by daily watering.

The shade houses designed to create two different light regimes emulated two kinds of disturbance that could be found in the Sinharaja forest: (i) a lethal disturbance simulating conditions of full exposure and (ii) a disturbance creating partial shade from tree falls. Each shade house has a wooden framework 2.5m wide, 3m long and 2m height. Both were covered in clear plastic film (1000 gauge polythene) that was durable when exposed to direct sunlight. One of the two was additionally covered with shade cloth to provide 35% of full light on sunny days.

Germination was observed over a 35 week interval (15th May 1995 - 31st January 1996). All newly germinated seeds were tagged and counted once every five days. Seedlings, were identified and then removed once a month.

### Analysis of data

Percentages of germinants from the different treatments were recorded. Diversity indices were calculated for each treatment using Shanon's Diversity Index. Means of ecological species groups were calculated for comparison among treatments. Cumulative frequency of geminants was plotted for comparison among treatments.

Table 1: Germinated species, their families, habits, sites they observed, light regimes in which they germinated and regeneration characteristics.

| Species                           | Family        | Habit | Top/p <sup>2</sup> | light <sup>3</sup> | RIDGE |                 |      |      | VALLEY |      |      |        |
|-----------------------------------|---------------|-------|--------------------|--------------------|-------|-----------------|------|------|--------|------|------|--------|
|                                   |               |       |                    |                    | FS    |                 | PS   |      | FS     |      | PS   |        |
|                                   |               |       |                    |                    | mean  | se <sup>5</sup> | %    | mean | se     | %    | mean | se     |
| <i>Schumacheria castaneifolia</i> | Dilleniaceae  | T     | V                  | P                  | na    | na              | na   | na   | na     | na   | 1.00 | 0.00   |
| <i>Macaranga peltata</i>          | Euphorbiaceae | T     | V/R                | F/P                | 1.00  | -               | 4.50 | 2.50 | 1.50   | 0.30 | 6.00 | 5.00   |
| <i>Trema orientalis</i>           | Ulmaceae      | T     | V                  | F/P                | na    | -               | na   | na   | -      | 2.00 | 2.00 | -      |
| <i>Breynia retusa</i>             | Euphorbiaceae | S     | V                  | F                  | na    | -               | na   | na   | -      | 1.00 | na   | na     |
| <i>Croton laccifera</i>           | Euphorbiaceae | S     | R                  | F                  | 1.00  | -               | 4.50 | na   | -      | na   | na   | na     |
| <i>Hibiscus furcatus</i>          | Malvaceae     | S     | V                  | P                  | na    | -               | na   | na   | -      | na   | 6.00 | -      |
| <i>Clidemia hirta</i>             | Malastomaceae | S     | V/R                | F/P                | na    | -               | na   | 44.4 | -      | -    | 3.01 | 107.00 |
| <i>Osbeckia octandra</i>          | Malastomaceae | S     | V/R                | F/P                | na    | -               | na   | 1.67 | 0.33   | 0.30 | 8.00 | 5.00   |
| <i>Hedyotis auricularia</i>       | Rubiaceae     | S     | R                  | P                  | na    | -               | na   | na   | -      | 0.10 | na   | na     |
| <i>Hedyotis fruticosa</i>         | Rubiaceae     | S     | R                  | F                  | 1.00  | -               | 1.00 | na   | -      | na   | na   | na     |
| <i>Acronychia pedunculata</i>     | Rutaceae      | S     | V/R                | F/P                | 2.00  | -               | 2.00 | 1.00 | -      | 0.06 | 1.00 | -      |
| <i>Ageratum conizoides</i>        | Compositae    | H     | V/R                | P                  | na    | -               | na   | 1.00 | 0.00   | 2.20 | 3.00 | -      |
| <i>Emilia exserta</i>             | Compositae    | H     | V                  | F                  | na    | -               | na   | na   | -      | 1.00 | na   | na     |
| <i>Erigeron sumatrensis</i>       | Compositae    | H     | V                  | F                  | na    | -               | na   | na   | -      | 1.00 | na   | na     |

Table 1: *Contd.*

| Species                        | Family                 | Habit | Top/p <sup>2</sup> | light <sup>3</sup> | FS   |                 |                | PS   |      |      | FS   |      |      | PS    |      |      |
|--------------------------------|------------------------|-------|--------------------|--------------------|------|-----------------|----------------|------|------|------|------|------|------|-------|------|------|
|                                |                        |       |                    |                    | mean | se <sup>5</sup> | % <sup>6</sup> | mean | se   | %    | mean | se   | %    | mean  | se   | %    |
| <i>Eupatorium odoratum</i>     | Compositae             | H     | V/R                | F/P                | 1.00 | -               | 1.00           | 2.00 | -    | 0.23 | 2.00 | 0.00 | 3.80 | 1.00  | 0.00 | 0.03 |
| <i>Vernonia cinera</i>         | Compositae             | H     | V/R                | F/P                | na   | -               | na             | 2.00 | -    | 0.10 | 1.00 | -    | 1.00 | na    | na   | na   |
| <i>Dorstanja indica</i>        | Moraceae               | H     | V/R                | F/P                | 5.00 | -               | 5.00           | 2.75 | 0.48 | 0.60 | 2.50 | 1.50 | 4.80 | 7.33  | 2.33 | 0.70 |
| <i>Oxalis barrelieri</i>       | Oxalidaceae            | H     | V/R                | F/P                | na   | -               | na             | na   | -    | na   | na   | na   | na   | 1.00  | -    | 0.03 |
| <i>Lindernia hirsuta</i>       | Scrophulariac -<br>eae | H     | V                  | P                  | na   | -               | na             | na   | -    | na   | na   | na   | na   | 1.00  | -    | 0.03 |
| <i>Melochia corchorifolia</i>  | Sterculiaceae          | H     | V                  | P                  | na   | -               | na             | na   | -    | na   | na   | na   | na   | 1.00  | -    | 0.03 |
| <i>Stachytarpheta indica</i>   | Verbanaceae            | H     | V                  | P                  | na   | -               | na             | na   | -    | na   | na   | na   | na   | 1.00  | -    | 0.03 |
| <i>Costus speciosus</i>        | Zingibaraceae          | H     | V                  | P                  | na   | -               | na             | na   | -    | na   | na   | na   | na   | 1.00  | -    | 0.03 |
| <i>Ellettaria cardamom</i>     | Zingibaraceae          | H     | V/R                | P                  | na   | -               | na             | 1.00 | -    | 0.10 | na   | na   | na   | 1.00  | -    | 0.06 |
| <i>Carex baccans</i>           | Cyperaceae             | G     | V/R                | F/P                | 1.00 | -               | 4.50           | 1.33 | 0.33 | 0.23 | 3.00 | -    | 2.80 | na    | na   | na   |
| <i>Frimbristylis manticola</i> | Cyperaceae             | G     | V/R                | P                  | na   | -               | na             | 8.50 | 3.50 | 2.00 | 8.00 | 3.00 | na   | 13.25 | 6.86 | 1.60 |
| <i>Cryptochloa muricatum</i>   | Gramineae              | G     | V                  | P                  | na   | -               | na             | na   | -    | na   | na   | na   | na   | 1.00  | -    | 0.03 |
| <i>Panicum gardneri</i>        | Gramineae              | G     | V/R                | P                  | na   | -               | na             | 1.75 | 0.48 | 0.40 | 1.00 | -    | 1.00 | 1.00  | 0.00 | 0.06 |
| <i>Eragrostis japonica</i>     | Gramineae              | G     | V/R                | F/P                | 1.00 | -               | 4.50           | na   | -    | na   | na   | na   | na   | na    | na   | 0.03 |
| <i>Uncaria thwaitesii</i>      | Rubiaceae              | V     | V/R                | F/P                | 2.50 | 1.50            | 22.7           | 28.2 | 11.1 | 10.0 | 2.00 | 1.00 | 3.80 | 10.17 | 2.99 | 2.00 |

Table 1: Contd.

| Species                       | Family          | Habit | Top/p <sup>2</sup> | light <sup>3</sup> | FS   |                 |      | PS   |      |      | FS   |    |      | PS     |      |       |
|-------------------------------|-----------------|-------|--------------------|--------------------|------|-----------------|------|------|------|------|------|----|------|--------|------|-------|
|                               |                 |       |                    |                    | mean | se <sup>5</sup> | %    | mean | se   | %    | mean | se | %    | mean   | se   | %     |
| <i>Ipomoea angustifolia</i>   | Convolvulaceae  | V     | V                  | P                  | na   | -               | na   | na   | -    | na   | na   | na | na   | 2.50   | 1.50 | 0.15  |
| <i>Ficus diversiformis</i>    | Moraceae        | V     | V/R                | P                  | na   | -               | na   | 2.50 | 1.50 | 0.30 | na   | na | na   | 4.00   | -    | 0.12  |
| <i>Smilax zeylanica</i>       | Smilacaceae     | V     | V/R                | F/P                | 3.00 | -               | 3.00 | na   | -    | na   | na   | na | na   | 1.00   | -    | 0.03  |
| <i>Cissus heyneana</i>        | Vitaceae        | V     | V                  | F                  | na   | -               | na   | na   | -    | na   | 1.00 | -  | 1.00 | na     | -    | na    |
| <i>Cissus stigma</i>          | Vitaceae        | V     | V/R                | P                  | na   | -               | na   | 7.67 | 2.56 | 2.70 | na   | na | na   | 19.33  | 8.18 | 3.06  |
| <i>Asplenium</i> spp.         | Aspleniaceae    | F     | V/R                | P                  | na   | -               | na   | 8.75 | 1.55 | 2.00 | na   | na | na   | 12.25  | 4.42 | 1.50  |
| <i>Dicranopteris linearis</i> | Gleicheniaceae  | F     | V/R                | P                  | na   | -               | na   | 63.0 | 10.3 | 18.5 | na   | na | na   | 22.25  | 7.92 | 2.70  |
| <i>Ophioglossum pendulum</i>  | Ophioglossaceae | F     | V                  | P                  | na   | -               | na   | na   | -    | na   | na   | na | na   | 1.00   | -    | 0.03  |
| <i>Blechnum orientale</i>     | Blechnaceae     | F     | V/R                | P                  | na   | -               | na   | 110. | 23.5 | 38.7 | na   | na | na   | 107.00 | 20.2 | 19.70 |
| <i>Lygodium</i> spp.          | Schzaceae       | F     | V/R                | P                  | na   | -               | na   | 5.75 | 0.85 | 1.40 | na   | na | na   | 3.33   | 133  | 0.30  |
| <i>Lycopodium</i> spp.        | Lycopodiaceae   | O     | V/R                | P                  | na   | -               | na   | 1.00 | 0.00 | 0.10 | na   | na | na   | 1.00   | 0.00 | 0.06  |
| <i>Seleginella</i> spp.       | Seleginellaceae | O     | V/R                | p                  | na   | -               | na   | 4.25 | 1.11 | 1.00 | na   | na | na   | 5.80   | 1.16 | 0.90  |

1. T - tree, S - shrub, H - herb, G - grass, V - vine, F - fern, O - other lower plants

2. Top/p - topographic position : R - only in ridge soils, V - only in valleys soils, V/R - in soils of both ridges and valleys

3. Light-treatments : F - only under full sunlight, P - only under partial shade, F/P - under both full sunlight and partial shade

4. Mean values of germination,

5. se - standard error of mean,

6. % - percentage of total individuals.

## RESULTS

### Floristic composition

Seedlings of 41 taxa representing 39 genera and 26 families were identified during the study. (Table 1). The partial shade treatment was the most favourable for seed germination. The number of germinants represented in full sun treatment (2.5%) was negligible compared with the partial shade (97.5%). Number of germinants observed in valley soils (66%) was nearly twice the number observed from ridge soils (34%).

Among the taxa a larger proportion was only recruited under the partial shade treatment (20 spp - 48.5%) as compared to only the full sun treatment (8 spp. - 19.5%). A considerable number of species (13 spp. - 32%) germinated under both treatments. The number of species that germinated was also significantly affected by topographic position. Results showed that 4 species (10%) were from ridges only, 14 species (34%) were from valleys only, and 23 species (56%) were common to both valleys and ridges.

In all treatments the species composition of regeneration was dominated by herbs (29% of total germinants). Pioneer trees (7.3% of total germinants) had the least number of species represented excepting lower plants (ferns and their allies) (see Table 2).

**Table 2 : Percentage recruits of major ecological groups**

| Ecological group   | No : of species | Percentage |
|--------------------|-----------------|------------|
| Trees              | 03              | 7.3        |
| Shrubs             | 08              | 20         |
| Herbs              | 12              | 29         |
| Graminoids         | 05              | 12         |
| Vine               | 06              | 14.6       |
| Ferns              | 05              | 12         |
| Other Lower Plants | 02              | 4.8        |

When considering total number of germinants irrespective of species, shrubs (51%) were the most abundant among all treatments. The second most abundant class of plants was ferns and their allies (37%). All ferns and their allies germinated only under the partial shade treatment. The lowest proportion was represented by pioneer trees. *Clidemia hirta* an exotic shrub contributed the most number of germinants (49%) followed by *Blechnum orientale* (26%) a fern. (Fig 1) Twenty seven species represented less than 10 individuals each among the germinants (Table 3).

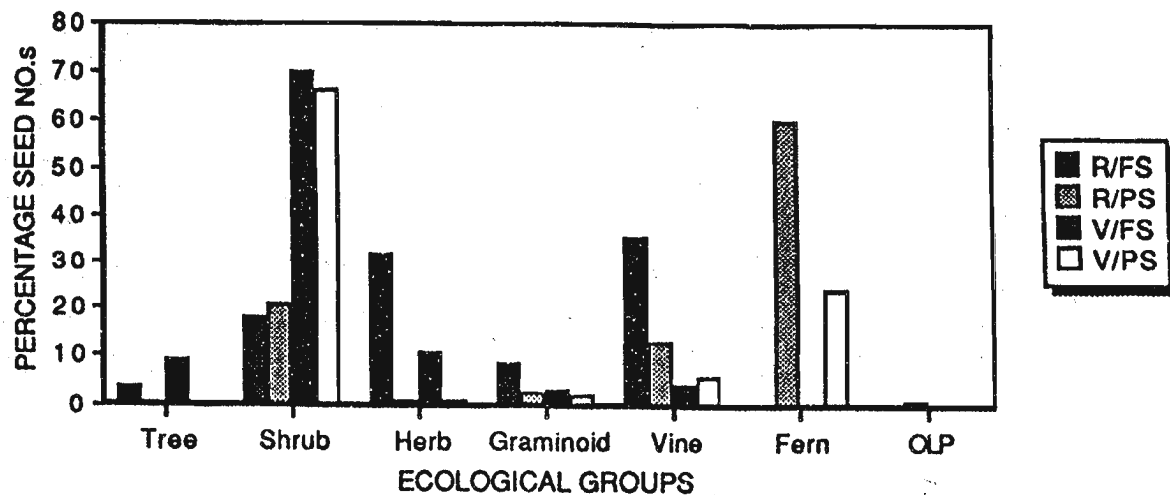


Figure 1 : Proportional seed numbers of each ecological group (%)

Table 3 : Number of individuals and percentage of germinants of ecological groups

| Ecological group | RIDGE  |    |        |     | VALLEY |     |        |     | Total | %   |
|------------------|--------|----|--------|-----|--------|-----|--------|-----|-------|-----|
|                  | FS ind | %  | PS ind | %   | FS ind | %   | PS ind | %   |       |     |
| Tree             | 1      | 4  | 5      | 0.3 | 10     | 9.5 | 15     | 0.5 | 31    | 0.6 |
| Shrub            | 4      | 18 | 363    | 21  | 74     | 70  | 2142   | 66  | 2583  | 51  |
| Herb             | 7      | 32 | 22     | 1.3 | 12     | 11  | 33     | 1   | 74    | 1.5 |
| Graminoid        | 2      | 9  | 44     | 2.6 | 4      | 3.5 | 56     | 2   | 106   | 2   |
| Vine             | 8      | 36 | 220    | 13  | 5      | 4.5 | 187    | 6   | 420   | 8   |
| Ferns            | 0      | 0  | 1033   | 60  | 0      | 0   | 791    | 24  | 1824  | 36  |
| Other LP         | 0      | 0  | 19     | 1   | 0      | 0   | 31     | 0.1 | 50    | 1   |

FS - Full sunlight, PS - Partial shade, Other LP - Other lower plants

Species diversity of germinants was calculated after 35 weeks using Shanon's diversity index formula (Table 4). Diversity among germinants recorded was highest in the valley partial shade treatment, followed in declining order by ridgetop partial shade, valley full sun and lastly ridgetop full sun.

Table 4 : Diversity indices for each treatment

|                 | RIDGE    |               | VALLEY   |               |
|-----------------|----------|---------------|----------|---------------|
|                 | full sun | Partial shade | full sun | partial shade |
| Diversity index | 0.01427  | 0.41752       | 0.0491   | 0.48277       |

### Temporal pattern of distribution of seed bank regeneration

Over the 35 weeks of observation, two types of germination were recorded; (i) very early (within first month) and (ii) delayed germination. For the partial shade treatment in which the earliest germination was observed, 16 species germinated during the first month. This included three tree species (*Macaranga peltata*, *Trema orientalis*, *Acronychia pedunculata*), the shrub *Clidemia hirta*, a herb *Dorstanias indica*, and a grass *Panicum gardneri* (Table 5). No vines and ferns germinated during the first two months. In the full sun treatments only five species were observed to germinate early. These included two trees (*Acronychia pedunculata*, *Macaranga peltata*), two grasses (*Eragrostis japonica*, *Panicum gardneri*), and a vine (*Cissus heyneana*).

Results also suggest time taken to germinate may also be affected by topographic position. Valley soils had more species (12 spp.) that germinated early as compared to ridge soils (9 spp.). However, no ferns or their allies were observed to germinate during the first two months. Ferns started germination during the third month and that was only in partial shade treatment. Fig. 2 shows the temporal pattern of germination under each treatment. In both partial shade treatments the graphs still continue to increase because of fern germination. Table 5 categorizes the species into early and delayed germination types based on the time taken to start germination.

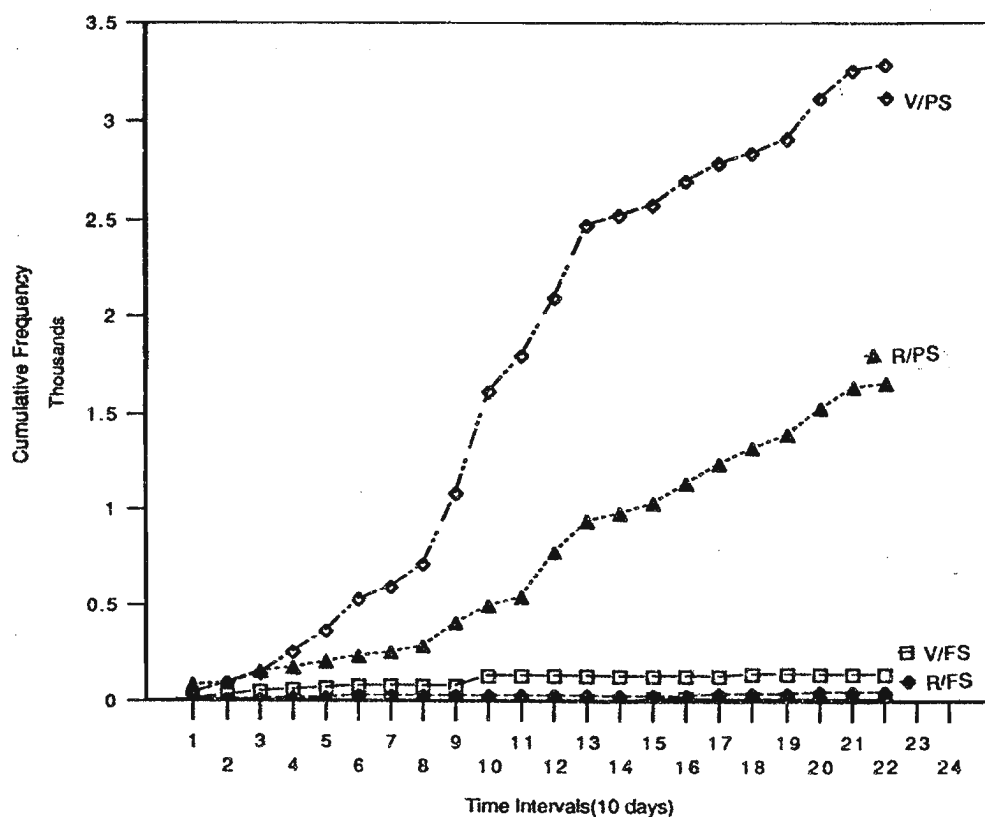


Figure 2 : Temporal distribution patterns of germinants.

Table 5 : Early and delayed germination

|               |                                                                                                                                                                                                                  | RIDGE                                                                                                                                                                                                                                                                                                                                                                                                                                  |               | VALLEYS                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|---------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|               | Early Germination                                                                                                                                                                                                | Late Germination                                                                                                                                                                                                                                                                                                                                                                                                                       |               | Early Germination                                                                                                                                                                                                                                                              | Late Germination                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Full sun      | <i>Acronychia pedunculata</i><br><i>Eragrostis japonica</i>                                                                                                                                                      | <i>Macaranga peltata</i><br><i>Croton laccifera</i><br><i>Hedyotis fruticosa</i><br><i>Eupatorium odoratum</i><br><i>Dorstanian indica</i><br><i>Oxalis barrelieri</i><br><i>Carex baccans</i><br><i>Uncaria thwaitesii</i><br><i>Smilax zeylanica</i>                                                                                                                                                                                 | Full sun      | <i>Macaranga peltata</i><br><i>Panicum gardneri</i><br><i>Cissus heyneana</i>                                                                                                                                                                                                  | <i>Trema orientalis</i><br><i>Breynia retusa</i><br><i>Clidemia hirta</i><br><i>Osbeckia octandra</i><br><i>Emilia exserta</i><br><i>Erigeron sumatrensis</i><br><i>Eupatorium odoratum</i><br><i>Vernonia cinera</i><br><i>Dorstanian indica</i><br><i>Carex baccans</i><br><i>Uncaria thwaitesii</i>                                                                                                                                                                                                                                                                                     |
| Partial shade | <i>Macaranga peltata</i><br><i>Clidemia hirta</i><br><br><i>Acronychia pedunculata</i><br><i>Ageratum conizoides</i><br><i>Eupatorium odoratum</i><br><i>Dorstanian indica</i><br><br><i>Ellettaria cardamom</i> | <i>Osbeckia octandra</i><br><i>Hedyotis auricularia</i><br><br><i>Vernonia cinera</i><br><i>Carex baccans</i><br><i>Frimbristylis manticola</i><br><i>Panicum gardneri</i><br><br><i>Uncaria thwaitesii</i><br><i>Ficus diversiformis</i><br><i>Cissus stigma</i><br><i>Asplenium spp.</i><br><i>Dicranopteris linearis</i><br><i>Blechnum orientalis</i><br><i>Lygodium spp.</i><br><i>Lycopodium spp.</i><br><i>Seleginella spp.</i> | Partial shade | <i>Schumacheria casteneifolia</i><br><i>Macaranga peltata</i><br><i>Trema orientalis</i><br><br><i>Clidemia hirta</i><br><br><i>Acronychia pedunculata</i><br><i>Eupatorium odoratum</i><br><i>Dorstanian indica</i><br><br><i>Costus speciosus</i><br><i>Panicum gardneri</i> | <i>Hibiscus furcatus</i><br><i>Osbeckia octandra</i><br><i>Ageratum conizoides</i><br><br><i>Oxalis barrelieri</i><br><br><i>Lindernia hirsuta</i><br><i>Melochia corchorifolia</i><br><i>Stachytarphyta indica</i><br><br><i>Frimbristylis manticola</i><br><i>Cryptochloa muricatum</i><br><i>Uncaria thwaitesii</i><br><i>Ipomea angustifolia</i><br><i>Ficus diversiformis</i><br><i>Smilax zeylanica</i><br><i>Cissus stigma</i><br><i>Asplenium spp.</i><br><i>Dicranopteris linearis</i><br><i>Ophioglossum pendulum</i><br><i>Blechnum orientalis</i><br><i>other lower plants</i> |



## DISCUSSION

In soil seed bank studies, the crucial and controversial question is how to distinguish regeneration originating from a soil seed bank and regeneration originating from seeds that have recently dispersed into the site (Whitmore, 1978; 1983; 1984). To avoid this controversy, in this study we considered the soil seed bank to include only those soil horizons immediately below the litter layer.

Natural regeneration initiates or is released at the forest groundstorey in forest from a variety of canopy disturbances. Canopy disturbances can occur from falling branches, uprooting of trees, landslides, wildlife activities or from shifting agriculture and selective logging. To trigger soil seed bank germination, disturbance of soil and removal of the forest canopy play a major role through alteration of light, temperature and moisture regimes at the soil surface (Vazques-Yanes, 1976). From our study it is obvious that the regeneration of the soil seed bank in mixed dipterocarp forest of Southwest of Sri Lanka was significantly affected by light. Partial shade that emulated amounts of groundstorey light like a tree fall was the most favourable. This finding transcended soils from both ridges and valleys. In our study, initiation of germination was inhibited in the full sun as compared to the partial sun treatment.

Our results also indicate that valley sites contribute greater amounts of seed bank to the soil by means of both number of individuals and number of species as compared to ridgetop sites. This suggests that the disturbed valley sites can regenerate more effectively than that of ridges. The amount of regeneration is increased by disturbances that create partial shade as compared to more lethal disturbances such as land slides or shifting cultivation that can create full sun conditions.

In some studies, rapid germination of pioneer species after disturbance was observed often in less than two weeks (Whitmore, 1983). We observed the appearance of pioneer trees such as *Acronychia pedunculata*, *Macaranga peltata*, *Trema orientalis* and *Schumacheria castaneifolia* during the first month of this study, particularly under partial shade. The short-lived pioneer shrub *Clidemia hirta* also germinated within the first month. All these species have fruits that are copiously produced every year and are eaten by small birds and rodents. Their role in building a soil seed bank within a forest appears critical. The results of this study also emphasize the dominance of weed species such as the exotic *Clidemia hirta* grasses (*Fimbristylis manticola*), and ferns (*Blechnum orientalis*, *Dicranopteris linearis*) in soil seed bank of Sinharaja forest. However, there is no relationship between species composition of late successional forest and that in the seed bank. No primary species could be found that germinated during the period of this study.

In summary, this study demonstrated that soil seed banks in mixed-dipterocarp forest of southwestern Sri Lanka comprise mostly pioneer species that are unrelated to the primary forest species that currently occupy the site. Valley sites had a higher proportion of seeds

and species in the soil than ridge sites, and greater germination was obtained under partial shade conditions that simulated canopy trees falls as compared to catastrophic disturbances that can create full sun conditions. However, soil seed banks may play an important role in regenerating catastrophically disturbed sites, because they serve as the only regenerative mechanism for regeneration.

## ACKNOWLEDGMENT

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# CONSERVATION OF GENETIC RESOURCES OF IMPORTANT TREE SPECIES IN SRI LANKA

D. Tilakaratna

## ABSTRACT

*Sri Lanka is blessed with a rich tree flora. Many of the species are high quality hardwoods and endemic to the country. Expansion of the human population has resulted in deforestation which has reduced the natural habitats of the flora to about 24% of its original extent. This deforestation has definitely reduced the diversity of the gene pool of many tree species. As deforestation is continuing, so is the shrinkage of the gene pool. The loss is more serious with respect to economically important tree species, of which people selectively cut the phenotypically superior trees that carry most of the genes that can produce useful qualities. Loss of habitats and the selective removal of phenotypically superior trees can degrade the gene pool so that in the future the potential for the production of high quality wood from these tree species will be lost. Urgent action is necessary to safeguard the genetic resources of these important species. It should be one of the priority actions in the conservation of biological diversity in Sri Lanka. Protection of the remaining natural habitats, identification of the areas with high genetic diversity for strict conservation, establishment of artificial plantations, and the selection and propagation of genetically superior individual trees are some of the measures that can prevent further depletion of the genetic resource.*

## INTRODUCTION

All living things maintain and transfer to their offspring their qualities, similarities and dissimilarities by a group of molecules called genes. Genes are part of the structure of the chromosomes which are found in the nuclei of the cells. Each gene or group of genes determines some feature of an individual. A gene or a group of genes which controls a particular feature of an organism varies among the individuals across the population of the species, so that there are many differences that help to identify each individual separately. The total variation of the genes of a species is called the gene pool; it represents the genetic diversity of that species. In order to ensure the continuing existence of a species, the conservation of the gene pool is important. Very often it is difficult to determine its size and limits. The total gene pool may be spread over an extensive area latitudinally and altitudinally. What is commonly attempted is the conservation of whole ecosystems. Sri Lanka, being a tropical island, has a rich flora which contains many valuable tree species. Some are found only in this country; 24% of the flowering plants are endemic (Gunatilleke & Gunatilleke 1983). These species have been isolated from the Asian mainland since the late Mesozoic era, and have evolved and adapted to the local environment. Many of these species will have genes or gene

complexes unique to Sri Lanka. With the expansion of population, forest cover has been depleted at an alarming rate. The loss of forest cover during the period 1956-1985 is 1.15 million ha, and the annual loss is about 42,000 ha (Bandaratillake 1990). This inevitably causes a narrowing of the diversity of the gene pool of the important tree species. Forest management which mainly involves harvesting of important tree species effects a change of genetic composition and endangers such species (Kemp *et. al.* 1976). Erosion of the gene pool of economically important tree species needs urgent attention. Unless this is prevented the potential of these species will be lowered in the future and they will even face extinction. This aspect of conservation was not taken seriously in the past as such a risk was not foreseen.

## **FACTORS AFFECTING THE LOSS OF GENETIC RESOURCES**

Any large-scale destruction of habitats and the recurring destruction of some phenotypes of a species can lead to loss of genetic resources. The following factors contribute to the loss of genetic resources of important tree species in Sri Lanka.

### **Deforestation**

Sri Lanka's natural forests have been under destruction over several decades resulting in a reduction to about a quarter of their original extent. The present natural forest cover is approximately 23.9% of the land area (Legg & Jewell, 1985). This deforestation has undoubtedly narrowed the gene pool of many species of important trees.

### **Shifting cultivation**

Shifting cultivation involves clearing of forest land for short-term cultivation of crops and eventually abandoning the land to the regrowth of vegetation. After 5-10 years the land is again cleared for cultivation. This alternate clearing and abandoning continues indefinitely. This practice endangers the existence of tree species which need 25-30 years for completion of a life cycle (seed to seed). In the areas cleared for shifting cultivation, these species cannot regenerate to ensure the flow of genes to future generations. This problem is evident in many of the dry-zone lands at present.

### **Fire damage**

Once the original natural vegetation is cleared, the land is quickly colonized by short-lived annuals. These species complete their life cycle during the wet season and become dry during the dry season, making the area susceptible to fire damage. Fires can occur annually, or once in several years, destroying the regenerating tree species. Lack of regeneration and reproduction of tree species leads to the loss of genetic resources.

## **Grazing**

Regenerating tree species are subject to grazing by many animals. Grazing leads to soil compaction, debarking of stems, and browsing of foliage. Continuous grazing retards the regeneration of tree species.

## **Selective logging**

Selective logging, although practised as an accepted silvicultural system for managing natural forests, can contribute to the erosion of gene pools of important tree species (Zobel & Talbert, 1984). Trees meeting size criteria and of economically important species are felled. The trees with better growth and form are selected, leaving the trees with poor growth and form. When this selection is practised for several generations it can eliminate certain genes and gene complexes responsible for important characteristics. This dysgenic effect deteriorates the gene pool, resulting in the loss of valuable genes.

## **Illicit felling**

In effect this is similar to selective logging. Species with the most economic value and desirable qualities are felled. When practised over several years this can also lead to genetic erosion of the important tree species.

## **Inbreeding**

Inbreeding is a result of fertilizing or exchange of pollen between closely related individuals, or of self pollination. When flowering trees are sparsely distributed or isolated, inbreeding occurs. Due to inbreeding the genetic potential of the offspring is reduced, resulting in low fertility, vigour and resistance to pests and diseases (Barrett, 1980).

After several generations of inbreeding, the survival of the species can be at risk. Populations of very important tree species, for example *Diospyros*, *Chloroxylon* and *Vitex* species in the dry zone, are now reduced to such very low levels that there is a danger of inbreeding. Another factor which can increase inbreeding is the planting of trees in home gardens. People plant many economically important trees in their home gardens. In many instances only a few of these trees survive and grow to produce flowers and fruits. In other words the flowering trees are sparsely located in the homesteads so that the tendency to inbreed is greater.

## **Contamination by genes of external origin**

Sometimes seeds of important species are procured from foreign sources and planted adjacent to native populations. The pollen from these plantations disperses over the native stands and contaminates the local gene pool. Repeated contamination by genes of

foreign sources will gradually change the local gene complexes and the original gene pool will be lost (Plamberg, 1985). This may not be a major problem in Sri Lanka as there is no considerable import of seeds of native species.

## CONSERVATION OF GENETIC RESOURCES

Conservation to prevent the extinction of a species and gene conservation are two different objectives (Zobel & Talbert, 1984). A species that is not faced with extinction can be under threat of losing part of its gene pool. Genetic conservation is aimed at preventing further loss of genes, gene complexes and genotypes. Strategies adopted for gene conservation are somewhat different from strategies to prevent extinction of species. Efforts are made to conserve the broad spectrum of genetic variability. The two options available for genetic conservation are, *in-situ* and *ex-situ*.

### *In-situ* conservation

Conservation of the species within its natural ecosystem is the best method for genetic conservation, provided that the area can be well protected and the genetic material conserved is made available for future use without difficulty (Whitmore, 1975; Lampray, 1975). It allows the natural interaction and evolutionary changes in the gene pool which are important for the successful existence of the species in the changing environment. Sri Lanka is conserving natural forests and ecosystems under several programmes; the protected areas are categorized as follow (Anon, 1995) :

- Proposed reserves
- Forest reserves
- National heritage wilderness areas
- Jungle corridors
- National parks
- Nature reserves
- Sanctuaries
- Strict nature reserves
- Conservation areas *and*
- World heritage areas

The objective is to protect the entire ecosystem from destruction. The main criterion for the selection of forests for conservation is species diversity. A survey (National Conservation Review) is being carried out to assess the species diversity in natural forests with the objective of identifying areas for strict conservation and other areas for sustainable management for forest products. (Jayasuriya, 1995). Although this approach is suitable for the conservation of species, it may not fulfil the needs of genetic conservation for those species in which all or an important part, of the gene pool does not fall within the areas identified for conservation. For example, important tree species like

nadun (*Pericopsis mooniana*), lunumidella (*Melja dubia*), and Jak (*Artocarpus heterophylla*) are mainly found in homesteads. A high proportion of the population of some species, for example species of *Vitex*, *Chloroxylon*, *Diospyros*, *Berreya* etc. occurs on the periphery or outside the natural habitats. Some other species occur as very isolated and localized populations, e.g. gammalu (*Pterocarpus marsupium*), suriyamara (*Albizzia odoratissima*), bulu (*Terminalia bellerica*) and nelli (*Phyllanthus emblica*). The gene pool of these species may not be conserved well under the present regime. This shows that there is a need for a different approach to the genetic conservation of important tree species.

### Ex-situ conservation

*In situ* conservation is the ideal method for conserving species and gene pools. Yet it is difficult to practise as large extents of forests have to be protected. Also in some instances the areas in which a major part of the tree population occurs are not within state jurisdiction, and are therefore difficult to protect. The alternative is *ex-situ* conservation. This involves taking a sample of the gene pool out from its natural habitat and growing it in an area where it can be well protected. For this purpose knowledge about propagation and planting of these species must be acquired. This information is now available for most of the economically important tree species in Sri Lanka. The size of the sample needed for *ex-situ* gene conservation is difficult to decide (Eldridge *et al.*, 1994). It is a subject of considerable debate and controversy. There are no sampling techniques or guidelines set for this purpose, but one should attempt to capture as great a variety as possible of genes needed for recombination and future use (Namkoong, 1979). A random sample across the population, covering the entire habitat, must be collected. A large sample is always preferred if resources permit. From such collections, stands can be planted, with replications at different locations. The stands will serve as gene reserves for future use. Action has already been initiated for *ex-situ* conservation of *P. marsupium* (Tilakaratna, 1994) and *P. mooniana*. Storage of germplasm is another method for *ex-situ* gene conservation. This requires testing of viability, and trials of different conditions for long-term storage. Work on this subject has also been initiated with the collaboration of the Plant Genetic Resources Centre (PGRC). However, this preservation type of conservation is not preferable in the long run as it does not allow for adaptation, evolution and change for future existence (Arnold & Midgely 1995).

### RECOMMENDATIONS

In order to prevent further loss and to conserve the genetic resources the following actions are suggested:

- Review the seriousness of the problem of the loss of genetic resources of important tree species.



- Identify and map genetic diversity and areas having important germplasm.
- Gene-ecological studies to determine what are the genetically variable populations and individual trees.
- Planning of specific conservation strategies, based on the above studies. For example if trees with important economic characters are found on private land, arrangements must be made with the land owners to keep those trees in their compounds and not to fell them. Such trees should be recorded for the collection of propagules for use in production, conservation and tree improvement.

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# MEDICINAL PLANTS : UNDERSTANDING THE GROUND SITUATION TO DEVELOP STRATEGY

D.B. Sumithraarachchi

## ABSTRACT

*In Sri Lanka, dependence on herbal treatments has been gaining popularity over the recent past. The population of 17.1 million on this small island demands fresh and dried plants and plant material for treatments of ailments and illnesses. There has been state support to preserve and develop herbal treatment systems and as a result significant changes have been brought about and established in this important area. These endeavours have increased the demand for medicinal plants and their products.*

*Sri Lanka has an interesting flora with a remarkable diversity both at species and genetic levels. This is attributed to many aspects special to Sri Lanka.*

*A survey of presence, abundance, conservation and sustainable utilization of some important medicinal plants of Sri Lanka is presented. In this presentation, ten important woody species are discussed. The survey results are presented from three dry zone districts of the Island.*

*This survey revealed the serious reduction of population sizes thus narrowing down the genetic base which calls for an immediate need to conserve the existing population levels.*

*The survey also recognizes the immediate need to expand the cultivation of medicinal plants to reduce pressure of wild populations and to meet the increasing demand for medicinal plants.*

## INTRODUCTION

Consecutive political leadership over the last 25 years has supported the native treatment practices in Sri Lanka. They have not only recognized but also supported the ancient healing systems. This has increased the demand for plants used in herbal medicine. These endeavours have ended up in the establishment of a Ministry for this subject.

In addition to national support, international assistance too has been provided in various disciplines of Ayurveda. Commendable efforts were made to recognize important aspects related to medicinal plants. Recognition and identification of plants used in herbal medicine, research in pharmacognosy, review of plants and plant materials imported from other countries, use of plants available in Sri Lanka, cultivation of common medicinal plants in the Island, review of use of plants from natural forests and their cultivation are a few to be placed on record. A number of efforts have been made to conserve the wild populations of medicinal plants, so that the important genetic diversity could be preserved in their natural habitats.

Sri Lanka has over 3300 species of flowering plants. In the field of plant conservation, there are important and effective state departments in Sri Lanka responsible for the conservation of **Habitat Diversity**, **Species Diversity** and **Genetic Diversity** separately. Over 500 species of **Flowering Plants** are used in the treatment of human disorders using ancient/herbal treatment systems. The popularization of traditional herbal treatment systems has correspondingly increased the demand for fresh and dried planting material. Supply of increasing quantities of planting materials has to come from the plant populations in the wild, thus reducing the diversity at species level and narrowing down genetic diversity. There are some plant species that come from home gardens and other areas with little pressure on the wild stocks.

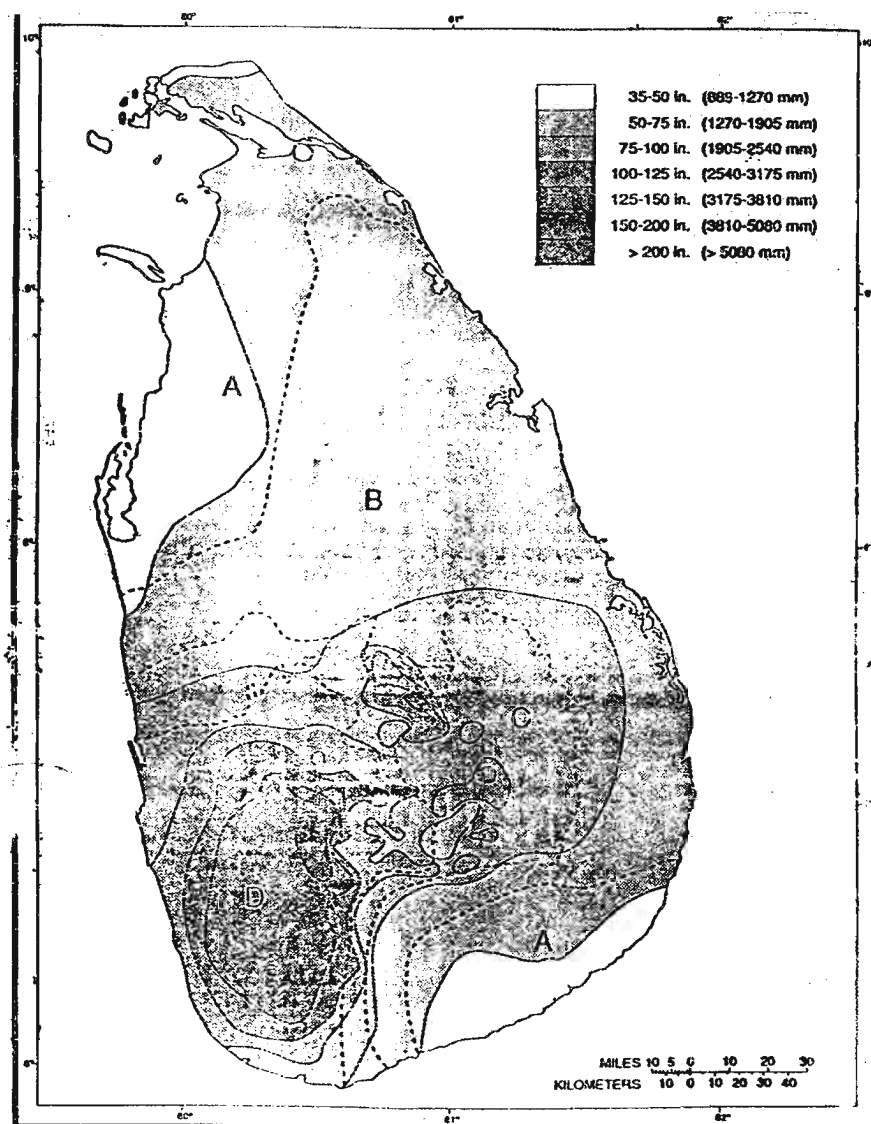


Figure 1: Sri Lanka : Average annual rainfall, 1931 – 1960 ( from de Silva, 1980); and ecological zones (Mueller-Dombois, 1969, and Crusz, 1986, A-D, A & B = Dry Zone, C = Intermediate Zone, and D = Wet Zone). (Computer graphic realization by G.L. Venable, SI Dept. Entomology, 1989).

This presentation is based on 10 woody plant species of the dry zone forests of Sri Lanka commonly used in herbal medicine. The objective of this presentation is to show the ground situation of medicinal plants in the natural forests.

## METHODOLOGY

The wet zone forests possess high species diversity compared to the intermediate and dry zone of Sri Lanka. The distribution of forest areas in Sri Lanka is summarized below. The present studies are based on sampling made from three districts of the dry zone of Sri Lanka, Polonnaruwa, Puttalam and Monaragala. According to the available statistics forested areas of these three districts represent about 30% (240,520 ha of 773,566.9 ha) of the total forested area of Sri Lanka. Of the nearly 30% forest area in reference, a 221 x 500 square meter area has been sampled. This is a small area compared to the total area and it exhibits the magnitude of the sampling needed to obtain accurate statistics. Investigations have been based on **Gradsect Sampling** technique.

The area statistics are from the NCR database.

### Wet Zone and Montane Zone Districts

|    |                       |                     |
|----|-----------------------|---------------------|
| 1. | Colombo district      | 3,284.2 ha          |
| 2. | Galle district        | 35,997.1 ha         |
| 3. | Gampaha district      | 103.0 ha            |
| 4. | Kalutara district     | 19,646.9 ha         |
| 5. | Kandy district        | 80,849.3 ha         |
| 6. | Kegalle district      | 26,869.2 ha         |
| 7. | Matara district       | 12,464.2 ha         |
| 8. | Nuwara Eliya district | 34,054 ha           |
| 9. | Ratnapura district    | 42,458.8 ha         |
|    |                       | <u>255,726.7 ha</u> |

### Dry Zone and Intermediate Zone Districts

|    |                       |                     |
|----|-----------------------|---------------------|
| 1. | Anuradhapura district | 91,650.1 ha         |
| 2. | Badulla district      | 68,043.2 ha         |
| 3. | Hambantota district   | 49,553.7 ha         |
| 4. | Kurunegala district   | 26,346.3 ha         |
| 5. | Matale district       | 41,726.9 ha         |
| 6. | Monaragala district   | 106,952.7 ha        |
| 7. | Polonnaruwa district  | 71,564.5 ha         |
| 8. | Puttalam district     | 62,002.8 ha         |
|    |                       | <u>517,840.2 ha</u> |

These figures too are however deceptive as a sizeable proportion of these recorded natural forests come under various pressures resulting in the conversion of these natural forests into agricultural lands and human settlements.

Review of distribution of plants used in herbal medicine reveals that it is the dry zone plants that are larger in number compared to the wet zone plants. While over 100 plant species from the dry zone forests are regularly collected for use as medicinal plants, the number of species collected from the wet zone forests amount to less than 20. However, the collection of these plants with and without permission has resulted in the reduction of wild populations and genetic diversity. At the present deliberations only 10 species of plants are discussed. Here again the quantification is not presented as national statistics are still being collected.

These are listed below.

1. *Azadirachta indica* A. Juss.  
(Meliaceae)
2. *Bridelia retusa* (L.) Spreng.  
(Euphorbiaceae)
3. *Butea monosperma* (Lam.) Taub.  
(Leguminosae)
4. *Munronia pinnata* (Wall) Theob.  
(*Munronia pumila* Wight)  
(Meliaceae)
5. *Phyllanthus emblica* L.  
(Euphorbiaceae)
6. *Pterocarpus marsupium* Roxb.  
(Leguminosae)
7. *Syzygium cumini* Skeels  
(Myrtaceae)
8. *Terminalia arjuna* (Roxb.) Wight & Arn.  
(Combretaceae)
9. *Terminalia bellerica* (Gaertn.) Roxb.  
(Combretaceae)
10. *Terminalia chebula* Retz.  
(Combretaceae)

1. ***Azadirachta indica* A. Juss.**  
**(Meliaceae)**

A well known tree both in historic and modern times. It is well known for its value as a timber. The wood is as durable as Teak and is insect repellent. As a result the timber was used in making wardrobes and other household furniture. It has been recognized as one of the most important trees in the field of Agriculture and biological control of pests and diseases. At present leaves, barks and oil are used in herbal medicine.

It is well known as a tree that cools the environment and is planted around dwellings in drier parts of the island. Its historic role in the prevention of infectious/epidemic diseases, control of paddy pests in storage, and silver fish inside books are some of the other uses. Oil extracts are also used in making soap, toothpaste and lotions.

*Azadirachta indica* is a dry zone plant that becomes a sizeable tree upto 15m. Very few trees have been encountered in our survey of 50 forests in the dry zone. The tree is also naturally found in some savannahs.

However it is now found in cultivation in the dry areas as a shade tree and as a street tree. It has also entered into mixed/forestry and plantations programmes of the Forest Department in the dry zones.

In addition to the forest plantations, the Department of Ayurveda produces and distributes for planting at least 10,000 seedlings per year from its nurseries in Haputale.

2. ***Bridelia retusa* (L.) Spreng.**  
**(Euphorbiaceae)**

A fairly well known tree is principally again from the drier parts of the Island. A small tree upto 6m. This plant is also found in the intermediate and wet zone forests. This is another tree of multiple uses. This tree also produces valuable timber. The bark of trees is heavily used in the treatment of fractures and other orthopaedic disorders. It is now becoming difficult to obtain sufficient quantities of mature bark which is needed for native treatment.

During our survey, too, we encountered this species in our forests. However, the abundance of mature trees is markedly low in the forests surveyed. The genetic diversity is reasonable as forests of all districts possess a small population.

The nurseries of the Department of Ayurveda produce around 500 seedlings per year for distribution. The seeds are a delicacy of birds and hence there is a good dispersal agency. The seedlings germinate under varying conditions and hence there should

be a natural regeneration if the plants are left to natural growth in protected areas. It could also be cultivated under plantation conditions.

3. ***Butea monosperma* (Lam) Taub.  
(Leguminosae)**

This tree is well known for its bright orange red flowers. The tree can reach upto 8-10 m in height. The tree seems to have a restricted distribution. It is found in the dry country. We encountered natural distribution of this species in the Damana grasslands of Gal Oya NP area especially in Nilgala, Bintenna, Ratugala and associated degraded grasslands around Monaragala and Bibile. Wood is soft and is of little use as a timber.

The tree produces a gum which is known as "Begal Kino" and this gum is used in herbal medicine. Other parts of the plant used are flowers, seeds, barks and leaves.

This tree again is in danger due to the excessive debarking of the tree. Abundance in natural forests seems to have gone down to low levels. However, the genetic diversity seems to be still reasonable.

At present there is no programme to cultivate this tree although this could be introduced into urban planting and school programmes.

4. ***Munronia pinnata* (Wall) Theob.  
(*Munronia pumila* Wight)  
(Meliaceae)**

*Munronia* is one of the woody plants in highest demand in herbal medicine at present. It is found in the dry and some of the intermediate forests of Sri Lanka in gregarious populations and it seems to be one of the most threatened plants of Sri Lanka at present.

This is a small unbranched shrublet upto 15 (60)cm. There are many variations of this species. The diversity extends to the height, leaf, flower and the hairiness of the plant. Some of the populations from Yala National Park seem to grow tall. In natural forests one can now locate them in and around rock crevices and so on, where the sambar deer cannot reach them.

The commercial value of this plant as a dried plant material for herbal medicine as well as the preference of sambar deer for this plant poses high threats for this plant in its natural habitats.

In 50 forests where the survey was carried out, the plant was found only in Polonnaruwa district. It was rare in the Monaragala district and other districts.



This plant is one of the most important plants. At present there is a national demand for about 10,000 kg of dried plants per year. The propagation and cultivation techniques have been perfected at the Botanic Gardens, Peradeniya and Haputale Ayurvedic nurseries. A plant takes 12-18 months to achieve its full growth and such a plant which will weigh about 30 g would weigh about 10 g when dried. We will therefore need at least 300,000 plants per year to supply the national demand.

5. *Phyllanthus emblica* L.  
(Euphorbiaceae)

A moderate sized tree/treelet of the dry zone grasslands. The plant is somewhat fire resistant and is easily cultivated. The fruit of this plant is of high value and demand and is a main component in most of the herbal treatments and medicine both in fresh and dried form. The fruit is very rich in Vitamin C and is also made into fruit cordials at present. Other parts of this plant such as bark, leaves and seeds are also used in herbal medicine.

The natural populations of this plant in the surveyed forests seem to be low. There seem to be elephant damage to these plants when in fruit, in addition to the human pressure on them when in fruit. In most of the Damana grasslands of Gal Oya National Park we noticed the coppicing of this plant flushing after the rains.

The germination of the seeds is after the firing of grasslands where the seeds dehisce due to the excessive heat. The liberated seeds germinate with the onset of the rains.

Some figures available from 1987, 88 and 89 on the quantities of fruits of this plant imported to Sri Lanka are presented here. The reduction of quantities is an indication of collection and supply of required fruits from the wild.

|                            | 1987     | 1988     | 1989     |
|----------------------------|----------|----------|----------|
| <i>Phyllanthus emblica</i> | 57068 kg | 56973 kg | 38250 kg |

Sri Lanka has spent about Rs 1 million to import the dried fruits. The fruits from the wild do not get into the hands of the herbal sector. They are generally sold as fruits and a majority that fail to be sold are thrown away. This is one of the most important products for national support for collection and curing. The plants are popular and a large number of seedlings is sold to the public for planting. This is done by the Forest Department, Botanic Gardens and the Ayurvedic Department nurseries.

6. ***Pterocarpus marsupium* Roxb.**  
(Leguminosae)

One of the common trees of the Damana and Thalawa grasslands of the Monaragala, Badulla and Hambantota districts. This is one of the dominant species of these communities. The tree grows upto about 30 m. The timber is of high demand for both furniture and housing. The trunk is tapped for its resinous exudate which is of high medicinal value against diabetes. The red resin is collected and sold in bottles. Reduction and disappearance of its habitat is causing concern for the conservation of this species and their habitat. Mature trees are still found in their habitats although they are one of the most vulnerable tree species.

The forest department and many other agencies have taken over this species for cultivation as they are important. However, what is planted most is *Pterocarpus indica* and not *P. marsupium* as the latter is not easy to propagate. There is also an insect that damages the seeds when they are young. The seed when undamaged has a dormant period.

7. ***Syzygium cumini* Skeels**  
(Myrtaceae)

A large shrub to a large canopy tree upto 25 m. The tree is common in dry zone forests especially along the margins of streams and tanks. The tree seems to have had regular felling from its natural habitats due to its high timber value. It is still found in a number of forests subjected to survey. However discussions with herbal doctors revealed that they are unable to obtain their normal supply requirements for herbal treatments. The fruits, leaves, barks and dried leaves are used in herbal medicine. At present these barks seem to be extracted on a regular basis from protected areas under licence. This is one tree that does not seem to have got into the priority list for cultivation.

This is one plant that has no propagation and planting programme.

8. ***Terminalia arjuna* (Roxb.) Wight & Arn.**  
(Combretaceae)

A common dry zone tree abutting riverbanks, streamsides and marshes in grasslands of dry parts of the country. The timber is water resistant and is of high demand. The barks are used in herbal decoctions in the treatment of heart ailments. Other parts such as leaves, flowers and fruits are also used in herbal medicine.

The highest risk for this tree is from illicit loggers.

The seeds are easily propagated and the seedlings can be planted even under somewhat degraded conditions. There is an ancient belief that this species when planted will improve water resources.

At present about 10,000 seedlings are propagated and distributed by the Ayurveda nursery at Haputale.

9. ***Terminalia bellerica* (Gaertn.) Roxb.**  
(Combretaceae)

A large tree in the savannahs and some intermediate forests of low altitude common in the Gal Oya National Park and a number of grasslands in the Monaragala and Badulla districts. In other natural areas it is not so common. This tree is listed as a plant for reforestation and in the rehabilitation of degraded lands in the intermediate zones of Sri Lanka. As large quantities of fruits are required for herbal treatments it is a tree that has to be cultivated.

Local produce is successfully collected and supplied to the Ayurvedic sector. Seedling germination is not difficult. The seedlings take on well on any soil. It is a plant for rehabilitating degraded grasslands as the species can withstand fires.

10. ***Terminalia chebula* Retz.**  
(Combretaceae)

A large tree very similar to *T. bellerica* and found in the same habitats. This species is also in danger due to the loss of its habitat for village expansion programmes etc. The timber of both *Terminalia bellerica* and *T. chebula* are not in high demand. The fruits of both these species are main ingredients in herbal prescriptions and preparations.

This is also successfully propagated and cultivated by all government agencies of the island.

## RESULTS

Tables I and II represent the summarized distribution of plant species against the forests that possess these plant species.

| District    | Number of Forests surveyed |
|-------------|----------------------------|
| Polonnaruwa | 7/24                       |
| Monaragala  | 13/18                      |
| Puttalam    | 0/4                        |

Table I : Summarized distribution of plant species in the Polonnaruwa district

| POLONNARUWA DISTRICT                       | Azad.<br>indi. | Brid.<br>retu. | Bute.<br>mono. | Monr.<br>pinn. | Phyl.<br>embl. | Pter.<br>mars. | Syzy.<br>cumi. | Term.<br>arju. | Term.<br>bell. | Term.<br>cheb. |
|--------------------------------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Gal Oya-PR 8897.4 ha                       |                |                |                | P              |                |                |                |                |                |                |
| Giritale- 8897.4 ha                        | P              |                |                |                |                |                |                |                |                |                |
| Medirigiriya Tulana-OSF 8000.0 ha          |                |                |                | P              |                |                |                |                |                |                |
| Minneriya-Giritale-S 6693.5 ha             |                |                |                |                |                |                |                |                |                |                |
| Minneriya-Giritale Block 1-NR<br>7529.1 ha | P              |                |                | P              |                |                | 4              |                |                |                |
| Sigiriya-S 5099.0 ha                       |                |                |                | P              |                |                |                |                |                |                |
| Wasgomuwa Lot 1-NP 29036 ha                | P              |                |                | P              |                |                |                |                |                |                |

Field work was carried out for 23 days and 113 plots have been investigated.

Total recorded forested area is 71564.5 ha.

P - presence of species in the form of saplings. Individuals above 5cm DBH are represented by numbers.

Figures - number of individuals recorded in 2500 m<sup>2</sup> plots.

Table II : Summarized distribution of plant species in the forests in the Monaragala district.

| MONARAGALA DISTRICT          | Azad.<br>indi. | Brid.<br>retu. | Bute.<br>mono. | Munr.<br>pinn. | Phyl.<br>embl. | Pter.<br>mars. | Syzy.<br>cumi. | Term.<br>arju. | Term.<br>bell. | Term.<br>cheb. |
|------------------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Bogaha Patana-OSF 325 ha     |                |                |                |                | 1              | 3              | 3              |                |                | 2              |
| Bolhindagala-OSF 375 ha      |                |                |                |                |                |                |                |                |                |                |
| Diggala-OSF 250 ha           |                | P              |                |                | P              | 1              | 2              |                | 4              |                |
| Gal Oya Valley-NP 25899.9 ha |                | 1              |                | P              | P              | 5              | 5              | 2              | 4              | 20             |
| Kitulhela-OSF 450 ha         |                |                |                |                |                |                |                |                |                |                |
| Korathalhinna-OSF 1500 ha    |                |                |                |                |                |                |                |                |                |                |
| Lolehela-OSF 400 ha          |                |                |                |                |                |                |                |                |                |                |
| Monerakelle-OSF 1650 ha      |                |                |                |                |                |                |                |                |                |                |
| Murutukanda-OSF 800 ha       |                |                |                |                |                |                | 10             |                |                |                |
| Randeniya-OSF 300 ha         |                | P              |                |                | 2              | 11             | 2              |                | 4              |                |
| Ulgala-OSF 1500 ha           |                |                |                |                |                |                |                |                |                |                |
| Velihela-OSF 900 ha          |                |                |                |                |                |                |                |                |                |                |
| Wadinahala-OSF 700 ha        |                |                |                |                |                |                |                |                | 1              |                |

Total area of recorded forests is 106952.7 ha.

P - presence of species

Figures - Number of individuals recorded in 2500 m<sup>2</sup> plots.

**Distribution of plant species in the forests in the Puttalam district**

The total area surveyed in the Puttalam District was 62,002.8 ha (Chilaw lake – OSF 300 ha, Sellankandal PR 4542.2 ha and Wanniyagama – PR 14417.8 ha). Twenty plots were investigated during four days. None of the 10 species of medicinal plants subjected to the survey, not even the saplings, were present.

**DISCUSSION**

These figures show that the plants in reference are constantly under human pressure not only as medicinal plants but due to other reasons also. Unfortunately, other than the meagre efforts made by the Nursery at Haputale which belongs to the Department of Ayurveda other efforts are grossly inadequate to meet the future pressures on the wild populations of medicinal plants. This presentation calls for urgent plans to develop the cultivation of medicinal plants on a national basis.

# SUSTAINABLE DEVELOPMENT THROUGH SUSTAINABLE USE OF

## BIODIVERSITY: ECONOMIC POLICY OPTIONS

Hemesiri B. Kotagama

### ABSTRACT

*Sri Lanka is persevering to achieve simultaneously, the development objectives of alleviating poverty and conserving the environment. Biodiversity is an environmental resource that Sri Lanka is richly endowed with which if sustainably used could contribute to sustainable development of Sri Lanka. Regrettably, there are powerful economic forces acting against conservation and use of biodiversity. This paper examines economic policy options that could be implemented to conserve and sustainably use biodiversity in Sri Lanka.*

*The concept of sustainable development has evolved as a development paradigm, that recognizes the need to conserve the environment such that future generations too would be provided with the same or better opportunities of development. Conservation of the environment is required because it contributes to development through its source, sink and global functions, of which some cannot be substituted by human creations.*

*Biodiversity is the diversity of plants and animals living on earth. As an environmental resource, it contributes to development through its multifaceted uses. These are direct uses for food, fibre, clothing, medicines and recreation etc, indirect uses of maintaining ecological functions, watershed protection etc, and optional uses of potential of biodiversity to be directly used in the future. Further people prefer the undisturbed existence of biodiversity too.*

*The term 'sustainable use of biodiversity' although widely used has not been precisely defined. Sustainable use of biodiversity systems could be defined as increased (or least non decreasing) use of biodiversity over time, whilst maintaining constancy of production of uses of biodiversity, resilience of the ecological system in supplying biodiversity and achieving equitable intra and inter-generational sharing of use of biodiversity.*

*At present what has been achieved in Sri Lanka in biodiversity conservation and use is the gathering of biodiversity information and development and implementation of strategies for conservation of natural habitats. Policies and strategies for biodiversity use have not been adequately addressed.*

*Sustainable use of biodiversity requires that the benefits of uses are larger than costs of conservation. Knowing the factors determining benefits and costs would enable to identify policies to promote increased benefits and reduce costs of biodiversity conservation and use. Biodiversity conservation is a land use economic policy issue. This*

*paper identifies the factors that determine the magnitude of the benefits from the pharmaceutical industry (number of plants endangered, probability of inventing a drug from a plant, rate of royalty payment, probability of appropriating values, market value of medicines, extent of land conserved) and the factors affecting the cost of biodiversity conservation as the value of development opportunities foregone on land. The opportunity cost of land depends on rationality of land use, policies affecting land use, land tenure etc. Specific policies to influence the above mentioned variables are identified in a policy matrix. This methodology can be used to identify economic policy to influence sustainable use of other biodiversity uses, such as provision of genetic material for plant and animal production improvements etc.*

## INTRODUCTION

Sri Lanka is persevering to achieve simultaneously, the development objectives of alleviating poverty and conserving the environment. Given the intricate mix of complementary and conflicting interdependencies between the two development objectives national policy decision making has become complicated. National policy decisions, proposed development plans and projects are often subjected to controversial public debate. Policy makers, (politicians and bureaucrats) and the public require scientific information to resolve these controversies amicably, such that pursuit to achieve national development is unhindered.

Sri Lanka is bestowed with a rich environmental/natural resource base. Biodiversity is one such resource that has vast potential economic value<sup>1</sup>. If biodiversity is sustainably used it could greatly contribute to the sustainable development of the country.<sup>2</sup> Regrettably, although biodiversity is valuable, there are powerful economic forces acting against its conservation which explains its loss.<sup>3</sup>

Figure 1 compares the biodiversity of Sri Lanka with other Asian countries. It is observed that Sri Lanka has a very high biodiversity and also a very high human density per unit land area.

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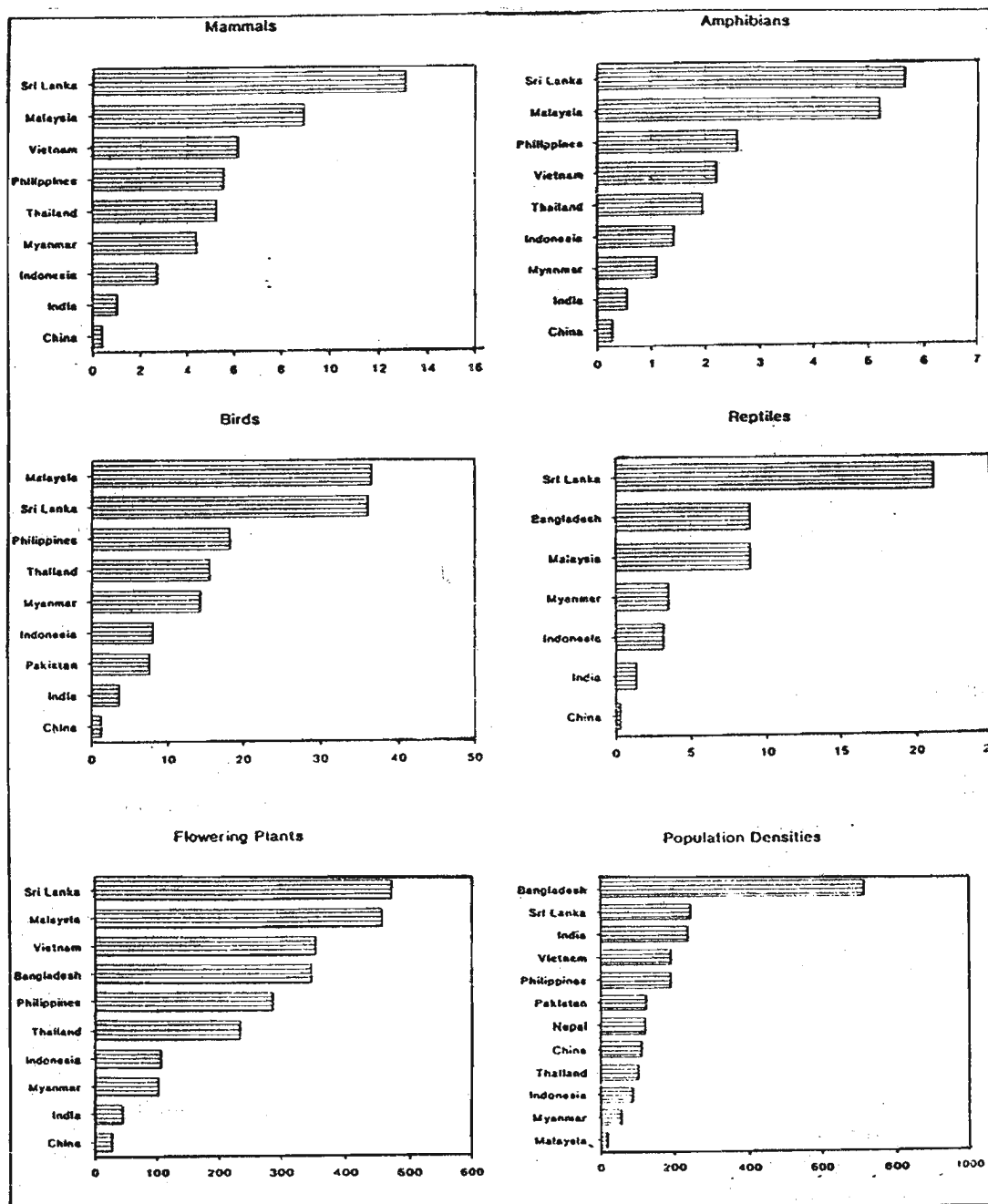
<sup>1</sup> However it needs to be recognized that biodiversity conservation could be a "Pandora's box", which when opened may uncover misery too !. To quote Nesiah (1995):

Biological pollution could be even more threatening than chemical or nuclear and chemical pollution. Preparedness to avert such disaster is required, whilst focusing efforts on the conservation and use of biodiversity.

<sup>2</sup> Sri Lanka is also a signatory to the International convention on the conservation of biodiversity. It makes Sri Lanka to commit to the international community to conserve biodiversity, given the global significance of biodiversity.

<sup>3</sup> The economic causes of biodiversity losses are development pressure due to population increase, market failures (property rights, externalities, uncertainty and irreversibility, market imperfections), policy intervention failure (ineffective positive interventions and unintentional negative interventions through fiscal, monetary, land policy etc).





Source : Natural Resources of Sri Lanka Conditions and Trends

**Figure 1 : Biological Diversity of Asian Countries (Ranked according to average number of species/10,000 sq.km)**

The increasing population pressure on limited land area has led to rapid degradation<sup>4</sup> of biodiversity which may continue unabated. Thus there is an imperative and impending need to take deliberate policy action to conserve and use at least the remaining biodiversity of Sri Lanka.

This paper examines economic policy options that could be implemented to conserve and sustainably use biodiversity in Sri Lanka. The paper first clarifies the concept of sustainable development, by considering the evolution of the concept as an economic development paradigm. Second, the role of biodiversity in achieving sustainable development is discussed within the framework of the role of natural capital in sustainable development. Third, the conceptual meaning of sustainable use of biodiversity is explored based on concepts of productivity, stability, and resilience of ecological-economic systems and inter-generational equity in sharing benefits of using biodiversity. Fourth, a logical framework is proposed to identify strategies for sustainable use of biodiversity based on the potential use of biodiversity in the pharmaceutical industry. Finally, economic strategies to sustainably use biodiversity in Sri Lanka are proposed on a policy matrix.

## **SUSTAINABLE ECONOMIC DEVELOPMENT**

Development as commonly understood is a process of increasing the satisfaction of human beings of a nation. Although the meaning of development is intuitively clear the concept of development has undergone an evolution through the addition of new operational attributes. The evolution of the concept of development is summarized in table 1.

In the decade of 1950 development was thought to be a process of growth in national income (i.e. the monetary value of commodities produced within the country in a given year). The basic presumption was that the higher availability of commodities and their consumption increase satisfaction of a nation's society. The experience of the 1960s decade was that increased national income per se had not achieved development. It was understood that "the rich were getting richer and the poor were getting poorer" although national income increased, resulting in discontent of the society. It was hence thought that development requires not only a growth in national income but also an equitable sharing of the national income among the population.

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<sup>4</sup> Globally, 10-20,000 species become extinct per year. Another estimate is that the world loses 100 species a day. In Sri Lanka biodiversity of natural forest has decreased due to loss of natural forest cover from 70% to 22% of the land area within a century. Of the flowering plants known in Sri Lanka 14.3% are considered threatened of extinction. Sri Lanka has had 305 known paddy varieties of which most are extinct. The genetic diversity of plantation crops too has drastically dropped. Of the more visible animals, within a century the elephant population has dropped from about 10,000 to 3,000.

**Table 1 : Evolution of the concept of sustainable development**

| Period | Operational Attributes of Development                                                                                                                                                                                                                                                                                  |
|--------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1950s  | Growth in national income.                                                                                                                                                                                                                                                                                             |
| 1960s  | Growth in national income + Intra-generational equity/fairness in the distribution of national income.                                                                                                                                                                                                                 |
| 1970s  | Growth in national income + Intra-generational equity in the distribution of national income + Improvement in the quality of life.                                                                                                                                                                                     |
| 1980s  | Growth in national income, Intra-generational equity in the distribution of national income + Improvement in the quality of life + Safeguarding human rights, women's rights, children's rights and democracy.                                                                                                         |
| 1990s  | Growth in national income + Intra-generational equity in the distribution of national income + Improvement in the quality of life + Safeguarding human rights + Environmental conservation to achieve inter-generational equity in the distribution of benefits of development , i.e. <b>Sustainable development</b> . |

During the periods<sup>5</sup> of 1970s and 1980s further attributes, such as the necessity to achieve an acceptable quality of life (i.e. availability of basic facilities of education, health/sanitation, shelter etc.), the necessity to safeguard human rights of various sectors of the society (women, children, social minorities etc.) were added as necessary attributes of development.

In the 1990s the concept of sustainable development emerged with the realization of the importance of the role of environment in sustaining the satisfaction of society over time. Sustainable development recognizes the environment as an integral resource that contributes to development by being:

- [1] A source of supply of renewable (e.g. natural forests, fisheries) and non-renewable (e.g. land, mineral deposits, biodiversity) resources;
- [2] A sink absorbing the wastes resulting from production and consumption of commodities (e.g. CO<sub>2</sub> sequestration by forests);
- [3] A source of supply of global support services (e.g. protection by ozone layer). Past development activities have led to rapid depletion of renewable and non-renewable resources, harmed the environment's ability to assimilate waste, and damaged global support services. Thus looms the uncertainty whether past development trends could be sustained in the future.

Sustainable development recognizes the human sentiment of wanting to take care of development needs of future generations. In this regard it is recognized that conservation (socially optimal use of environmental resources over time) of the environment is crucial

<sup>5</sup> The periods are only indicative and not empirically based. The periods are author's judgement of the period during which the different development concepts were publicly made aware in Sri Lanka.

in meeting development needs of the future generation. Thus sustainable development is most commonly defined as a process of development that “best satisfies the present generation without compromising the opportunities for future generations to satisfy themselves”.

Operationally sustainable development is where development has the following characteristics :

- [1] Economic growth (national income) increases or is constant over time.
- [2] Economic growth is subject to least variance over time
- [3] Economic growth if dropped could adjust rapidly to earlier growth rates.
- [4] The benefit of economic growth is equitably shared intra and inter generationally.

Some have argued that sustainable development could be achieved even through the conversion of the environment/natural resources to man-made capital. This, however, is refutable, for the following reasons:

- [1] Natural capital and man-made capital are not perfect substitutes particularly in supplying global support services.
- [2] Although man-made capital can be rebuilt if destroyed, natural resources cannot be rebuilt if destroyed. The destruction of natural resources is irreversible.
- [3] Man-made capital lacks diversity whilst natural capital possesses diversity that enables it to withstand shocks of change.

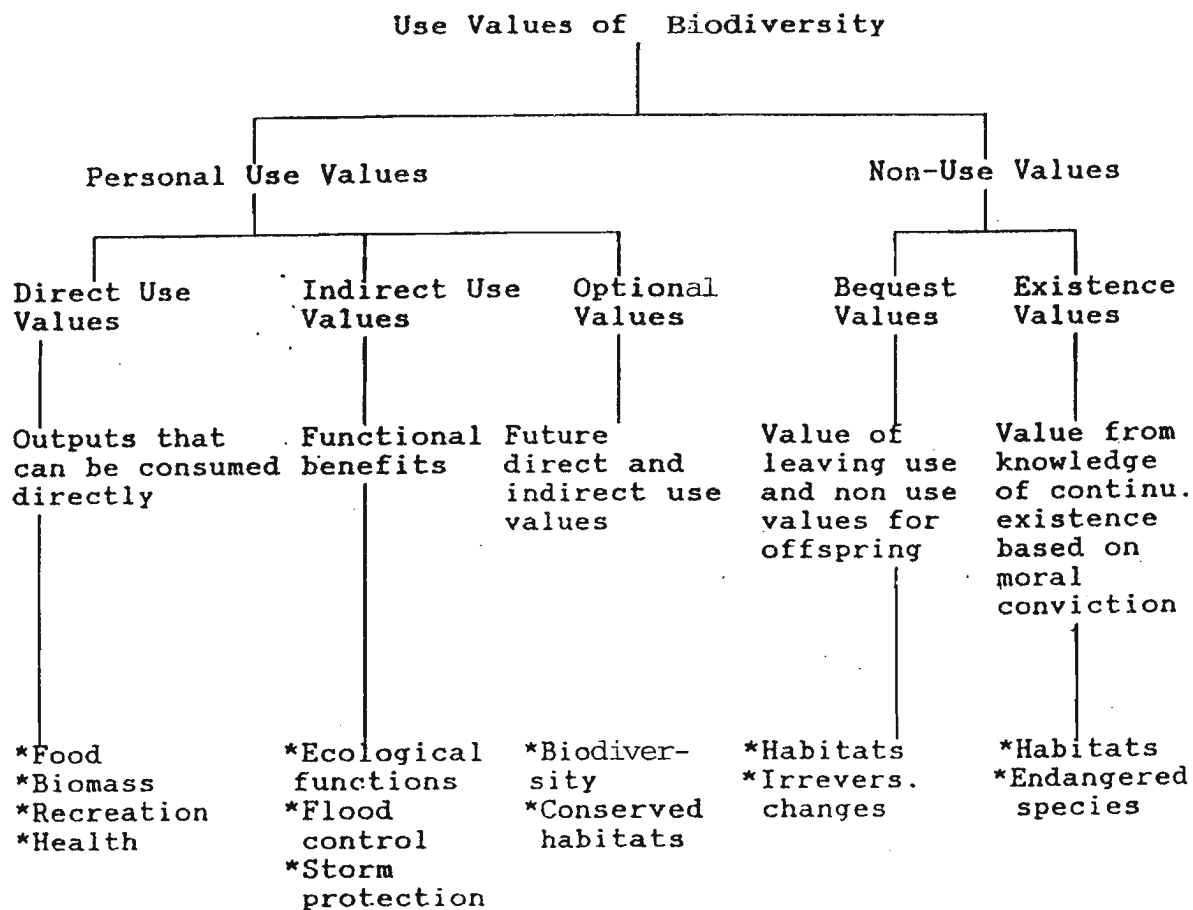
Thus conservation of natural resources is imperative to achieve sustainable development. Natural or environmental resources are free gifts of nature, i.e. non-producible by human beings. One such environmental resource is biodiversity.

## **ROLE OF SUSTAINABLE USE OF BIODIVERSITY IN SUSTAINABLE DEVELOPMENT**

Biodiversity refers to the variety of biological beings (plants and animals) on earth.<sup>6</sup> Biodiversity is a resource that could be used to produce commodities that could satisfy human beings. Thus sustainable use of biodiversity could contribute to sustainable development. The probable human uses of biodiversity are portrayed in figure 2.

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<sup>6</sup> There are broadly three levels of biodiversity; genetic variation within species, the variety of species within a habitat and the variety of habitats in the world. Biodiversity could be natural as found in natural habitats or artificial as found in artificial habitats that human beings have created. Estimates on the number of species on earth vary from 5-50 million of which only 1.4 million have been identified.



Source: Modified from Munasinghe (1992).

**Figure 2: The probable uses of biodiversity.**

Human use of biodiversity could be either personal or non-personal. In personal use of biodiversity individuals gain satisfaction by meeting individualistic/selfish desires. In non-personal use biodiversity is not used by individuals; instead individuals derive satisfaction on the feeling that it will be available for use by some other individual, particularly of the next generation.<sup>7</sup>

Personal use of biodiversity could take three forms, viz; direct use, indirect use, and optional use. Direct use refers to the direct consumption of products of biodiversity either destructively or non-destructively. Examples of destructive use of biodiversity are harvest of non-timber forest products such as food, fibre, medicines etc. from forests.<sup>8</sup> Non-destructive use of biodiversity is exemplified by enjoying the scenery of diverse nature, use of biodiversity for education, photography, eco-tourism etc.

Indirect use of biodiversity is through the maintenance of ecological functions. For example the maintenance of food chains, regulation of pests in cultivated crops through natural predators etc. Further, habitat conservation of biodiversity could indirectly contribute to preservation of watersheds.

Optional use of biodiversity refers to the satisfaction gained through opting to conserve diversity with the hope that in future it could be used directly or indirectly. Conserved biodiversity could probably be used as a source of genetic material in crop or livestock improvement or in extracting chemicals for pharmaceutical purposes.<sup>9</sup>

Non-personal use of biodiversity could take two forms viz. bequest use and existence use. Bequest use is where people gain satisfaction on the knowledge that biodiversity exists to be used by future generations. Existence use is where people gain satisfaction on the knowledge that biodiversity exists for its own sake-- for the sake of the ecosystem.

Which of these values are important to a nation's society would depend on its stage of development and the cultural association with environmental conservation. Generally poor developing countries would value more the direct uses that give immediate benefits, whilst affluent developed countries would value the use of existence of biodiversity.

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<sup>7</sup> Biological resources are different to biodiversity as a resource. The value of biodiversity as a resource is the difference between a range of genes/species/habitat and less diverse range of genes/species/habitat. Hence the value of biodiversity is not the total value derived from a habitat.

<sup>8</sup> Around 20,000 plant species are believed to be used medicinally in the world and around 500 plant species in Sri Lanka. About 80% of the world population depends on traditional medicines. Most traditional medicines are plant based. One fourth of all prescriptions in developed countries are based on plants, including 21 mainstream drugs (Fling, 1991) Villagers in the periphery of the Knuckles forest range use 48 forest plant types for food, medicines, roping material etc.

<sup>9</sup> If Paddy yield in Sri Lanka could be increased by 1% biotechnological means using indigenous biodiversity it would generate a value of Rs. 160 million per year and feed 174000 people.

**CHARACTERISTICS OF BIODIVERSITY SYSTEMS THAT ARE SUSTAINABLY USED.**

The term 'sustainable use of biodiversity' although widely used has not been precisely defined.<sup>10</sup> The often quoted definition of sustainable development can be modified to define sustainable use of biodiversity as follows:

"Use of biodiversity such that needs of the present generation are best met without compromising the ability of future generations to meet their own needs."

This definition although philosophically appreciable to provide broad macroeconomic policy guidance, is too vague and therefore not useful in guiding micro level system management for sustainable use of biodiversity. A definition of sustainable use of biodiversity to be useful (to guide policy and management decision making), should clearly identify characteristics/attributes that are comprehensible, observable and measurable.

Biodiversity is a harvestable and usable commodity as much as an agricultural commodity. Hence, the concept of sustainable agriculture should be able to provide guidance in defining sustainable use of biodiversity. Sustainable use of biodiversity could be defined as increased (or non decreasing) use of biodiversity over time, whilst maintaining constancy of production of uses of biodiversity, resilience of the ecological system in supplying biodiversity and achieving equitable intra and inter-generational sharing of the use of biodiversity. These are listed as follows and are graphically portrayed in figure 3.

- [1] Productivity: Increased (or constant) use value of biodiversity per unit area of habitat, over time (fig. 3.1)
- [2] Stability: Constancy of productivity is maintained, in circumstances of minor and normal changes in the environment, over time (fig. 3.2)
- [3] Resilience: Maintenance of productivity in circumstances of major disturbances in the environment, over time (fig. 3.3)
- [4] Equity: Sharing of the uses of biodiversity equitably intra and inter-generationally (fig. 3.4)

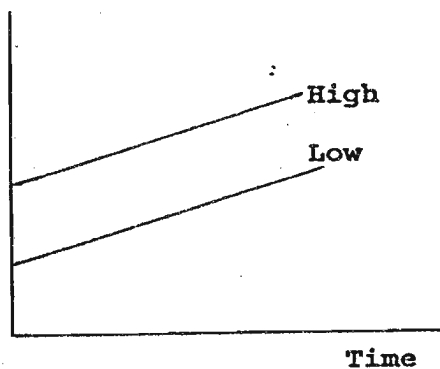
Sustainable use of biodiversity requires that the above conditions are met simultaneously. Sustainable use of biodiversity may also be defined as use of biodiversity without leading to reductions of the future productive capacity of biodiversity habitats. This paper focuses only on the first criterion of increased use value of biodiversity per unit area over time. The measurement of other criteria has not yet been developed.<sup>11</sup>

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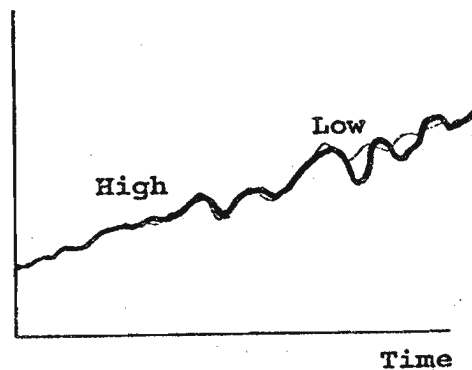
<sup>10</sup> Personal communication with Dr Sarath Kotagama and confirmed on survey of literature available in Sri Lanka.

<sup>11</sup> This could be developed by ecologists.

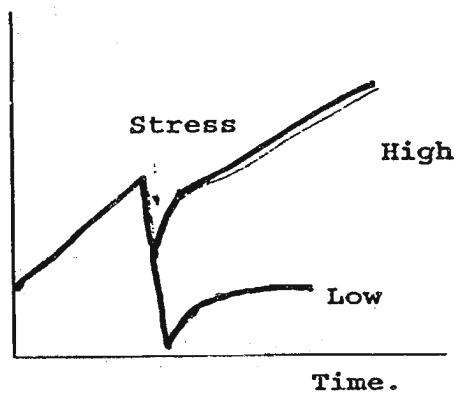
## (3.1). PRODUCTIVITY.

Value of  
Biodiversity.

## (3.2). STABILITY.

Value of  
Biodiversity.

## (3.3). RESILIENCE.

Value of  
Biodiversity.

## (3.4). EQUITY.

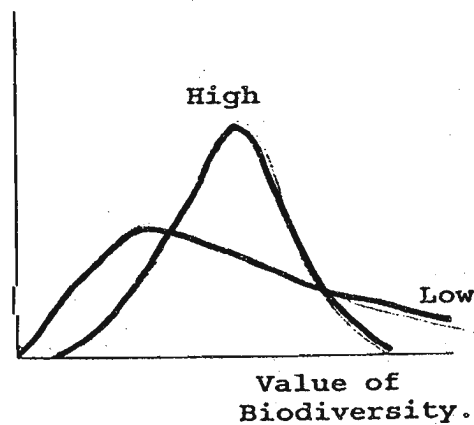
No. of  
Beneficiaries.

Figure 3 : Characteristics of Biodiversity Systems that are Sustainably Used.



## STRATEGY CYCLE FOR SUSTAINABLE USE OF BIODIVERSITY.

The sustainable use of biodiversity involves the operation of a cycle among inter-linked activities. These activities are identified in figure 4. Biodiversity could be sustainably used only if the activities are cyclically connected such that owners and contributors to the use of biodiversity are adequately (to forego opportunity costs) compensated and the compensations are equitably shared.

For sustainable use of biodiversity, it is initially required that the society through intellectual deliberation and awareness creation understands what is biodiversity and why it should be conserved<sup>12</sup>. The outcome would be the society being convinced that biodiversity has an economic value and thereby needs to be sustainably used. The activities thereon ought to be pragmatic.

It is first required to have information on the existing biodiversity. This information could be collected through research/sample surveys of fauna and flora.<sup>13</sup> Upon having information on existing biodiversity decisions could be made on optimal extent on localities etc. to be conserved for biodiversity.<sup>14</sup> Conserved biodiversity requires to be used. Some biodiversity uses, such as genetic improvement of agricultural production possibilities would require the application of biotechnology.<sup>15</sup>

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<sup>12</sup> There isn't yet a precise understanding of what is biodiversity. The absence of precise definition and measure of biodiversity hinders effective management. The difference between biological resources and biodiversity remains ambiguous. The ethical objective of preserving all existing biodiversity is often mixed-up with the anthropocentric economic objective of conserving what is of value to human beings.

<sup>13</sup> Information on biodiversity would help in its conservation through priority setting of habitats to be conserved and also in expediting the use of biodiversity. The important fact to consider is that information gathering is intellectually stimulating and brings personal glory. Thus it has its internalized incentive. On the contrary biodiversity conservation implementation is more a public activity with most benefits external to those involved. Both activities, research and implementation, compete for the same limited resources. In the past interests and investments have been more on research and information gathering and rather less on implementation of biodiversity conservation. This however, would be corrected with implementation of the biodiversity action plan.

<sup>14</sup> It need to be recognized that decisions on biodiversity conservation (e.g. selection habitats and extent) should not be based solely on ecological criteria but should also recognize socio-economic criteria. Some such socio-economic criteria are to consider the possibility of maximizing complementary benefits, appropriating use values in the shortest possible time, the eminence of threat, comparative advantages, likelihood of success etc. An approach of conserving extent of 'safe minimums' is most appropriate.

<sup>15</sup> Although biodiversity is most found in poor countries, biotechnology is most found in rich countries. Therefore cooperation between rich and poor countries is required. This requires processes of biodiplomacy.

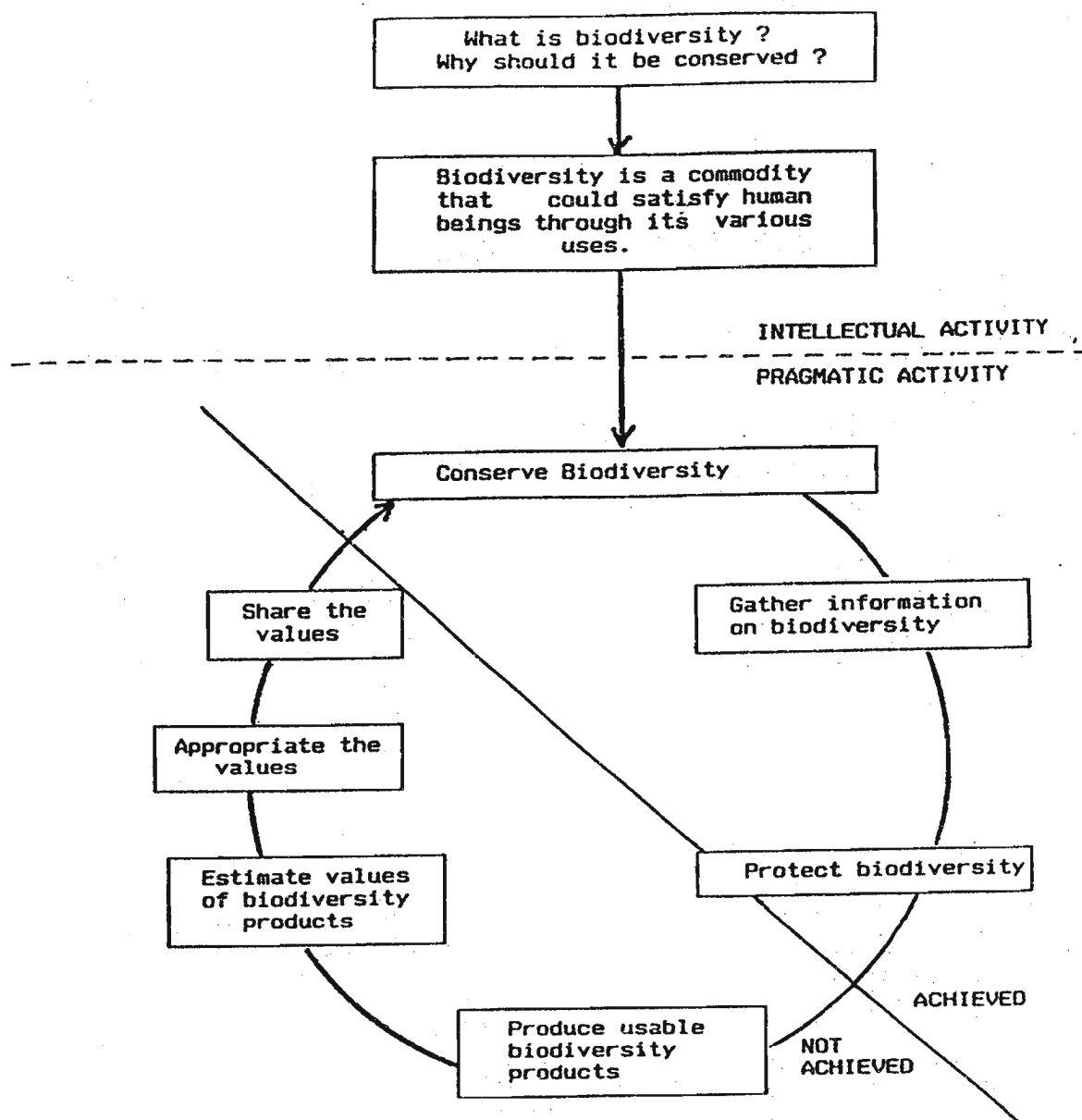


Figure 4 : Strategy Cycle for Sustainable Use of Biodiversity

Next the values of the products need to be known. Since the markets do not value some biodiversity uses (indirect use, option use, bequest use, existence use) values may have to be estimated.<sup>16</sup> These values then have to be appropriated.<sup>17</sup> The appropriated values have to be finally shared among the custodians and contributors to generating use values of biodiversity.<sup>18</sup>

**Sustainable use of biodiversity requires:**

- [1] The completion of the cycle of activities.
- [2] The benefits of biodiversity uses are larger than the costs of biodiversity conservation and the benefits and costs are equitably shared.

Policy should be implemented that the cycle is effectively completed. However, at present what has been at least moderately achieved is the formal gathering of biodiversity information and the development and implementation of some strategies for conservation of mostly natural habitats. Policies and strategies for biodiversity utilization have not been adequately addressed. Even if addressed it is mostly focussed to the aspect of technology rather than socio-economics. To quote The Strategy for the Preparation of the Biodiversity Action Plan (1995):

“As regards the use of biodiversity, both traditional and non-traditional uses, science and technology have a vital role to play in determining sustainable levels of use and developing methods of optimizing yields from in situ and ex situ sources. Much has to be done in developing these aspects of science and technology”.

The assertion of this paper is that whilst development of technology is necessary, it is not sufficient to promote sustainable use of biodiversity. As the strategy cycle for biodiversity conservation and use suggests the socio-economic aspects of developing national and

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<sup>16</sup> To quote the Strategy for Biodiversity Action Plan of Sri Lanka: “It would be useful if some quantified economic value could be placed on the components of biodiversity, not only of those components that are (directly) used, but also the opportunity cost of conserving biodiversity. Such an economic valuation is a longstanding conundrum, but one that deserves to be attempted, however difficult the task and however imperfect the result achieved”.

<sup>17</sup> Biodiversity prospecting refers to the process of appropriating commercial values of biodiversity products. The most known example of biodiversity prospecting is between Costa Rica's National Biodiversity Institute (INBio) and the US based pharmaceutical firm Merck & Co., Ltd. The agreement between the two parties was financing an initial research budget of US\$ 1,135,000 (for 2 years) and royalties would be paid to INBio of any invention of a commercial product. INBio to contribute 50% of the royalty to the government's national park fund for the conservation of those.

<sup>18</sup> The highest biodiversity is found internationally and nationally among the poor nations and poor people. Tropical forests that cover 7% of the earth's, surface contain 50% of all species. However, biotechnology is available in the rich countries. This suggests the need for cooperation between rich and poor countries which would allow the use of biodiversity. What is equally important is the sharing of the value of biodiversity. Currently developing country germplasm adds US \$ 50 billion/year. Developing country germplasm adds US \$ 32 billion / year to the pharmaceutical industry in USA. It has been estimated that medicines derived on indigenous knowledge accounts for US \$ 43,000 million of which less than 0.001% goes to indigenous people.

international markets, valuing biodiversity, appropriation of such values and equitable sharing is necessary for sustainable use of biodiversity.

### **ECONOMIC POLICY MODEL ON SUSTAINABLE USE OF BIODIVERSITY**

For sustainable use of biodiversity it is necessary that the benefits of use are larger than costs of conservation. This section examines the factors that determine the benefits of biodiversity use and costs of conservation. Knowing the factors would enable to identify policies to promote the sustainable use of biodiversity.

Biodiversity conservation is a land use economic policy issue. The benefit of biodiversity conservation is the ability to derive satisfaction through use of biodiversity directly, indirectly etc. Only the use of biodiversity in the pharmaceutical industry is considered, in this paper for convenience.

The cost of biodiversity conservation is the value of development opportunities foregone on land. The opportunity cost of land would be dependent on the stage of development of the country, on macro-economic variables (fiscal policies), welfare policies, institutional strengths (property rights) etc.

According to estimates by Pearce and Morgan (1994) the option value of a hectare of land on biodiversity conservation for use in developing medicines globally, is 20 US\$ per hectare.

Tentative estimates made by the author suggest that flowering plants of natural forests have an option value of 15 US\$ per hectare per year in developing medicines.<sup>19</sup> This is well below the opportunity cost of land under tea (Rs. 3000/hectare/per month) near Sinharaja forest. Hence the phenomenon of forest encroachment is explained. However, the estimated value of biodiversity is only one component of the total economic value of biodiversity. Nevertheless, the magnitude of the challenge to sustainable conservation and use of biodiversity is indicated.

### **PROPOSED ECONOMIC STRATEGIES FOR SUSTAINABLE USE OF BIODIVERSITY**

Policies to promote sustainable use of biodiversity should either increase the benefits from biodiversity conservation or reduce the opportunity cost of land allocated for biodiversity conservation. Table 2 identifies the variables that affect the benefit and costs and gives policy suggestions. The suggested policies are not exhaustive; perhaps more could be added. The purpose of the policy matrix is to provide a logical framework to methodically derive rational policies for sustainable use of biodiversity. In addition to the proposed strategies, policies in the matrix, sustainable biodiversity conservation and use could be promoted by conducting environmental impact assessments on policies, plans and projects,

<sup>19</sup> The estimation was based on the following.  $N_R = 480$  (number of flowering plants endangered),  $p = 0.0001$ ,  $r = 0.05$ ,  $a = 0.5$   $V = 720$  billion US\$,  $n = 40$ ,  $H = 1443420$  hectares of natural forest.

by incorporating the total economic value of biodiversity to national income accounting such that values of biodiversity are recognized in national decision making.

A policy of promoting people's, participation at all levels of biodiversity conservation and use would be useful.

The benefit of conservation of a hectare of land for biodiversity use in the pharmaceutical industry in developing medicines/drugs could be expressed as :

$$V_{mp}(L) = \{N_R \times p \times r \times a \times V/n\}/H$$

$V_{mp}(L)$  = Value of unit of land per annum allocated for biodiversity conservation. The  $V_{mp}(L)$  of tropical forest is calculated based on Pearce & Morgan (1994). Figures within parenthesis are estimates given by Pearce & Morgan (1994), which are only indicative.

$N_R$  = Number of plant species at risk of extinction. [60,000 plants per 50 years]

$p$  = Probability of inventing a drug from a plant. [1/10,000 to 1/1000]

$r$  = Rate of royalty [0.05]

$a$  = Probability of appropriating values [0.1 to 1]

$V$  = Market value of one of the following

1. Market value of trade in medicinal plants. [24.4 billion US\$/per year, world, 1980]
2. Market value of plant based drugs. [84.3 billion US\$, world, 1985]
3. Value of avoided deaths by use of plant based drugs. [720 to 1008 billion US\$ per year, considering value of statistical life as 4 million US\$ in 1990 and lives saved as 42000 per year].

$n$  = Number of drugs based on plant species [40 in USA]

$H$  = Extent of land under biodiversity conservation. [1 billion hectares approximately the area of tropical forests].

Table 2 : Policy Matrix for Sustainable Conservation and Use of Biodiversity

| Policy Variable                                          | Implication of change of variable                                            | Policy Prescription                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|----------------------------------------------------------|------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| A. Increasing the benefits of biodiversity use           |                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| 1. $N_R$ = Number of plant species at risk of extinction | Higher the value of $N_R$ higher would be the value of biodiversity use      | Identify biodiversity (habitats, species) under imminent threat of extinction of large numbers of plants, animals for conservation                                                                                                                                                                                                                                                                                                                                                               |
| 2. $p$ = Probability of inventing drug from a plant      | Higher the value of $p$ higher would be the benefits of biodiversity use     | Invest on education and research on biotechnology<br>Liaise with developed countries on research                                                                                                                                                                                                                                                                                                                                                                                                 |
| 3. $r$ = Rate of royalty                                 | Higher the value of $r$ higher would be the benefits of biodiversity use     | Gather indigenous knowledge on use of biodiversity to support biotechnological research<br>International negotiations<br>Establish intellectual property rights (biodiplomacy).<br>Estimate total economic value of biodiversity for royalty payments                                                                                                                                                                                                                                            |
| 4. $a$ = Probability of appropriating values             | Higher the value of " $a$ " higher would be the benefits of biodiversity use | Address local and global market failure of biodiversity value appropriation, particularly intellectual property rights on biodiversity, and smuggling of biodiversity<br>Address local market failure due to open access, insecure land tenure, high uncertainty and transaction costs.<br>Address issues on local intellectual property rights on indigenous conservation and knowledge.<br>Develop effective biodiversity prospecting.<br>Link international aid to biodiversity values (GEF). |

Table 2 : *Contd.*

| Policy Variable                                                                                                                                                                                | Implication of change of variable                                                                                              | Policy Prescription                                                                                                                                                                |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 5. $V$ = Market value one of the following<br>1. Market value of trade in medicinal plants<br>2. Market value of plant based drugs.<br>3. Value of avoided deaths by use of plant based drugs. | Higher the value of $V$ higher would be the benefits of biodiversity use                                                       | Adopt environmental valuation techniques to estimate total economic value of biodiversity.<br><br>Market prices may not be controllable when decided in world markets.             |
| 6. $n$ = Number of drugs based on plant species                                                                                                                                                | Higher the value of $n$ lower would be the benefit of biodiversity                                                             | Regulate supply, depending on elasticities of supply and demand for biodiversity.                                                                                                  |
| 7. $H$ = Extent of land under biodiversity conservation                                                                                                                                        | Higher the value of $H$ lower the value of use of biodiversity                                                                 | Minimize the area under conservation<br><br>Select representative sample areas<br><br>Consider other forms of conservation <i>ex situ</i> , home gardens, gene freezing etc.       |
| B. Reducing the Opportunity Cost of biodiversity conservation                                                                                                                                  | Higher amounts of land, and land most suitable for agricultural productivity etc. would increase the opportunity cost of land. | Do scientifically rational land use planning.<br><br>Select areas that give complementary benefits such as watershed protection, potential for eco-tourism.                        |
| 1. Land use                                                                                                                                                                                    |                                                                                                                                | Select only restricted sample areas for conservation, where biodiversity is very high, high endemism, highly threatened habitats or unique and livelihood of conservation is high. |
| 2. Economic policy distortions                                                                                                                                                                 | Economic policy favoring forest land clearing will increase the opportunity cost of land.                                      | Remove economic policy distortions supporting clearing of forests, supporting mono-cropping                                                                                        |
| 3. Institutional local                                                                                                                                                                         |                                                                                                                                | Establish property rights to avert open access to land.                                                                                                                            |
| 4. Institutional international                                                                                                                                                                 |                                                                                                                                | Compensate local population on opportunity cost of land on biodiversity conservation through international transfer of funds on buffer zone management activities etc.             |

## CONCLUSION

The paper examined the economic policy options available to promote sustainable use of biodiversity. The focus was mainly on proposing a logical framework that could be used for the above purpose. Only benefits from the use of biodiversity in the pharmaceutical industry have been considered. The logical framework can be used to examine further policies required to promote sustainable use of biodiversity other than in the pharmaceutical industry.

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## Note by Editor

The author has confined his estimate of the economic value of biodiversity to the option value in relation to the possible future use of plants in the pharmaceutical industry. In Sri Lanka's context this is probably the least important criterion for making a realistic valuation of the country's natural forests. The author has used Sinharaja, a wet zone forest, as the example. The importance of these forests for soil conservation, water



recharge, power generation, flood control, etc. would no doubt provide estimates of economic value far in excess of the option value for pharmaceuticals. This view was expressed during the discussion that followed the presentation of the paper.

**LINKS BETWEEN SUSTAINABLE DEVELOPMENT OF FOREST  
RESOURCES AND CONSERVATION OF BIODIVERSITY**

## CONSERVATION AND DEVELOPMENT IN HUMID TROPICAL FORESTS

*Michel Batisse*

Apart from the interest and pleasure of participating in this regional seminar in Asia, it is a particular privilege for me to celebrate with you the fortieth anniversary of the 1956 Kandy Symposium on Tropical Vegetation, which took place in the framework of a UNESCO programme which I had the honour to conduct.

The subject today is forestry. I am not a forester, nor even a biologist, but originally a physicist who has devoted most of his time to natural resources and environmental issues. I shall not therefore venture into technical questions of forestry and will confine myself to more general remarks.

Forestry has always struck me as being a subject where generalizations could be hazardous. I come from a country which, a thousand years ago, was almost entirely covered with deciduous temperate forests. It was only during the eleventh century, largely under the drive of the monasteries, that land was deforested and put under cultivation. The wealth and strength of France has largely been derived since then from its agricultural capacity and this is still true to a certain extent today, since we are the second largest exporter of agricultural products in the world, after the United States. Thus, in many ways, the place that France has acquired in history has been an outcome of its deforestation. This apparent paradox holds true to some extent for other temperate climate countries. A reverse paradox occurs today since, as the European Commission and the world market consider that we produce too much, land is set aside and the forest cover is increasing.

The situation is different in dry climates. At the time of the first Kandy symposium, I was working for UNESCO in the Middle East on another scientific programme dealing with arid zones. Aridity, in much of these areas, has been aggravated over time, or has even been the result of deforestation, soon followed by loss of soil through erosion and a perturbed water regime. This toll paid to historical development has occurred all over the Mediterranean region and the Middle East. The Greek civilization provided the roots of Western civilization, but I doubt whether it could have emerged if the country had been in the denuded state in which it is now. The famous cedar tree can hardly be found in Lebanon today, although it is the emblem of its flag. Many parts of India and Africa have indeed suffered the same fate. Thus we know the evils of deforestation under dry climate.

When we come to the humid tropics, we find that there is now an open debate on the matter. On the one hand, there are those who wish to preserve what is left of the tropical forests for the sake of conserving Biodiversity, ensuring a major sink for CO<sub>2</sub>, and maintaining ecosystem functions for soil and water conservation. On the other hand, there are those who claim that if Europe and the United States have developed while

logging their forests, tropical countries which badly need to produce food and commodity exports are perfectly entitled to transform their forested lands into agricultural and urban areas. Clearly, the debate is more subtle, but when you hear some statements at the diplomatic level made in New York or Geneva, we are not far from this simplistic approach. Here again, generalizations are hazardous.

Our terminology itself may lead to such generalizations, since reference is constantly made to tropical forests in the broad sense, without introducing the necessary distinction between tropical rain forests, tropical moist deciduous forests and tropical montane forests, not to mention the various types of tropical dry forests and woodlands. As much of the debate tends to focus on tropical forests in general and as many of the available data and statistics do not make distinctions among them, some misunderstandings are bound to arise in international fora.

Generally speaking, perspectives concerning tropical forests have changed dramatically over the forty years since the 1956 Kandy symposium. In the first place, the world population has more than doubled and most of this increase has taken place in the developing world, including South and South-East Asia. According to FAO (Lanly 1996), the total tropical forest cover of the world has decreased from 2,281 million hectares (Mha) to 1,660 Mha, which represents a reduction of some 27%. This is somewhat compensated by an increase through plantations - however, not exceeding 40 Mha. Today, tropical forests in Ivory Coast cover only 18% of the area they were covering forty years ago. The reduction is about the same in Costa Rica. Considering more specifically the tropical rain forest, its total cover has decreased during the same period from 868 Mha to about 680 Mha. This decrease of 22% of the most complex and intriguing terrestrial ecosystems on Earth has been practically without compensation. Even more striking are the changes which have taken place in international trade of tropical timber. The removal of tropical broadleaved timber amounted to 42 million cubic meters in 1956 and today amounts to some 175 million cubic meters representing a more than fourfold increase. For the same period, the export of tropical timber jumped from 8 million cubic meters of log equivalent to more than 90, representing a more than tenfold increase. For tropical forests in general, the current rate of deforestation amounts to 15.4 Mha per year. Considering specially the tropical rain forest, most of it is located in Latin America. The Asia Pacific region has approximately 25%, but it is here that deforestation rates have been the highest, with over 21 Mha between 1981 and 1990.

In the light of this situation, it should be no surprise to note that while the concern for conservation of tropical forests was relatively secondary forty years ago although a number of people were already calling for action - this concern has now become top priority in the international debate amongst the different actors involved (Poore 1989). Curiously, while the debate would appear to be of concern to the forestry community and while it could have been expected that some formal agreement would be reached from within this community, it is from outside and for other considerations that major international decisions have been taken. These are embodied in two world Conventions

adopted at the UN Rio Conference in 1992 and which have now entered into force, namely the Convention on Climate Change and the Convention on Biological Diversity, the latter not yet ratified by some countries, including the United States. Both Conventions have indeed a considerable impact on the forestry debate.

The basis for the Convention on Climate Change is the fear of an increase in the greenhouse effect which controls the mean temperature of the Earth's surface, resulting particularly from the increase in the carbon dioxide level in the atmosphere. As we all know, vegetation, especially forests with their high biomass, have a net CO<sub>2</sub> absorption and thus tend to reduce its atmospheric concentration. Tropical forests of all kinds have the potential to sequester the largest amounts of carbon, more than 80% of what can be sequestered by all forests of the world. Forests of tropical Asia account for more than one-third in the balance. Temperate forests account only for 17% and boreal forest for a mere 3%.

However, deforestation without plantations obviously reduces this major carbon sink, which is second only to the sink offered by the oceans. Because of their energy requirements and of the magnitude of deforestation, tropical countries at the moment are more a source of carbon (from any origin including, of course, fossil fuels) than a sink, and this is particularly the case in Asia with its high population density.

Naturally, forests which are not affected by human activity continue to play their role as carbon sinks. But the question is: What can be done to mitigate the carbon loss in tropical forests and to enhance its fixation? Three management options are possible, which can obviously be combined within a country.

The first consists in **conservation management**. It simply means reducing carbon emissions, either through controlling deforestation, using sound forest management practices, with appropriate pest and fire control, as already achieved in a number of countries in Asia like India or Thailand, or through forest protection and conservation by means of various types of protected areas, particularly in those areas with large biomass such as the rain forests. This first option can be adopted without any delay and can therefore be considered as a short-term option.

The second option consists in **carbon storage management**. This can be achieved through plantations, forest regeneration, development of tree cover, etc. and can be considered as a medium-term option.

Finally, the third option consists in what is called **substitution management**. The idea is simply to use wood instead of fossil fuel. Since the trees sequester carbon, burning them and regrowing them will amount to zero carbon emission, while burning fossil fuels will produce a net positive emission. This may sound somewhat paradoxical at first glance since it encourages fuelwood consumption, but the challenge is naturally to maintain the

total biomass. Such a substitution is a long-term option which cannot be generalized overnight since it requires a plantation strategy.

According to the Intergovernmental Panel on Climate Change (IPCC 1995) the combination of the first two options could sequester up to 15% of the foreseen emissions of fossil fuel between today and 2050. Tropical countries have therefore the greatest long-term potential for carbon sequestration by protecting lands for regeneration, slowing deforestation and developing agroforestry. The share of Asian tropical countries in this process is approximately one-third of the world potential.

Thus, in many ways and somewhat unexpectedly, forests will be at the forefront in the strategies which all countries will have to follow to abide by their obligations under the Convention on Climate Change. This does not mean that the expected global warming will itself constitute a major problem for tropical countries, and tropical forests, including the rain forests in particular, will be more affected by changes in land-use than by climate change, at least as long as deforestation continues at the current high rate.

The other international agreement having major consequences for tropical forestry is the Convention on Biological Diversity. Originally, this Convention was simply meant to co-ordinate and encourage the conservation of nature. The use of such a broad concept as biological diversity opened indeed a Pandora's box during the negotiations since the issue became not only the conservation of biological resources but also their use. In addition the term *biological diversity* refers to much more than what is usually covered by the term *nature conservation*. Biodiversity covers the entire spectrum of living entities or systems, ranging from genes and cells to individual organisms, species and populations, and to communities, ecosystems, landscapes and biomes. Biological systems are hierarchical and diversity appears at every level of this hierarchy, from DNA molecules to the biosphere itself. Biodiversity therefore covers not only the immense variety of life forms but also their interactions. In fact, it covers so many things that it could be considered as a rather confusing concept, something like lumping together electrons and atoms with stars and galaxies in the physical world. In this respect, it may seem extraordinary that a world convention could be signed on such a broadly defined subject. When one considers the use of biodiversity at the molecular and cellular level, one enters the realm of biotechnology with its formidable economic, technological, ethical and legal implications.

But even at the species level, biodiversity is far from being clearly defined since we keep hearing that only 1.4 million species have been described out of a total which has been guessed at being between 10 million and 100 million (Wilson 1992). Clearly, most of these unknown species, which are microscopic, will never be known and we could assume that they will be able to survive if ecosystems of sufficient size and variety are conserved on the planet. We must not forget, that any one of these minute creatures could do a lot of harm, as the HIV virus demonstrates, or possibly a lot of good. Foresters have to cope with possible pests of this kind but their role is clearly focused on

management at the ecosystem level, considering not only trees but the variety of plant and animal species associated with them.

When biodiversity is assessed at the world level, it is generally stated that tropical rain forests, which cover only 6% of the land surface of the planet, contain more than half the total number of terrestrial species. Since, as we have noted, this total number is unknown, such a statement is only based on some local extrapolations relating to species of a reasonable size, such as trees, epiphytes, insects, arthropods, birds, mammals, etc. But this is the diversity which concerns us most from an economic, aesthetic and ethical view point, and which provides a good indication of the health of ecosystems. It can be reaffirmed that tropical rain forests constitute the major repository of known and unknown terrestrial biodiversity and should be conserved for that reason at all costs.

Conservation does not necessarily mean strict protection from any human interference and from any economic use. Some studies made in Latin America indicate that some conservative uses of the tropical rain forest, such as collecting non-timber products or ecotourism, can bring more benefits to the local population than clear cutting. This supposition cannot however be generalized and applies more to ethnic groups and poor rural populations than to wealthier people who can venture into agricultural activities. One must avoid a somewhat naive Rousseauist approach and rather promote multiple activity systems ensuring a *critical mass* of income.

The issues at large for conservation are the control of human activities and the size of the ecosystems concerned. Destruction of the rain forest is generally due to clearance and burning to expand agricultural land and cattle ranching. Unfortunately, most of the soils thus denuded are not fit for continuous agriculture - contrary to what happens in temperate countries or in some tropical deciduous forests - and the traditional method of slash-and-burn cultivation often turns out to be a self-defeating process. Foresters tend to claim that they have little responsibility in deforestation since they follow sound management practices, including selective logging or tree harvesting. Unfortunately, this is not quite true since the construction of logging routes opens the way for agriculturists and also since forestry practices - especially when operating abroad - are far from being sustainable. Large concessions have been given to American, European and Japanese companies which today are still creating irreversible damage to rain forests in Asia and elsewhere. Some Asian countries are themselves now holding concessions abroad, as for example, in Surinam with little guarantee of sustainable management. Incidentally, in a country like Canada very concerned with environmental issues, clear cutting of the unique temperate rain forest of British Columbia, with its spectacular conifers, is still going on. Equally disturbing are the mining and oil prospecting activities which nowadays invade even national parks in Latin America (for example, Yasuni in Ecuador or Manu in Peru), in Africa (for example, Mount Nimba in Guinea or Tai in the Ivory Coast), in Queensland in Australia, or in Irian Jaya in Asia. The argument that sufficient patches of the forest are always left behind to maintain biodiversity has to be viewed with extreme caution. All scientific experiments made on the subject, for example, near

Manaus in Brazil, show very clearly that biodiversity can be drastically reduced when the forest *islands* which are left are too small. This has also been proven from paleobotanical records when islands have been separated from the mainland through sea-level rise. At the same time, natural regeneration of the full array of biodiversity of a deforested area is an extremely slow process under tropical conditions. It may well take more than a hundred years - the Angkor temples area in Cambodia, which was abandoned 500 years ago, has still not fully recovered its original richness.

While much more could be said about the imperative need to manage tropical forests in a sustainable manner and to do the utmost to protect the remaining stands of the rain forests, the two world conventions which have been mentioned include one particularly important feature: they contain a provision for the financing of action in favour of the developing countries. For the time being, this is carried out by the Global Environment Facility (GEF) which can finance the *incremental cost* of measures taken by countries to reduce carbon emissions or to protect biodiversity. This may not be a cure for all evils but represents a major step forward by the international community, with most of the financing coming from the industrialized countries which have probably been those who have benefited most from the tropical forests in the last four decades. However, incremental cost is fairly easy to define for greenhouse gas reduction but not for biodiversity. There is therefore a tendency to mix biodiversity protection with climatic change under GEF which is unfortunate. Biodiversity has a value on its own, including for the country where it occurs.

As a consequence of what has been said above, the sequence of issues and actions relating to tropical forests and especially rain forests, is first to conserve them, even in the uncertainty of knowledge on what should precisely be conserved and, only when appropriate conservation measures have been taken, to use them in a sustainable way to be defined on a case-by-case basis. How to achieve this **conservation-study-use sequence** in concrete situations is, of course, the difficulty which all countries are facing. Since each case is unique from an ecological, social, cultural and economic point of view, a number of approaches has been attempted. Conservation through national parks can be very successful when the integrity of the park can be ensured. However, mounting external pressures from populations around the parks can be witnessed in many countries and many parks have been designed without adequate surrounding buffer zones. In fact, seen from the air, the contrast between the interior of a park and the agricultural land around is often as sharp as that of two colours of a flag. On the other hand, not much has usually been done to associate the local surrounding population with the management and possible benefits of a national park. In some instances, the local population was in fact displaced to make way for national parks and are now claiming back their lands. The problem often is that rural populations either invade protected areas or move to the slums of urban centres. Too little attention is paid to this situation all over the world although the link between population increase and deforestation is clearly established. Rural populations tend unfortunately to be the losers of development and often biodiversity



conservation suffers from short term ill-oriented efforts to temper *unsustainable underdevelopment*.

A new, non-conventional approach to combine conservation of ecosystems and their biodiversity with the sustainable use of biological resources, in co-operation with and for the benefit of local populations was therefore required. Such an approach has been developed since the mid-seventies under the Man and the Biosphere (MAB) Programme of UNESCO (Batisse 1990). For each individual site, this concept of *Biosphere reserve* rests upon the fulfilment of three basic functions: a **conservation function**, to preserve genetic resources, species, ecosystems and landscapes; a **development function**, to foster sustainable economic and human development; and a **logistic support function**, to support demonstration projects, environmental education and training, and research and monitoring related to local, national and global issues. The combination of these three functions will vary from case to case but they should always be present in an appropriate balance. A **zonation pattern** is proposed, consisting of a legally constituted core area or areas devoted to long-term protection and of sufficient size, of a buffer zone or zones clearly identified where only activities compatible with the conservation objectives can take place, and an outer transition area where sustainable resource management practices are promoted and developed. The organizational arrangements for the management of a Biosphere Reserve should provide for the involvement and participation of stakeholders, including local communities with their knowledge and traditions, as well as public authorities. A major characteristic of the concept is its flexibility which allows for accommodation of the many different situations occurring all over the world. While these sites can be viewed from different angles, the basic idea is to make sure that some of the benefits from sustainable development activities around the protected core area go to the local people and not only to the government or to private interests in the country or abroad.

Biosphere Reserves are not isolated entities but are designated through a specific procedure under the auspices of UNESCO and all together form a World Network (UNESCO 1996). This World Network of Biosphere Reserves is operated in accordance with a Statutory Framework which was formally adopted by the General Conference of UNESCO in November 1995. While many of the existing 337 Biosphere Reserves, located in 85 countries, are far from performing their three functions adequately, the potential exists for their improvement. This is particularly so after the adoption of the *Seville Strategy*, which was elaborated by a major conference held in this Spanish town in 1995, attended by some 400 scientists and Biosphere reserve managers from all over the world (UNESCO 1995). The Seville Strategy provides a common platform and action-oriented recommendations for the development of the three functions of Biosphere Reserves and for effective operations of the World Network. Already, the MAB Secretariat has taken steps to organize the exchange of data and experience among Biosphere Reserves on a regular basis, firstly through a periodic newsletter and secondly through the UNESCO - MAB net which is operating on Internet. Thanks to an agreement between Conservation International, the INTEL Corporation and UNESCO, a first batch

of some twenty five Biosphere Reserves in developing countries are being equipped with the necessary material for international communication and networking.

What should perhaps be stressed here is that Biosphere Reserves, provided they are adequately organized and managed, do offer a very useful tool to reconcile some of the conflicting situations which arise in tropical forests, i.e. (i) ensuring the conservation of sizeable ecosystems; (ii) providing opportunities for the development of local populations, including ethnic groups living within certain areas, through the sustainable use of forest products and amenities; (iii) allowing for sustainable forestry practices; and (iv) ensuring permanent sites for scientific research and training. The momentum seems to be growing all over the world for a real step forward in the development of Biosphere Reserves which would adequately cover all major ecosystems. In this context, one is bound to note that a number of countries in South and South-East Asia are still unevenly represented in the World Network of Biosphere Reserves. It seems undeniable that Asia in general, and particularly tropical Asia would benefit from greater involvement in this innovative tool. This holds for moist deciduous forests, for montane forests and, of course, for rain forests. An interesting approach would be to set up Biosphere Reserves not only inland but also in coastal regions, combining as the case may be the conservation of tropical rain forests with that of coral reefs, since both represent the richest ecosystems of Earth from the point of view of terrestrial and marine biodiversity respectively. It is to be hoped, that the present seminar will constitute a significant step forward in the establishment and reinforcement of tropical forest Biosphere Reserves in the Asian region and for the sustainable management of these most precious ecosystems in the long-term interest of the people concerned.

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## SUSTAINABLE DEVELOPMENT OF FOREST RESOURCES AND CONSERVATION OF BIODIVERSITY

*A.S. Tamrakar*

Nepal is a small country, the total area of which is approximately 147,480 square kilometers but it has a rich social and biological diversity. Nepal's location is in between latitudes 26° 15' and 30° 30' north and extreme topography gives rise to diverse landscapes and climates ranging from subtropical to arctic. Nepal has three main physiographic zones running parallel to the Himalayan range, the lowland plain of the terai and Siwalik hills, the middle hills and the high Himalaya.

Forests are one of the main resources of Nepal. Because of the variation in altitudes of different parts of this country, the forests of Nepal have been classified into four types viz., tropical and sub-tropical of the terai plain area, deciduous of the warm temperate hills, coniferous forest of the cool temperate mountains and the Alpine forest in the Himalayas. Lower altitudes contain hardwood Sal trees (*Shorea robusta*). Most of these forests in terai have now been cleared for agriculture. Large tracts of the Bhabar zone are still covered by Sal forests and form important forest reserves of Nepal. Besides Sal, Khair (*Acacia catechu*) and Sisso (*Dalbergia sissoo*) are to be found and yield valuable timber of economic importance.

Forest resources constitute the main source of energy, building materials and export items. Due to lack of alternate indigenous sources of building materials, timber is an important construction material found in the country.

The devastation of forests is a serious problem of Nepal. The intensity of the problem has been noticed much earlier, since forests have been cleared for increasing areas of land for agriculture, fuelwood supplies, timber, fodder etc. The deforestation has considerably disturbed the ecological balance causing siltation, floods and the deposition of debris in river beds and the courses of the main rivers have been diverted into fertile land. It is urgent to take immediate measures for protecting the forests of Nepal.

The future of tropical forests has been a major environmental worry in the past. The conventional view is that tropical forests should be protected against utilization. The felling of trees such as Sal (*Shorea robusta*) in Nepal should be opposed and since any human interference reduces biodiversity, the best alternative is to try and keep the forests as they are now.

### FOREST RESOURCES AND THEIR USE IN THE TERAI (HUMID FOREST)

During the past decades, the forest policy of Nepal has emphasized the protection of forests. This has led to passive management, producing over mature forests that degrade and

eventually disappear. The rate of decline in the past 12 years has been 1.3% per annum. Thus the total loss of forest area in the plain during that period has been 99,000 ha. Despite degradation, the forest resources of the terai are considerable, and offer an excellent basis for sustainable management. There are still about 546,000 ha of forest in the terai. Almost half of the standing volume consists of Sal, an indigenous species with good regeneration, fast growth and a high value.

In the absence of active management of the forest, uncontrolled felling and land clearing prevail. Regular management, on the other hand, has reportedly decreased smuggling and other illegal activities in the forest. The positive effects have been especially evident in the forest plantations. Hence regular management is necessary in the natural regeneration areas.

At present, Government forestry revenues in the terai come from removal of dead and dying trees. The total royalties and taxes from the forests of the entire country in 1992/93 were NRs. 172 million.

For successful forest management in the terai, the forest should be categorized according to the intended way of management. Also demarcations between agriculture and forestry is needed; any conversion of (degraded) forest areas into agriculture should proceed in a well planned manner. The main forest categories to be identified are as follows:

**1) Forest suitable for permanent national production**

Forests which could form large, contiguous blocks for timber production should remain under immediate government control. About 300,000 ha of such forest has been reported by the World Bank Project. The main purpose of the blocks would be timber production, mainly for commercial use. However by increasing yields, more wood and other products would be available to satisfy local needs.

**2) Forest for community and leasehold management**

Smaller patches of forest (about 240,000 ha) whose control cannot be managed as large blocks would be suitable for production oriented active management.

**3) Forest for protection**

Besides national parks and reserves there are special forest areas, riverine forest, steep erosion-prone slopes and wet lands which must be left for protection or minimum use.

Silviculture strategy has to be defined for the production forests. Since most of the forests are over mature there are two main options:

- i) Replace degraded natural forests by planting fast growing species and keep the remaining natural forests under protection without significant silvicultural inputs.
- ii) Commence active management of natural forest relying on natural regeneration of indigenous species, using plantations only to supplement in special cases.

The second strategy provides more environmentally sound alternatives. Sal and its associates are the most prominent feature of terai. The safest way to guarantee that Sal will not go on the list of endangered species is to immediately bring those forests under efficient management.

Nepal's status as one of the world's least developed and poorest nations brings special challenges to achieving sustainable community development and conserving biodiversity. Experience from community forestry programmes being promoted by the Government of Nepal shows that such programmes can build capacity within rural communities to undertake their own development and at the same time arrest the rate of forest decline, increase the total area of forests and increase biological diversity of forest modified by human impact.

In particular, the community forestry programme is being used by the Government to build the capacity within rural communities to manage local forests sustainably for their own development. The special feature of community forestry is that the local organization sponsored by Government to manage and conserve forests can play a major role in improving the welfare of their own communities. This situation is in contrast with activities that either focus on development or conservation separately. In community forestry a direct link is forged between community development and forest conservation.

Community forestry in Nepal is a viable strategy for arresting the rate of land degradation and fostering the return of species of previously degraded habitats. Reforestation and rehabilitation of forest and shrub land through community forestry have also increased the availability of forest products for domestic consumption and income generation. Community forestry can provide improvements in both rural welfare and forest conditions because the manager of the resource and its local users are the same entity. Forest users reap the benefits of forest management and can invest surplus production in community development. Forests have great importance in the economic and social lives of rural people. There is a high demand for fuel-wood, timber, charcoal, food and medicinal plants from the forest. The demand for forest products in many areas exceeds the productive capacity of the existing forest, resulting in local shortages of products and in some cases deterioration in the condition of forests.

There is an urgent need to improve the availability of forest products to support farming communities. Forests also contribute greatly to Nepal's biodiversity heritage. The country has a disproportionate share of the world's biodiversity. With only 0.15% of the world's forest, Nepal has 2.2% of the known plants and 9.4% of the known birds. There are more than 10,000 species of plants, 5,400 of which have been identified, 850 species of birds, 175 species of mammals, 63 species of reptiles, 20 species of amphibians and 185 species of fish.

There is a great national and international interest in the conservation of this rich biodiversity. Currently, Nepal has 8 National Parks and 7 other reserves and conservation areas which together account for 10.8% of Nepal's total land surface.

# CONVERSION OF *PINUS* PLANTATIONS IN THE BUFFER ZONE OF THE SINHARAJA MAB RESERVE TO RAIN FOREST ANALOGS

A.G. Sunil, P.M.S. Ashton, C.V.S. Gunatilleke and I.A.U.N. Gunatilleke

## INTRODUCTION

In the wet zone of Sri Lanka most forest reserves, particularly along their perimeters, are highly degraded. The degradation may range between illicit removal of timber and pole wood, to clear felling of small patches for shifting cultivation, which upon abandonment has reverted to *Dicranopteris linearis* fernlands or *Hedyotis fruticosa*, *Melastoma malabathricum*, *Osbeckia octandra*, *Trema orientalis*, *Wendlandia bicuspidata* and *Macaranga peltata* dominated secondary scrub (Joachim and Pandittesekara 1937, Joachim and Kandiah 1942, de Rosayro 1961). In Sinharaja, more than 20% of the reserve comprises fernland and scrub (Merritt and Ranatunga 1959, Banyard and Fernando 1988).

In 1978 when the entire extent of Sinharaja was declared a Man and the Biosphere Reserve (Sri Bharathie 1979), the degraded peripheral state lands were planted up with *Pinus caribaea*. The boundary zone of the Sinharaja forest was also planted up with this species. Prior to introduction of this exotic, a major drawback of the reserve was the absence of a clear cut boundary around it; a boundary that villagers could easily recognize.

A serious constraint to conservation of rain forests in Sri Lanka is their conversion to other land uses, particularly village expansion schemes and agriculture. Consequently, the actual forest extent has been gradually decreasing over the last few decades.

The restoration of degraded lands to near native forests, using indigenous species is therefore, urgently required. If this were done, it would not only ensure that the extent of forest reserves in the country would be maintained for posterity, but it could also potentially ensure the survival of some of the rare forest species endemic to Sri Lanka. This would also extend the range of some species that have become restricted due to human impact on these reserves.

This restoration effort was also urgently needed for other reasons. For example, when Sinharaja was made a strict conservation area, harvesting of non-timber products by villagers living around the forest (Ishwaran and Erdelen 1990, McDermott *et al.* 1990) was curtailed or only allowed on a limited permit system. Enforcement of this regulation provided a certain degree of protection to the forest resources and prevented over-exploitation of any single species within it. Although this seemed satisfactory, one of its outcomes was the loss of traditional knowledge regarding these non-timber species and their utilization. Prohibition of harvesting meant that the knowledge of village elders could not be passed down to the next generation.

It is to find answers to some of these problems that the present study was initiated.

## OBJECTIVES

The overall objective of this study was to determine the possibility of converting *P. caribaea* stands in the vicinity of the Sinharaja forest to a mixed indigenous stand of rain forest canopy species and selected non-timber species of utility value to villagers.

It is our contention that if the rain forest canopy species could be grown successfully in the *P. caribaea* plantation, then the micro-environment under the canopy species could be made suitable for introduction of other rain forest species requiring sub-canopy and understorey conditions.

As a first step in attaining these long-term objectives, a field experiment was carried out to monitor the survival and growth of five canopy species and four non-timber species within a *Pinus* stand in the buffer zone of Sinharaja. The experiment comprised four different treatments.

## METHODOLOGY

The experiment was located in the north-western part of Sinharaja, adjacent to the access road that runs between the Kudawa camp and the Field Research Station. At the time the trial was initiated in August 1991, the *Pinus* stand was about 13 years old, unthinned and had been protected from fire.

Site preparation for the experiment began with the removal of one and three rows of *Pinus* trees to create strip-shaped openings of different widths resulting in different amounts of light at the strip centres. The strips were aligned, more or less, in a north to south direction. The removal of one and three rows of *Pinus* created the first and second treatments, which on sunny days received amounts of light that were 10 and 22 mols/m<sup>2</sup>/day respectively. The third treatment was beneath the centre of three rows of pine that were adjacent to the strip openings. This treatment could be considered an edge environment and received an amount of light that was about 5 mols/m<sup>2</sup>/day on a sunny day. The last treatment was beneath a closed-canopy *Pinus* stand that had no tree removal. Amounts of light on sunny days in this environment were recorded as 3 mols/m<sup>2</sup>/day. These treatments are hereafter referred to by the approximate amounts of light they received over a sunny day (3,5,10 and 22).

The canopy species selected for the study were *Mesua ferrea* (Clusiaceae), *Dipterocarpus zeylanicus*, *Shorea trapezifolia*, *S. disticha* and *S. megistophylla* (Dipterocarpaceae), all timber species. The four non-timber species selected were *Coscinium fenestratum* (Menispermaceae), *Arundina graminifolia* (Orchidaceae), *Calamus ovoideus* (Palmae) and *Elettaria cardamomum* (Zingiberaceae). Seedlings of the test species were grown in pots for one year and then transplanted into the four different planting locations. The canopy species, 30-45 cm tall, were transplanted in August 1991; seedlings of *C. ovoideus* had 2-3 leaves and the remaining non-timber species were 50 cm tall when they were planted in 1992.



Each treatment was replicated three times. Each replicate comprised 20 individuals per species per treatment. Twenty planting locations were demarcated along a transect positioned along the central length of each treatment. At each location, a square of 50 cm was marked out. One seedling of each of the canopy species was then planted randomly at each corner of the square and in its centre.

The non-timber species were transplanted randomly at one meter on either side of the planting locations of the canopy species. In the understorey sites too, the non-timber species were planted in the same manner, but between the existing *Pinus* trees.

The experimental lay-out followed was a split plot design. The growth performance was monitored for over 4 years (1991 - 1995) for the canopy species and over three years (1992 - 1995) for the non timber species. Seedling height, basal stem diameter and survival for the canopy species were measured after four years; stem height, stem diameter and leaf number per plant for *C. fenestratum* and *Calamus ovoides*; stem length, stem diameter and number of stems per plant for *A. graminifolia*; and number of fronds per plant and number of leaves for *E. cardamomum*, were measured after three years.

The data was statistically analysed using ANOVA and differences among means were examined using Duncan's Multiple Range Test.

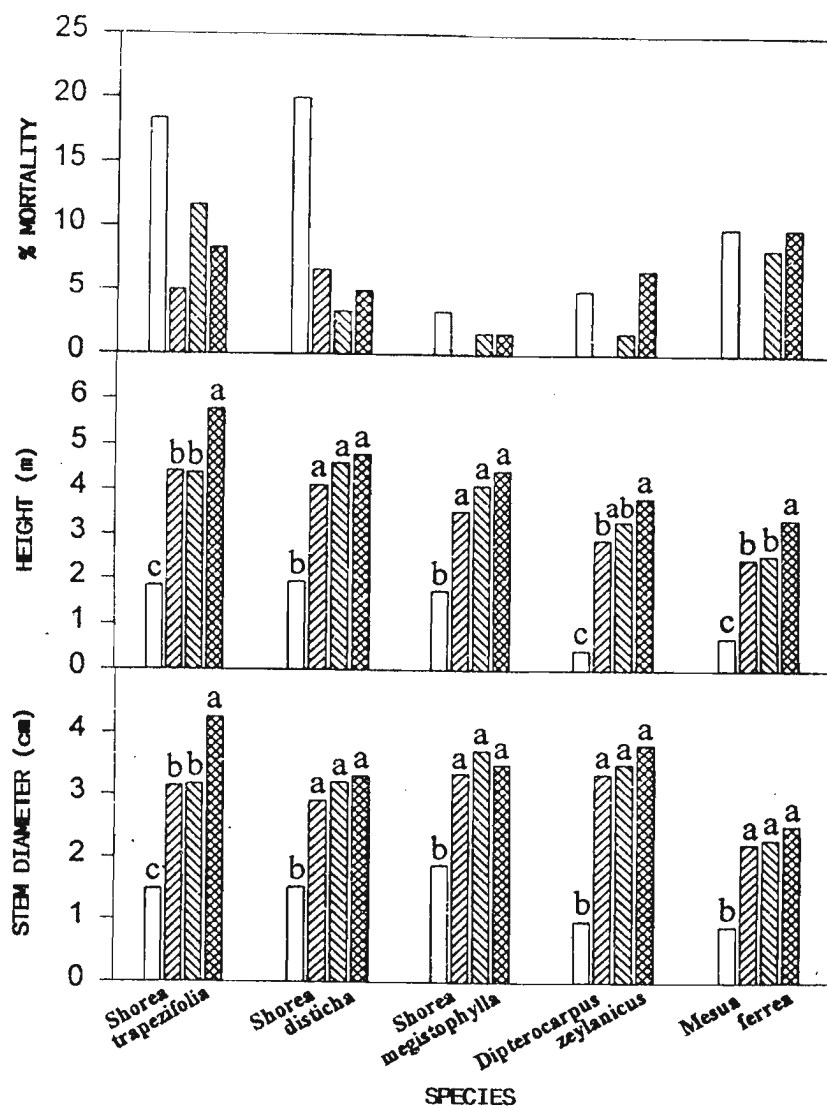
## RESULTS

### Performance of Canopy Species

Percent mortality in *S. trapezifolia* and *S. disticha* under 3 mols/m<sup>2</sup>/day treatment was higher than in each of the other treatments (Fig.1). The lowest mortality in *S. trapezifolia* and *S. disticha* was observed in the 5 and 10 mols/m<sup>2</sup>/day treatments, respectively. In each of the three remaining species, percent mortality in the 3, 10 and 22 mols/m<sup>2</sup>/day treatments appeared not to be different from each other. In *S. megistophylla* and *D. zeylanicus* mortality in each of these treatments was also greater than that under 5 mols/m<sup>2</sup>/day, where zero mortality was observed.

Height growth in all species was significantly greater in the treatment that received 22 mols/m<sup>2</sup>/day light intensity (i.e. 3 *Pinus* rows were removed), compared to the normal *Pinus* understorey treatment (Fig. 1). *S. trapezifolia* and *M. ferrea* showed significantly greater height growth in the 22 mols/m<sup>2</sup>/day treatment than that in each of the 5 and 10 mols/m<sup>2</sup>/day treatments. No significant differences were observed in *S. disticha* and *S. megistophylla* in these last two treatments.

Stem diameter growth showed a trend similar to that of height observed in these canopy species (Fig. 1). In all the species diameter growth in each of the three highest light treatments was significantly greater than that in the lowest light treatment. No significant differences in stem diameter were observed among the three highest light treatments in each of the species, except in *S. trapezifolia*.



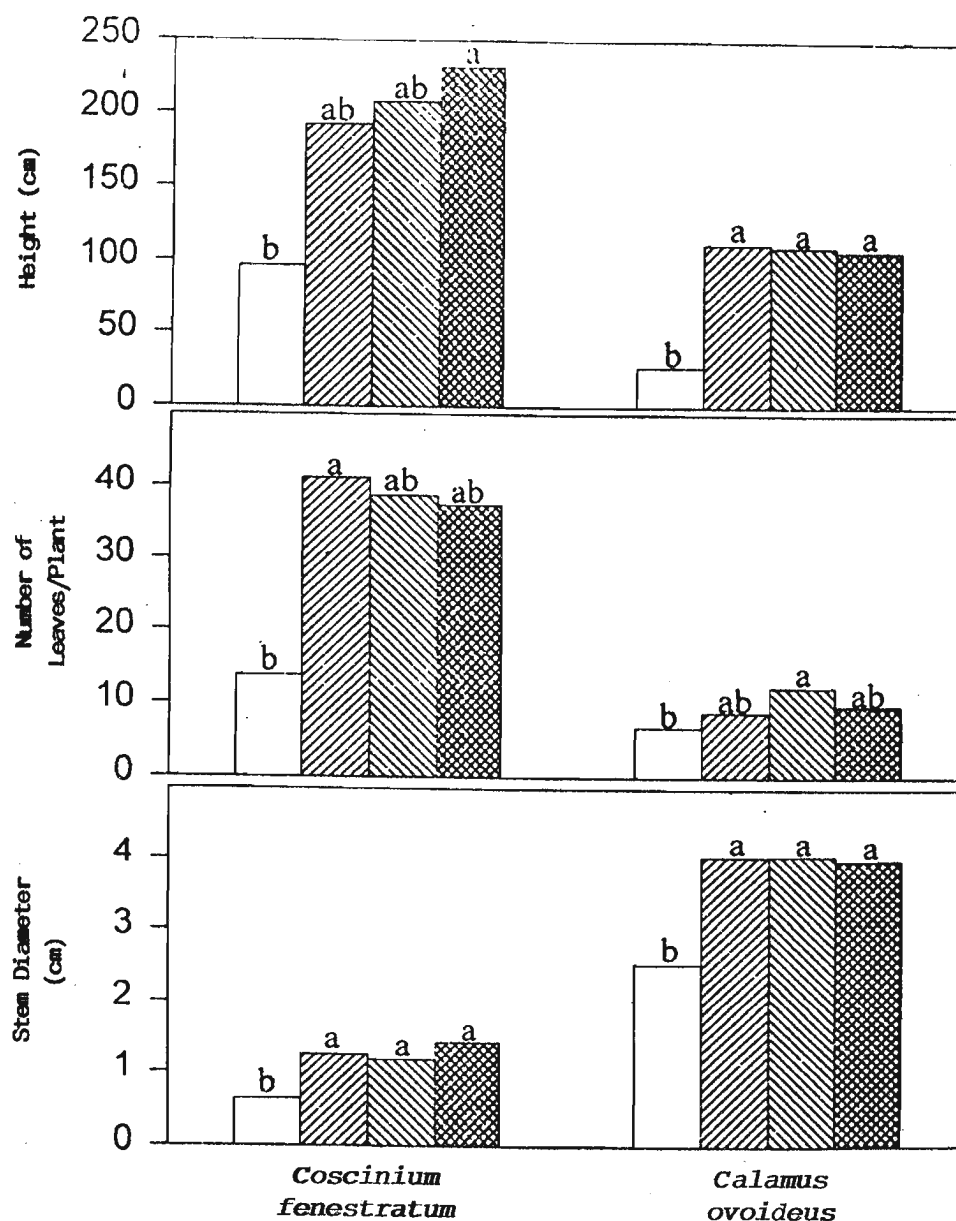
Clear = Understorey, normal Pine Stand: 3 mols/m<sup>2</sup>/day  
 Sloping left = Understorey, three Pine rows: 5 mols/m<sup>2</sup>/day  
 Sloping right = Centre, one Pine row removed : 10 mols/m<sup>2</sup>/day  
 Cross hatched = Centre, 3 Pine rows removed : 22 mols/m<sup>2</sup>/day

**Figure 1:** Performance of indigenous primary forest timber species under different light regimes in the enrichment planting trial, four years after initiation, in part of the *Pinus* buffer zone in the Sinharaja Man and the Biosphere reserve.

#### Performance of Non-Timber Species

Percent mortality of *C. oboideus* and *C. fenestratum* did not show a significant difference among the four treatments (Fig. 2). The pattern of mortality performance among treatments however varied between the two species. Mortality in *C. oboideus* decreased progressively from 22, 10, 5 and 3 mols/m<sup>2</sup>/day. In contrast, *C. fenestratum* had the highest mortality

under 3 mols/m<sup>2</sup>/day. Percent mortality in *E. cardamomum* was non-significant under the three highest light treatments; and mortality in each of them was significantly greater than that under 3 mols/m<sup>2</sup>/day (Fig. 3). Percent mortality in *A. graminifolia* was significantly higher under 3 mols/m<sup>2</sup>/day compared to each of the remaining treatments, which themselves were statistically similar, but decreased in the order 10, 5 and 22 mols/m<sup>2</sup>/day (Fig. 4).



|               |   |    |               |   |                             |
|---------------|---|----|---------------|---|-----------------------------|
| Clear         | = | 3  | Left Sloping  | = | 5                           |
| Right Sloping | = | 10 | Cross hatched | = | 22 mols/m <sup>2</sup> /day |

**Figure 2 :** Performance of the liana species of utility value under different light regimes in the enrichment planting trial, three years after initiation, in part of the *Pinus* buffer zone in the Sinharaja Man and the Biosphere reserve.

In *C. fenestratum* and *C. ovoideus* stem height, leaf number per plant and stem diameter in the three highest light treatments was not significantly different from each other; but the performance in each of them was significantly greater than that in the lowest light treatment (Fig. 2). In *C. fenestratum* the best stem height and diameter growth was observed in the highest light treatment, while the highest leaf number per plant was observed in the lowest light treatment. In contrast, *C. ovoideus* showed more or less similar height and diameter growth in the three higher light treatments and the largest leaf number per plant in the 10 mols/m<sup>2</sup>/day light treatment.

In *E. cardamomum*, stem number per plant was significantly greater in the two highest light treatments compared to that in each of the lower light treatments, which themselves were significantly different (Fig. 3). Leaf number per plant on the other hand, was similar and non-significant in the three highest light treatments.

In *A. graminifolia*, though stem length and stem diameter growth among the three highest light treatments were non significant, the tallest stems were observed in the treatment with 5 mols/m<sup>2</sup>/day light intensity and the largest diameter in the treatment with 10 mols/m<sup>2</sup>/day light intensity (Fig. 4). In contrast, number of stems per plant was significantly higher in the treatment with 22 mols/m<sup>2</sup>/day than each of the other treatments with lower light intensities. Stem number per plant decreased with decreasing light intensity.

## DISCUSSION

### Performance of Canopy Species

In each of the three highest light treatments, height growth among the timber species decreased sequentially from *S. trapezifolia*, through *S. disticha*, *S. megistophylla*, *D. zeylanicus* to *M. ferrea*. In the lowest light treatment however, both height and stem diameter growth of the three *Shorea* spp. were more or less similar but higher than that in *M. ferrea* and *D. zeylanicus*.

Stem diameter increment of these canopy species in the three highest light treatments showed a trend similar to height but with a few exceptions, viz., the rank order of *S. disticha*, *S. megistophylla* and *D. zeylanicus* did not show a consistent pattern. At the highest light intensity *D. zeylanicus* performed better than the two *Shorea* species, but in the treatments with light intensities of 5 and 10 mols/m<sup>2</sup>/day *S. megistophylla* performed best.

The differential performance of each species among light treatments shows that *S. trapezifolia* and *M. ferrea* are more sensitive to the differences in the three higher light treatments, as they perform best in the highest light treatment. They are sensitive to shade. The response of the three remaining species not being significant in the three highest light treatments suggests that they are more tolerant to shade conditions.

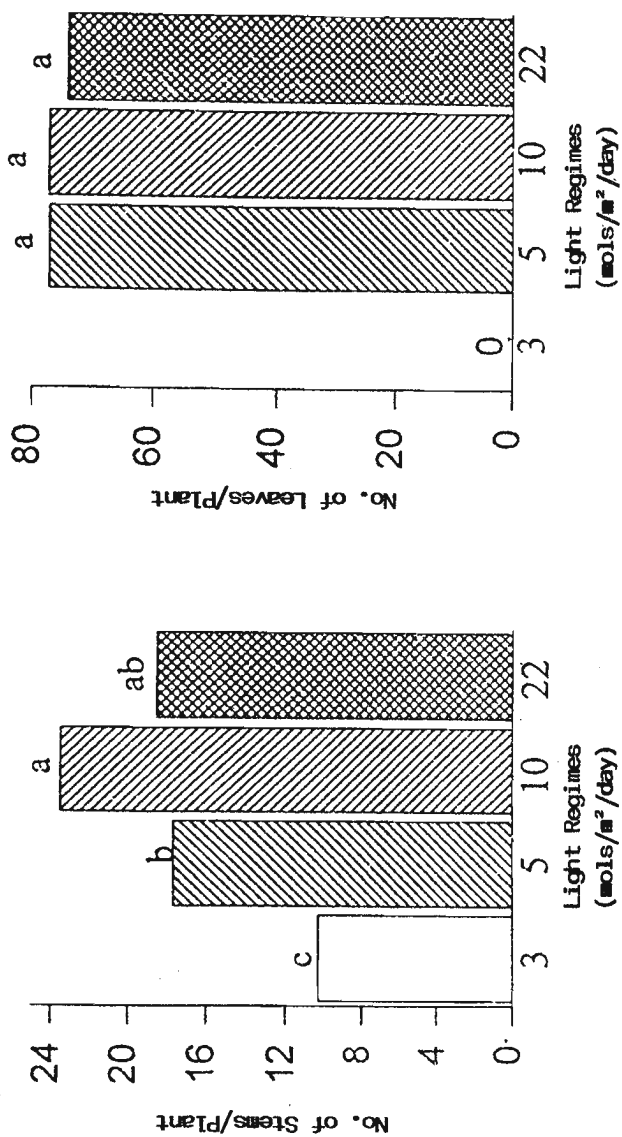


Figure 3 : Performance of *E. cardamomum*, a wild relative of the domesticated cardamom, under different light regimes in the enrichment planting trial, three years after initiation, in part of the *Pinus* buffer zone in the Sinharaja Man and the Biosphere reserve.

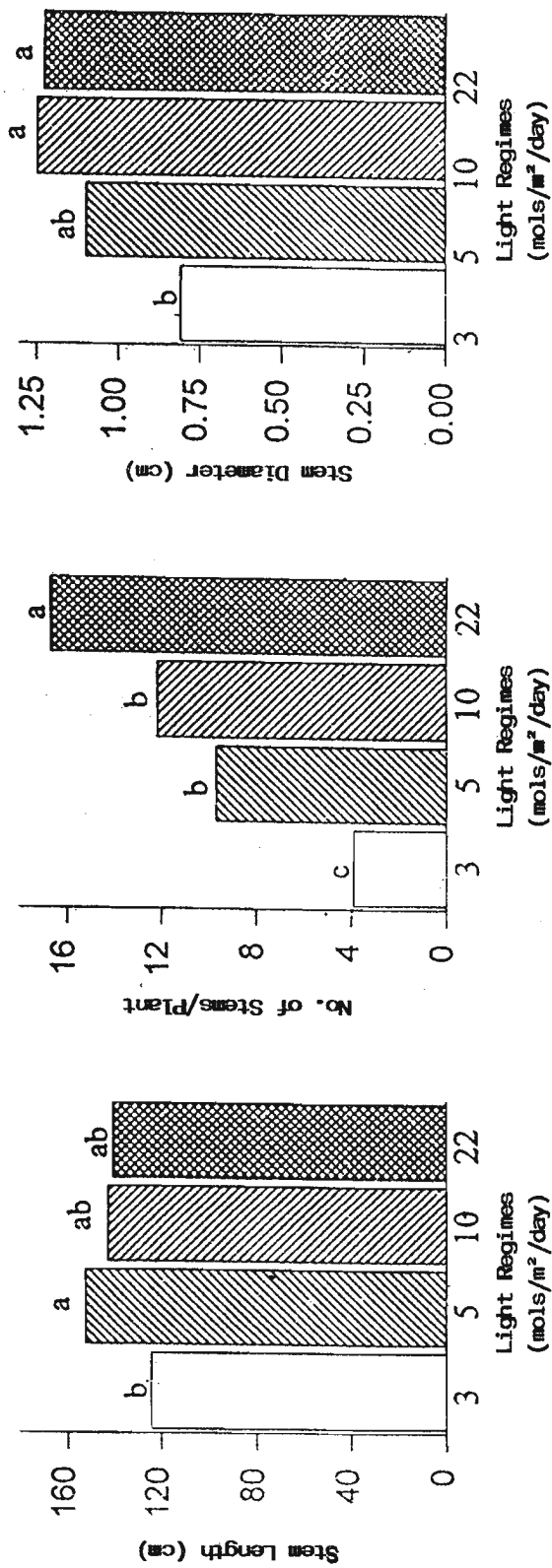


Figure 4 : Performance of *A. graminifolia*, a potential horticultural species, under different light regimes in the enrichment planting trial, three years after initiation, in part of the *Pinus* buffer zone in the Sinharaja Man and the Biosphere reserve.

The differences in performance among species in each light treatment may be due, among other factors, to their growth habitats. *S. trapezifolia* is a soft wood species and it shows the fastest growth, whereas *S. disticha* and *S. megistophylla* are both medium hardwood species showing medium growth; *D. zeylanicus* and *M. ferrea* on the other hand are hardwood species and they show the slowest growth under the environmental conditions of the trial over a period of 4 years.

### Performance of Non-Timber Species

*C. fenestratum* and *C. ovoideus* are both liana species growing well in forest fringes or selectively logged parts of the forest. Their relatively poor performance in the lowest light treatment provides one explanation why adults of these two species are rarely found in undisturbed forests. They are both light loving species, which can tolerate light intensities of 3 mols/m<sup>2</sup>/day.

Comparison of the growth performance of *C. fenestratum* and *C. ovoideus* depicts different growth strategies. Under each of the light intensities tested, *C. fenestratum* put on greater increase in stem height and leaf number per plant and a smaller stem diameter compared to *C. ovoideus* which showed relatively less stem height and leaf number per plant, but relatively greater stem diameter growth.

The results also show that *C. fenestratum* changes its stem height, leaf number per plant and stem diameter, though not significantly, in response to each of the three highest light treatments. *C. ovoideus* on the other hand shows very little change in stem height and stem diameter at the three highest light treatments, but its leaf number is more sensitive to light variations examined here.

Survival in the lowest light treatment suggests that both *C. fenestratum* and *C. ovoideus* are shade tolerant.

The performance of the two perennial herbs, *Elettaria cardamomum* and *Arundina graminifolia* show that all the parameters measured, vary with the variation in light. In both species the greatest variation to increasing light was seen in the number of stems per plant. The measure least affected in the three highest light treatments was, leaf number per plant in *Elettaria cardamomum* and stem diameter in *Arundina graminifolia*. These two species too grow better at the two higher light treatments.

From results of three years growth in each of the non-timber species tested, the best light intensities for enrichment planting can be recommended as follows: For *C. fenestratum* and *C. ovoideus* light intensities ranging between 5-22 mols/m<sup>2</sup>/day; for *E. cardamomum* light intensity of 10 mols/m<sup>2</sup>/day; and for *A. graminifolia* light intensity of 22 mols/m<sup>2</sup>/day.

### Experiments with Indigenous Species in the Past

In Sri Lanka between 1937 and 1957, 442 experimental garden trials had been set up to understand the different light requirements of indigenous species and their silvicultural

characteristics (Weeraratna 1958). In all 143 species in the wet, intermediate and dry zones have been examined. Attempts have also been made to introduce indigenous species into wet lowland grasslands. These early experiments with indigenous tree species have failed to identify those that could be successfully grown in plantations (Koelmeyer 1953, Vivekanandan 1988). Slow growth rates of indigenous species, taking over 150 years to produce trees of exploitable size (Ranatunga 1972) may be one of the reasons why research on the use of indigenous species was not continued in the 1960s and 1970s. In another effort the exotic *Fragraea fragrans* has been introduced to *D. linearis* fernlands in an attempt to control this weedy fern (Weeraratna 1956). More recently however, a trial in a degraded dry zone forest in the vicinity of Kataragama Maha Devale and Kirivehera has been planted up between 1984-1988 with medicinal tree species (Rodrigo 1990). The plants were introduced after clear felling, but leaving useful tree species behind, and burning. 98% survival in 1990 has been reported in this effort. Plantations of mixed species using Mahogany, Teak and Jak, all exotics, have been successfully established at Sundapola in the intermediate zone of Sri Lanka (Tissaveerasinghe and Satchithanathan 1957, Muttiah 1965). This trial depicts a polyspecific all aged plantation using exotic species (Wormald, 1992).

The present study shows for the first time that a plantation of mixed species of multipurpose value can be grown in the wet zone of Sri Lanka, using *Pinus* as a nurse crop. The failure of raising plantations using indigenous species in the past in Sri Lanka may be attributed to the lack of understanding of the above and below ground microenvironment required for their successful performance. In the present study the manipulation of the microenvironment in the existing *Pinus* stand permitted the successful growth of indigenous species, after their specific light and moisture requirements were examined under shade house conditions (Ashton and Berlyn 1992, Ashton 1995), and natural forest gaps (Ashton *et al.* 1995). The current trial is also one of its kind in Sri Lanka where both indigenous timber and non-timber species have been grown together.

## ACKNOWLEDGEMENTS

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#### CORRIGENDUM

Please note that at the end of each of the four figure captions 1-4 in the article the letters signify statistical differences in performance among light treatments of each species separately based on Duncan's Multiple Range Test. Significant differences ( $P < 0.05$ ) are indicated by different letters. Treatments with the same letter are not significantly different from each other.

**INTERNATIONAL COOPERATION ON ISSUES RELEVANT TO  
CONSERVATION AND DEVELOPMENT OF FORESTS IN  
ASIAN HUMID TROPICS**

# DEFORESTATION AND ITS IMPLICATIONS FOR CONSERVATION OF ELEPHANTS IN SUMATRA AND SRI LANKA

Charles Santiapillai

## ABSTRACT

Both Sumatra and Sri Lanka are land-bridge islands, whose fauna have been slowly dwindling since their separation from the Malayan and Indian mainlands respectively. This slow process of species loss is being accelerated by the wave of deforestation that is sweeping across these islands. The Asian elephant (*Elephas maximus*) becomes vulnerable and extinction prone when confined to limited areas. The main agents of deforestation in the humid tropics are logging, human settlements, shifting or swidden cultivation, agricultural expansion, forest fires, fuelwood collection and road building. One of the negative aspects of deforestation is that it has led to the fragmentation and isolation of some elephant populations in Sumatra and Sri Lanka, while the establishment of human settlements and agricultural expansion have resulted in increased conflicts between man and elephant. Road building has not only fragmented elephant habitats, but more seriously, has provided access to illegal settlers and ivory poachers. Poaching of tuskers can skew the adult sex ratio and in extreme situations, can result in lowered fertility among elephants and reduce their rate of growth. On the other hand, deforestation has had some beneficial effects too on the elephant populations: logging, if carefully controlled and selective, can enhance the carrying capacity of herbivores in general, and the elephant in particular. The best opportunity for elephant conservation in the tropics at present, lies in some form of multiple-use-pattern of land development. This could be achieved by the establishment of "Managed Elephant Reserves" where priority is given to the requirements of elephants, but human activities that are compatible with elephant conservation are permitted. This may be the last hope for the elephant in the densely populated islands of Sumatra and Sri Lanka.

## INTRODUCTION

Sumatra and Sri Lanka are both land-bridge islands that were formerly connected to the Malayan and Indian mainlands respectively. As such, the two islands might have had a full complement of the continental species at the time of their separation. Therefore it is reasonable to assume that their fauna have been slowly dwindling since then. This slow process of species loss is being accelerated today as a result of deforestation. We can expect large species to be extinction prone when confined to a limited area because of their intrinsically low population densities (Terborgh, 1974).

The importance of the Asian elephant (*Elephas maximus*) in Sumatran and Sri Lankan ecosystems, stems not only from the animal's enormous size, its intemperate appetite and

its high mean age of survival, but also from the fact that as a “**keystone**” species, the elephant plays a very important role in structuring habitats and maintaining biological diversity on a large scale. The Asian elephant is a megaherbivore, which by definition refers to any plant-eating mammal that typically attains an adult body mass in excess of one megagram, or one metric tonne (Owen-Smith 1989). Today, in both islands, natural habitats are on the decline and as far as the elephant is concerned, the situation has reversed from one in which human islands existed in a sea of elephants, to a sea of people with elephant islands! Changes in land-use patterns by a rapidly growing human population in Sumatra and Sri Lanka are resulting in continuous contraction of habitat available to the elephant. Such changes serve to cut off certain channels of response usually available to elephants, such as emigration and dispersion (Watson & Bell, 1969).

Elephants probably require larger areas of natural range than any other mammal species in tropical Asia, and therefore are among the first animals to suffer the consequences of development activities (Olivier, 1980). Over large areas of Sumatra and Sri Lanka, there is no longer room for elephants to move about and adjust their densities to changing patterns of land-use. As forests are converted to other land-use, all remaining elephant populations are undergoing or are threatened with, fragmentation. This leads to what has been called the “pocket-herd” phenomenon, which represents an extreme stage in the human-elephant conflict (Olivier, 1980). The “pocket” herds are created when elephants, living in development areas, are cut off from adjacent forest tracts, or when a clan or subgroup moves into a project area that was formerly used for foraging (Seidensticker, 1984). These elephants, like other wildlife, have lost so much of their former habitats, that they are often forced to invade the communities that have displaced them. This is the crux of the elephant-human conflicts in Sumatra and Sri Lanka.

## STATUS OF ELEPHANTS IN SUMATRA AND SRI LANKA

The Sumatran elephant (*Elephas maximus sumatranus*) is the smallest of the three subspecies of Asian elephant, and is endemic to the island of Sumatra. Prior to the large scale destruction of its habitat, the elephant was widely distributed throughout Sumatra across a wide variety of ecosystems. It was found in primary forest at altitudes above 1,750 m in the Gunung Kerinci in West Sumatra (Frey-Wyssling 1933). However, its preferred habitat was always the lowland forest. In the past, when the island was substantially forested, elephants made extensive migrations. These movements usually followed river courses where the canopy was broken, and included both hill forest as well as dipterocarp lowland forest. Elephants moved from montane areas to the coastal lowlands during the dry season, and retreated into the hills once the rains came (van Heurn 1929; Pieters, 1938). Such a strategy enabled the elephants to maintain relatively high numbers even in primary forests, where the absence of seasonal variation in rainfall and plant productivity usually results in reduced biomass in terrestrial herbivores (Eisenberg 1980). But today, with the conversion and/or clearance of lowland forests in Sumatra, the elephants are forced to move to higher altitudes, where remoteness,

difficulty of terrain and density of cover, provide some degree of protection. The Sumatran situation is just the reverse of what is seen in Sri Lanka, where the elephant (*Elephas maximus maximus*) has been almost completely squeezed out of its former habitats in the hills, with the clearance of forest, for the establishment of first coffee and later tea plantations. Today, the low country Dry Zone has become the last stronghold of the elephant in Sri Lanka. In both Sumatra and Sri Lanka, the elephant occurs in a number of small, fragmented and discontinuous populations both within and outside protected areas. Despite the difference in size of the two islands, Sumatra and Sri Lanka, each supports about 3,000 elephants in a variety of ecosystems. This is due to the fact that the largely mountainous areas in Sumatra where elephants currently occur, offer climax forest habitats where elephant densities are intrinsically low. By contrast, in Sri Lanka the dry scrub vegetation and the villu grasslands offer an increased diversity of habitat patches at different successional stages, which substantially improve the carrying capacity for elephants. This is the reason why Sri Lanka, despite being just one seventh the size of Sumatra, still supports a comparable number of elephants.

## DEFORESTATION

Prior to 1900, when agricultural settlement in Sumatra and Sri Lanka first led to a substantial degree of deforestation, these islands were heavily forested. In both, the conversion of forest into agricultural holdings, is a particularly serious cause of conservation problems, and the elephant has been among the species most seriously affected by it. In recent decades, the primary forest in Sumatra has been shrinking rapidly in extent. It is estimated that between 65 and 80% of the forest in the lowlands have already been lost (Whitten *et al.* 1987). Stands of ironwood (*Eusideroxylon zwageri*) of great commercial value, have almost been destroyed in the lowlands. The Barisan chain of mountains has extensive montane forests, while the lowland evergreen forests are dominated by the commercially important timber species belonging to the family Dipterocarpaceae. The mountain areas to date have been less seriously affected, but the disruption of continuous cover is already substantial in some cases, and perhaps 15% of their total area may tentatively be estimated as already removed. According to Collins *et al.* (1991) only about 230,660 km<sup>2</sup> (or 49%) of the original forest cover remains. In Sri Lanka, the natural closed-canopy forest cover declined in extent from 29,000 km<sup>2</sup> (44% of the land area) in 1956 to 16,590 km<sup>2</sup> (27%) in 1980. By 1983, forests accounted for 12,260 km<sup>2</sup> (19%), of which only 1,440 km<sup>2</sup> was rain forest (Collins *et al.* 1991).

## AGENTS OF DEFORESTATION

A number of factors, both natural as well as man-made, continue to threaten the tropical rain forest habitats of the elephant in Sumatra and Sri Lanka: logging, human settlements, shifting cultivation, agricultural expansion, forest fires, fuelwood collection, and road building are some of the more common agents of forest destruction and fragmentation.

1. *Logging* : The tropical rain forests of Sumatra contain a very high proportion of commercially valuable timber species of the family Dipterocarpaceae. On average, these forests contain as much as 200 m<sup>3</sup> per ha of commercial-size trees (GOI/IIED, 1985). In Sumatra, timber production means harvesting old growth timber from natural forests. The Department of Forestry has laid down strict limits on the exploitation of commercial species, stipulating a minimum of 50 cm diameter at breast height (dbh), and a cutting cycle of 35 years, leaving more than 25 trees per ha of commercial species of 20 cm dbh or greater (GOI/IIED, 1985). Commercially valuable dipterocarps, such as *Shorea* sp. take about 70 years to attain 60-70 cm dbh. As long as timber extraction is carried out selectively, and within strict limits, it can enhance the carrying capacity for elephants. Crude density of elephants in logged-over forests can be more than twice that in primary forests (Olivier, 1978a). In practice however, logging companies often cut trees well below the official limit of 50 cm dbh. Selective logging in Indonesia entails the removal of up to 20 trees/ha which can cause up to 40% damage to the residual stand (Kartawinata *et al.*, 1981). Furthermore, elephants may not have any escape routes to move from a disturbed area to a mature forest, which may be some distance away from the logged area. The maintenance of unlogged strips along water courses to link logging areas with mature forests would be a practical solution to the problem (Shelton, 1985).

2. *Human settlements* : Indonesia will face serious demographic problems in the medium term future. The population, currently 185 million and concentrated in Java, is growing at 2.1% per annum, with no controlling mechanism in sight, and with a forecast which must be regarded as optimistic, of ultimately stabilizing at 400 million. More than 2.5 million people from Java have already been decanted into the "outer islands" of Sumatra, Kalimantan, Sulawesi and Irian Jaya, and the movement of 65 million additional people is planned for the next 20 years (Colchester, 1986). Even with the best advice and control, this would risk causing serious environmental damage if done rapidly and on such a large scale. In addition to government-sponsored settlers, twice as many unassisted people reach these outer islands in search of a better life. The southern province of Lampung has been the target of most of the pioneers. Today, 80% of the 4.6 million people in Lampung are migrants. Conflicts between elephants and settlers have become serious conservation problems.

3. *Shifting cultivation* : Generally, shifting cultivators are blamed for much of the forest destruction in Indonesia. According to Myers (1980), they have been a major contributory factor to the loss of 15,000 km<sup>2</sup> of forest each year. However, much of the damage to the forests is caused by the new or shifted settlers rather than by the traditional shifting cultivators, who in the past, operated on a sufficiently long rotation to allow good forest regeneration. The new settlers clear forest for crops, but after two or three rapid rotations, the declining fertility of the soil and poor yields force them to move elsewhere. The land is taken over by *Imperata cylindrica* or 'alang-alang' which is a coarse weed extremely difficult to eradicate once established, and which is unpalatable to most wild

herbivores, including the elephant. But shifting cultivation, in its classical form, is the only self-sustainable system of agriculture in the tropical rain forest (Moss, 1984). When it functions correctly it can enhance elephant conservation. In Sri Lanka some of the best elephant areas today had been previously subjected to chena (swidden) cultivation. Wharton (1968) has provided convincing evidence that the distribution of the major large mammals of Southeast Asia is highly dependent on shifting cultivation. Traditional shifting cultivation is a system that is well adapted to tropical moist forest environments (Collins *et al.* 1991). However, excessive use of forest resources, including over cutting and removal of tree cover and inappropriate farming practices have resulted in a total of almost 8.6 million ha in 1984, classified as 'critical land' (i.e. land which has lost its normal soil functions). Sumatra contains the greatest total area of such critical land in Indonesia (GOI/IIED 1985).

4. *Agricultural expansion* : An area of 2,250 km<sup>2</sup> is under oil palm in Sumatra, while rubber plantations occupy 2,280 km<sup>2</sup> (Scholz, 1983). Oil palm is very vulnerable to raids by elephants, and in Sumatra estates in the vicinity of elephant habitats have experienced constant depredation. Oil palm and rubber estates have greatly reduced the life-support systems of the elephants in Sumatra. This is especially evident in the so called 'estate belt' of northeast Sumatra - an area of about 17,000 km<sup>2</sup> (Scholz, 1983). In the long run, existing lowland forests would prove to be far more valuable than oil palm plantations. In the provinces of North Sumatra and West Sumatra a combination of high human population and the clearance of enormous tracts of forest for oil palm, rubber and coconut plantations has virtually eliminated the elephants. Lampung has experienced some of the worst elephant problems because of the rapid loss of forest. In Aceh, almost all lowland forests under 1,500 m have been allocated for timber production (Blouch & Simbolon 1985). Elephants are now being forced to move out of their preferred habitats in the lowlands to more rugged and less attractive montane forests, from which they periodically raid crops. The situation in Riau is even worse. Although about 35-40% of Sumatra's elephants occur in this province, the areas designated for nature conservation are 'woefully inadequate' (Blouch & Simbolon 1985). Unlike in Aceh, the elephants have no mountainous retreats in Riau when development programmes constrict their habitats. Forests are still cleared to make way for oil palm plantations in Riau.

In Sri Lanka, the establishment of the Pelwatte sugar cane plantation so close to the western boundary of Ruhuna National Park in 1980 has led to constant depredations by elephants, causing an estimated loss of US\$ 2,000,000 in 1988/89. With the construction of an electric fence (280) km) around the perimeter of the plantation, the losses were reduced to US\$ 200,000 in 1994 (Thouless, 1994).

5. *Forest fires* : Fire is one of the most destructive forces in deforestation. During the period 1978-1982, an average of 28,500 thousand ha of forest land was razed annually by fires, virtually all caused by man (Statistik Kehutanan Indonesia 1982/83). All fires are however not necessarily destructive to the environment. The burnt area regenerates quickly attracting elephants and other herbivores.



6. *Fuelwood collection* : In both Sumatra and Sri Lanka, fuelwood collection by rural people for their domestic energy needs is probably the most important cause of forest degradation. In many parts of Southeast Asia, this surpasses logging in the intensity and extent of the damage caused. According to FAO (1981), about one-half of all the wood cut in the world ends up as fuel wood, mostly in Southeast Asia.

7. *Road construction* : Construction of roads and pipelines has fragmented the forest and isolated elephant populations. They provide easy access for illegal settlers, shifting cultivators, and poachers.

8. *Poaching* : Unlike in Africa, elephant poaching is not considered a terminal threat in Asia. Nevertheless, poaching in recent times, had a far more serious effect on the elephants in Sumatra than in Sri Lanka. This is due to the fact that Sumatra has more tuskers among its elephant population than does Sri Lanka. According to Deraniyagala (1955) 98% of the Sumatran elephant bulls were tuskers. In Sri Lanka, by contrast only 7.3% of the bulls possess tusks (Hendavitharana *et al.*, 1994). Tuskers are being poached for their ivory in Sumatra and to a lesser extent in Sri Lanka. Poaching affects the adult sex ratio. In Sri Lanka, where the poaching pressure is low, the adult sex ratio of the males and females is 1:2.9 (Hendavitharana *et al.*, 1994). In Sumatra, even within protected areas, where poaching had been rampant, the adult sex ratio is 1:5 in favour of the cows (Santiapillai & Suprahman, 1995). As Sukumar (1989) points out, hunting of male elephants will further widen this disparity in the sex ratio, and at some ratio there would be far too few males to ensure that all the available females are successfully mated, resulting in a lower rate of conception and a longer inter-calving interval. This lowered fertility could reduce the rate of population growth. An extreme example comes from Kerala (South India), where the poaching pressure was so intense, that the adult sex ratio was found to be 1:52 (Menon, 1990).

## CONCLUSION

Disturbed areas, as a result of deforestation are rarely considered useful in maintaining wildlife populations (Foster, 1980; Johns, 1983). While some agents of deforestation cause irreparable damage to the habitats, others could in fact enhance elephant conservation, if they are carefully controlled. While the need to retain large tracts of undisturbed climax ecosystems in the humid tropics is axiomatic, the dependence of elephants on primary tropical rain forest habitat should not be pushed too far. It is not *ipso facto* essential to stop commercial exploitation of timber in forests to be managed as a habitat for the elephant: it is simply necessary to control it strictly, since a logged forest has a great potential value in the long-term conservation of rain-forest animal species (Johns, 1985). Trees must be taken on a strictly selective basis and extraction limited to

those exceeding 50 cm diameter 1.5 m from the ground, leaving the remainder to provide open canopy until saplings grow up to replace trees removed. Such a policy is in any case required to provide sound long term forest management to replace the destructive exploitation that has been turning large areas in Sumatra and Sri Lanka into degraded environments of no economic or wildlife value.

In both Sumatra and Sri Lanka, the human population is growing rapidly. At the turn of the century, Sri Lanka had a population of 3.6 million people, equivalent to a density of 55 individuals per km<sup>2</sup>. During the 40 years between 1956 and 1996, while the human population has more than doubled, from 8 to 17 million, the forest cover has more than halved from 44% to less than 20%. In Sumatra too, the trend in natural forest cover runs opposite to the human population: while the human population has increased six-fold from 6 million in 1930 to 36 million in 1990, the forest cover during the period declined from about 80% to less than 50%. Given this background, it is inevitable that in the tropics, many conservation areas will shrink in the face of development, human competition for resources, and changes in political ideologies. Existing conservation areas are prone to environmental disturbances outside their boundaries. It would be a serious mistake to rely on the elephant being safe in perpetuity living in one or two large national parks only. The best opportunity for elephant conservation at present lies in some form of multiple-use-pattern of land development. As Olivier (1980) points out, the existence of forms of land use compatible with elephant conservation is important, as it creates opportunities for compromise with the political objections that are likely to arise in response to any call to annex large tracts of land exclusively for conservation purpose. Olivier (1978b) recommended the establishment of "**Managed Elephant Ranges**", where priority is given to the requirements of elephants, but compatible human activities such as sustained-yield forestry, slow-rotation shifting cultivation, controlled livestock grazing, and subsistence hunting are permitted. Man and elephant need to live together through mutual adjustment. Such an approach may be the last hope for the elephant in densely populated islands of Sumatra and Sri Lanka.

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# CHANGING RELATIONSHIPS BETWEEN FORESTRY RESEARCH AND LANDSCAPE MANAGEMENT IN THE HUMID TROPICS

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## INTRODUCTION

Before industrialization became the driving force for national economic development in countries of the humid tropics, tropical forests were used by local communities for the extraction of a range of resources and products. Industrial production of timber however, disrupted multiple-use regimes that favoured sustainable use of tropical humid forests. More recently, over the last two to three decades, sustainability of tropical humid forests has come to be recognized as a broader notion including, but not restricted to, sustainable timber production. As we near the end of the millennium, multiple use models are regaining their earlier importance as the basis for sustainable management of tropical humid forest landscapes. The present search for multiple - use models, however calls for the inclusion of (a) the long-term socio-economic development of forest-based communities and (b) the potential for commercializing exchanges of non-timber forest products, as initial conditions for model design. Neither of these conditions merited the concern it currently receives in pre-industrial economies of the humid tropics.

The challenge faced by researchers and managers today is to develop skills and knowledge for guiding changes to any given set of uses of tropical humid forests along ecologically, economically, socially and culturally sustainable pathways. In responding to this challenge, researchers and managers are forging new partnerships. Model parameters are likely to be site specific; but model design needs to: (a) be based on regional landscapes or similarly extensive spatial planning units; (b) incorporate short, medium and long-term time horizons; (c) include a role for the private sector; and (d) bring social and cultural benefits and economic profits to local communities, in the short-to-medium term. Issues centred around non-wood forest products and rehabilitation of degraded forest lands generate crucial research questions whose answers will significantly influence model designs for managing tropical humid forest landscapes.

This contribution focuses on the changing relationships between research on the ecological systems of the humid tropics and landscape management in these regions. The paper has two main parts: first, an overview of some of the major historical trends in the use and management of humid-tropical systems: the second part examines some of the principal characteristics of recent progress and challenges in harnessing research to the needs of socio-economic development, drawing mainly on examples from the South Asian region.

## **TRENDS IN TROPICAL RESOURCE MANAGEMENT**

### **Pre-industrial Multiple Uses**

It has been estimated that globally some 300 million people live in, or near the forests and are at least partly dependent upon forest resources. A substantial proportion of these people are in the Asia-Pacific region where they are represented by a large number of distinct ethnic groups, each with their own cultural inheritance and their own specific relationships with the forest, encompassing religion, ritual, art, medicine, and economic use.

For example, it is thought that between 30-80 million people in the region are dependent upon various forms of shifting cultivation and that the area affected by this lies between 75 and 120 million hectares. But as reflected in a study of forests and cultures in Asia (UNESCO 1992), shifting cultivators are only one segment of a much larger array of societies that depend upon forests. Numerous instances may be cited - from the mountains of Nepal to the dry forests of India and Indo-China, from the rain forests of South East Asia to the forests of the Pacific Islands - of groups who gather fodder, rattan, nuts, bark, fruits, resins, medicinal herbs and other forest products as a greater or lesser part of their livelihood. In every instance where such people/forest symbiotic relationships have existed for a long time, the social organization and culture of these people (knowledge systems, production techniques, tools, regulations, usufruct rights, values, traditions, rituals and symbols) have been shaped by changing local conditions and adapted to them.

### **Colonial Times and Shifts Towards Timber Production**

With the advent of colonial government in many tropical countries, the management of forest resources were taken away from local communities and placed under the aegis of government forest departments. Evidence suggests that in the early days at least, these government-based forest services did take on the broadly-based role of managers of tropical forest landscapes. In India, for example, scientific forest management started in the second half of the last century, as described in a foreword by the Secretary General of WWF - India (Singh 1994), in a reprint of an account of origins and early development of forestry in India (Brandis 1897).

Borrowing liberally from Samar Singh's foreword, the person who actually initiated this development was the German botanist Dietrich Brandis. In 1855 he was selected by Lord Dalhousie, the Governor General of India, to take charge of the teak forests of Pegu in Burma. For the next 28 years, Brandis dominated the forestry scene on the sub-continent, first by his outstanding work in Burma and then from 1864 as the first Inspector-General of Forests in India, which position he held until his retirement in 1883. It was during this period that the foundations of organized forest management were laid in India under the guidance and leadership of Brandis. To him, and to his immediate successors, Schlich

and Ribbentrop, both of whom were also Germans, goes the credit for the creation and organization of the Forest Department and for the introduction of methods of management, adopted from the best European schools, to suit the conditions of India. It was also during this period that the first comprehensive forest legislation was enacted to provide for the settlement, demarcation, protection and management of forests. Other important initiatives taken by Brandis included the introduction of the concept of working plans, the organized training of forest personnel and the establishment of the Central Forest School at Dehra Dun, which later grew to become the prestigious Forest Research Institute and Colleges.

An aspect of Brandis not so well known is his understanding of the social context within which state forestry was to operate in India and his faith in the capacity of the local communities and institutions for forest management. It is in this respect that Ramachandra Guha has categorized Brandis as one of the early environmentalists in India. To quote his words:

"The Indian Forest Department has been the subject of relentless criticism for its authoritarian style of functioning; and yet, in a curious paradox, the founder of the Forest Department had himself anticipated that a narrow reliance on state control and punitive methods of management would lead to great disaffection in the countryside. Keenly aware of rural rights and demands, this man had suggested, a century and a quarter ago, that India adopt a system of forest management based on a collaborative relationship between the state and local communities. In the event, his suggestions were rejected by the colonial government, which preferred to stand by the principle of state monopoly embodied in the Forest Act of 1878. Yet this forester's ideas have a strong contemporary resonance. While terms like 'social forestry', 'community forestry' and 'joint forest management' have come into currency only in the past two decades, the principles they embody would have been readily recognized, and infact warmly commended, by the first head of the Forest Department in India."

Illustrations of Brandis's perception of the social mission of the forestry service appear in several parts of his 1897 account:

- The idea of providing for coming generations may to many appear an unnecessary waste of time but when the present generation begins to derive substantial benefits from these measures, then their value will doubtless be fully recognized" (page 35).
- "As a matter of fact, had Government not stepped in to arrest the denotation of the country, by protecting the remaining forests and by planting, no action would have been taken in the matter, and the people of India would have suffered" (page 64).



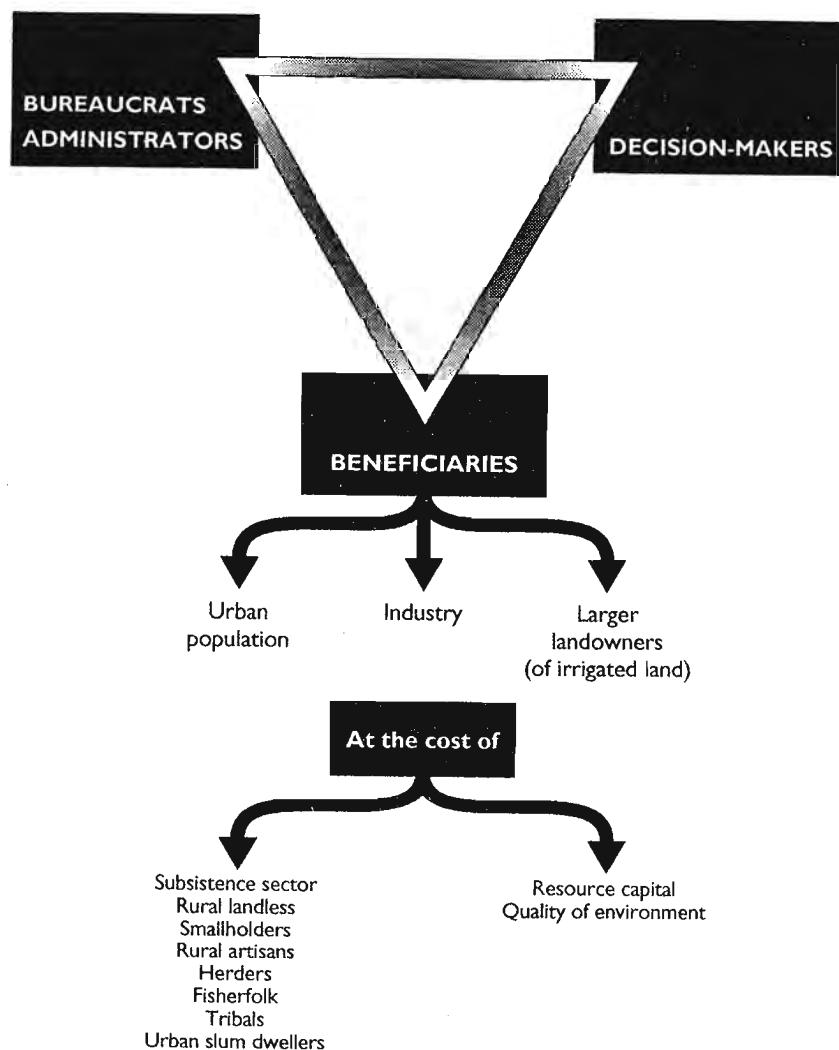
- "... during the great famine which devastated Rajputana from 1867 to 1869, the old forest preserves, which the chiefs of several native states (notably of Kishengarh near Ajmere) and large landowners had formed, were of extreme value to the people. Special permission was given to lop the branches of trees for the cattle of the towns and villages of the vicinity, and by these means many were saved from starvation" (page 67).

Brandis also reflected (page 115) on the challenge of inducing the colonial government "to insist upon a good management of the Crown forests, so as to set an example to private proprietors. In India, there is special difficulty. Private enterprise at present means European private enterprise and Europeans in business in India as a rule have one aim only, that is to get rich as quickly as possible".

As forests were increasingly perceived as storehouses for economic development, new alliances took shape, and resource flows were increasingly subsidized, as reflected in Gadgil's (1991) account of the relationships governing recent resource use patterns in India. In colonial times the upper castes became allies of the British in organizing the drain of the country's resources. The priests and accountants formed the bureaucracy, the warriors became landlords organizing the usurpation of the agricultural surplus to pass on a substantial fraction to the government as land revenue, and the traders served as partners of British merchants and industrialists. In the process, they consolidated their traditional supremacy within the Indian society.

The pursuit of economic development was accompanied, even driven, by the organization of subsidized flows of resources. Given that power within society flows from control over its resources, people benefiting from highly subsidized resource flows have a substantial share of the power. They have used this clout to organize themselves into a system that continually bolsters the subsidies. It consists of three components: those who benefit from the subsidies; those who administer them; and those who decide on who is to receive them and at whose cost (Repetto, 1986).

The direct beneficiaries of the subsidies were industry, intensive agriculture and the organized service sector- especially the bureaucrats who also administered the subsidies. Politicians ultimately decide on who receives the subsidies, and they largely came from among the larger landowners and from those engaged in the organized industry and service sectors. Together these constituted the iron triangle governing the resource use pattern of the whole country (Fig. 1).



**Figure 1 : The iron triangle governing resource use patterns in India with large state-sponsored subsidies creating an iron-triangle of components of Indian society benefiting from administering and deciding upon resource subsidies. Redrawn from Gadgil (1991).**

In many parts of the tropics as the colonial period progressed, there was a shift in the perceptions of forest and in societal arrangements for the management of forests. Forests and forest development became near synonymous with the production and harvesting of a single product: timber. Forestry research increasingly focused on the development of approaches and techniques for promoting the production of wood for different needs and purposes, with two principal silvicultural systems being developed:

*Polycyclic* i.e. several logging interventions within one lifetime of a typical harvested tree; intermittent removal of selected trees, ideally resulting in scattered, relatively small gaps in the forest canopy, thus perpetuating shade-tolerant and slow growing species; or

*Monocyclic* i.e. logging only once in a "rotation" or lifetime of a typical harvested tree; involves removal of all saleable trees in one operation, resulting in extensive opening of the canopy; thus favouring light-demanding and fast-growing pioneer species (e.g. Malayan Uniform Silvicultural System).

Successful implementation of these silvicultural systems has proven to be illusive, however. In most tropical regions, government policies have been inimical to sustained development, as vividly illustrated by Repetto (1987) in a study of some of the impacts on tropical forest development of investment incentives, tax and credit subsidies, pricing policies and concessions. Such incentives may lead to considerable economic losses, reductions in potential profits and net foreign exchange earnings, loss of badly needed government revenues, and increased windfalls for a favoured few businesses and individuals. A move away from such perverse economic incentives is among the shifts required if tropical resource use is to be put on a more sustainable basis.

### **Towards Greater Sustainability of Management**

As mentioned above, the forest-dwelling peoples of tropical forest landscapes have long practised sustainable management of their resources, otherwise the present generations of those forest dwellers would not be here. Such a sense of intergenerational relations is reflected in the general working definition of sustainable development given a decade ago by the World Commission on Environment and Development: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts: the concept of "needs", in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by a state of technology and social organization on the environment's ability to meet present and future needs" (WCED 1987).

The World Commission on Environment and Development, popularly known as the Brundtland Commission, did much to trigger and shape discussion on sustainable development, a process that was continued by the events associated with the United Nations Conference on Environment and Development, Rio, June 1992 and its follow-up.

The wide ranging nature of the debate associated with that process has meant that the very term "Sustainable development" has many dimensions and many interpretations, with many definitions being proffered by people from different disciplinary and professional backgrounds and resource-interests. At an operational level - four interlinked-dimensions of sustainable development can be recognized - economic, environmental, social and cultural - and di Castri (1995) has used the image of a

Renaissance chair to suggest that sustainable development can have a working sense only when these four dimensions of development are of equivalent importance and strength, with solid interactions between them provided by an adaptive institutional framework. If one leg of the chair is shorter or weaker than the others, there is no comfortable "sitting-down" state, there is no sustainability. No one country or region has reached an acceptable dynamic balance of the four legs. And growing disequilibria between the various legs in particular parts of the world are threatening the prospects of moving towards more sustainable ways of using natural resources and of improving the relations between people and their environment and above all between people with different identities (historical, cultural, ethnic, social).

Some other reflections on sustainability provide insights to other dimensions of this relative concept, which is markedly influenced by time and space scales and the perception of different groups of people.

- "Sustainable development of forest land and its multiple environmental values involves maintaining without unacceptable impairment, the productive and renewal capacity and species diversity of forest ecosystems" (Maini 1989)
- "Some might argue that this attention to sustainability is another political fad which will pass as fast as it arrived. I do not think so. There is considerable evidence that this is likely to be more than a short-lived, international, political ploy to obfuscate serious land use conflicts: Consider the large number of heads of state at the UNESCO conference in 1992; consider the seriousness with which many countries or groups of countries have taken the follow-up responsibilities to UNCED as witnessed by such activities as the "Helsinki process" and "Montreal process" aimed at developing internationally agreed upon Principles and Criteria for Sustainable Forestry, or the attention to the same concerns by the tropical countries.. The concept of sustainable development is easily understood even if the implementation is difficult. It is, in its most simple form, "economic activities thoughtfully and intelligently managed in such a way that they do not destroy or significantly impoverish the natural support systems on which they or other economic activities depend. "I conclude that the *concept* of sustainable development is here to stay, whether called by that name or something else" (Whaley, 1996).

## **PROGRESS AND CHALLENGES IN HARNESSING RESEARCH TO DEVELOPMENT**

Among the features of recent trends in approaches to natural resources management is that of bringing together all interested groups and sectors in partnership approaches involving different stakeholders. Accompanying this general trend are changing perceptions of the role of different partners and stakeholders, including local communities, government agencies, private-sector bodies and research groups.

### Involving Local Communities in Joint Forest Management

One of the most notable recent social developments in forest management has concerned local community groups taking on a focal role in the effective management of forest resources, working in tandem with non-governmental voluntary bodies and governmental agencies such as state and federal forest departments. The basic rationale is that village level institutions that allow everyone to take part in decision making, articulated with the advisory inputs from governmental and non-governmental groups, can provide a mechanism for setting agreed objectives and resolving disputes, while ensuring appropriate scientific and technological inputs under a given social structure. In many parts of Asia, it is especially important to ensure effective participation by women-folk, given their crucial role in the functioning of the local ecological system. Several examples are given in an analysis of issues in the rehabilitation of the rural landscape in South and Central Asia (Ramakrishnan *et al.* 1994).

One success story which offers many lessons is the case of the tribal women of Bankura in West Bengal who undertook and implemented ecosystem restoration activities through a joint initiative of the International Labour Organization (ILO), and non-governmental women's societies. Organized in a three-tier framework, the women participated from the very beginning in the formulation and execution of the programme, which has concerned 36 villages and 1500 families reafforesting with Sal (*Shorea robusta*) and Arjun (*Terminalia arjuna*) (ILO, 1988). Supplementary income to the women comes not only through the use of tree leaves for making tableware (leaf plate) and Bidis (local cigarettes) but also through rearing silk worm moths and collecting a variety of non-timber forest products. Agricultural activities in predetermined sites are also encouraged. The forest-based income so generated is over Rs. 7000 per hectare per year.

In a related experimental scheme in the Arabari area of West Bengal, the local villagers and the Forest Department created Forest Protection Committees covering about 152,000 hectares of degraded forest area (Malhotra & Poffenberger, 1989). Forest Protection Committees involve representation for each family, non-governmental grassroot level workers and the Forest Department representatives. Again, people's participation in these committees is ensured right from the beginning, which take decisions for implementation. In the *Shorea robusta* dominated forest, the income of villagers was augmented through enabling access to all non-timber forest produce, with a bonus share in the timber so protected. The villagers were also allowed to undertake limited agricultural activities along the periphery of the forest. The degraded forests regenerated rapidly. The approach to forest management was a truly integrated one, and provided income of up to about Rs. 3500 per family per year, based on access to one hectare of forest per family.

Forest Protection Committees, with people's participation along with governmental and non-governmental agencies, have now been recognized as the basis for forest management in other regions of India, and elsewhere in the region. The Nepal-Australia

Community forestry programme in the Bhagwan Thumki forest area of Nepal entails the formation of use groups for forest management and utilisation of forest products by local communities (Shrestha, 1992). The Forest User's Executive Committee, with representation from different villages and settlements, has evolved an elaborate set of rules for controlling access and appropriately redistributing pressure on the forest resources on a year-to-year basis. Here again, the involvement of the local people is ensured from the very beginning. Conserving forests has been reported to have improved soil moisture retention and water availability in the streams, which in turn may have had positive impacts on land use (agriculture) and animal husbandry.

The success of these various programmes is largely dependent upon building village level institutions that are able effectively to ensure a sustainable livelihood for the local communities. At a policy level, it would seem important that acts and policies are adapted so as to recognize clearly the role of local communities. The decision-making process is decentralized at all levels - a process that is particularly relevant for the governmental agencies, where organisation tends to be hierarchical and decisions are often remotely controlled.

These several case studies are illustrative of a variety of issues that are interactive and that need to be considered in designing strategies for the rehabilitation and improved management of forest resources. Ramakrishnan *et al.* (1994) have suggested that, as an ensemble, experience gained in such case studies can be distilled in the form of a series of assumptions and general hypotheses on which rehabilitation strategies may be based. A sampling of the hypotheses proposed by Ramakrishnan *et al.* is given in Table 1, in terms of general hypotheses and hypotheses related respectively to ecological, socio-economic and institutional-policy issues, with Figure 2 presenting an overview of the three major interacting issues (ecological, socio-economic, institutional-policy) and some of the subtending sub-issues. An overall conclusion is that rural landscape rehabilitation and management and the sustainable livelihood of the populations concerned are two sides of the same coin, in much of the Asian tropics. Many large-scale efforts initiated by governmental agencies have often failed to integrate the social, economic and cultural dimensions with other issues and problems. The institutional frameworks presently available in the region are often not geared to integrate the varied dimensions and to take a holistic approach to natural resource enhancement and management. Therefore, either new organizational mechanisms need to be created or existing mechanisms modified. In this effort, various actors - the local people, non-governmental grass-root level workers, governmental agencies and the scientific community, including social scientists - have to come together.

**Table 1 :** A sampling of hypotheses related to ecosystem rehabilitation in the Asian tropics, grouped under four headings - general, ecological, socio-economic and institutional-policy. Adapted from Ramakrishnan *et al.* (1994).

### General hypotheses

- Rehabilitation and management will only succeed if short-term economic benefits to local communities are assured, as a prerequisite for achieving long-term benefits and goals.
- Women's participation is necessary for rehabilitation and management strategies to be effective and successful.
- Without a broad understanding of the complexities of the system (through rapid appraisal methodology), rehabilitation strategies may not succeed.
- Unless ecosystem rehabilitation and management leads to a general improvement and maintenance of soil fertility and water quality, it is not sustainable.
- Ecosystem rehabilitation will be sustainable only if: (a) the internal control of processes (e.g. resource recycling) within the ecosystem are strengthened, (b) the dependence on external subsidies (e.g. fertilizers) is minimized, and (c) self-regenerating capacities are enhanced, to the extent feasible.
- In order to succeed, ecosystem rehabilitation should ensure strong

community participation in the planning, management, implementation, and continuous monitoring of all these parameters.

- Unless rights and responsibilities of ownership are clearly defined and understood by all the participants, ecosystem rehabilitation is not likely to succeed.
- If community participation is to be effective, community/user group institutions have to be built into the rehabilitation strategy.
- Unless there is integration of land capability analysis and classification, taking scientific and traditional knowledge into account, rehabilitation work will not be effective and sustainable.
- Empowerment (training, institutional development, access to facilities and resources) of local communities in general, and vulnerable groups (landless people and women) in particular, is crucial for the success of any rehabilitation programme.

### Hypotheses related to ecological issues

- A cost-effective way for rehabilitating degraded lands is to optimize the natural regeneration potential of the site by accelerating the natural processes of succession, wherever feasible.

Table 1 : Contd.

- The use of exotic species in restoration should be viewed only as a facilitator.
- Integrating traditional technology with other technological interventions (e.g. physical/mechanical intervention for soil and water conservation) is crucial for the success of rehabilitation.
- Nutrient deficiency in highly degraded ecosystems can be countered through the use of species that are nutrient enriching and/or nutrient use efficient.
- For effective integration of biodiversity concerns into ecosystem rehabilitation, it is crucial to consider. (a) local value system perceptions as reflected in such traditional conservation efforts as sacred groves or sacred species, and (b) identification of ecologically important keystone species and matching them with socially/economically selected and therefore valued species as identified by the community.
- Women and socially and economically vulnerable groups are involved in all aspects of rehabilitation.
- Environmental and social costs and benefits arising from the programme are incorporated.
- Emphasis is laid on rural-based processing and marketing of natural products that may be "value added".

#### **Hypotheses related to institutional and policy matters**

#### **Hypotheses related to social issues**

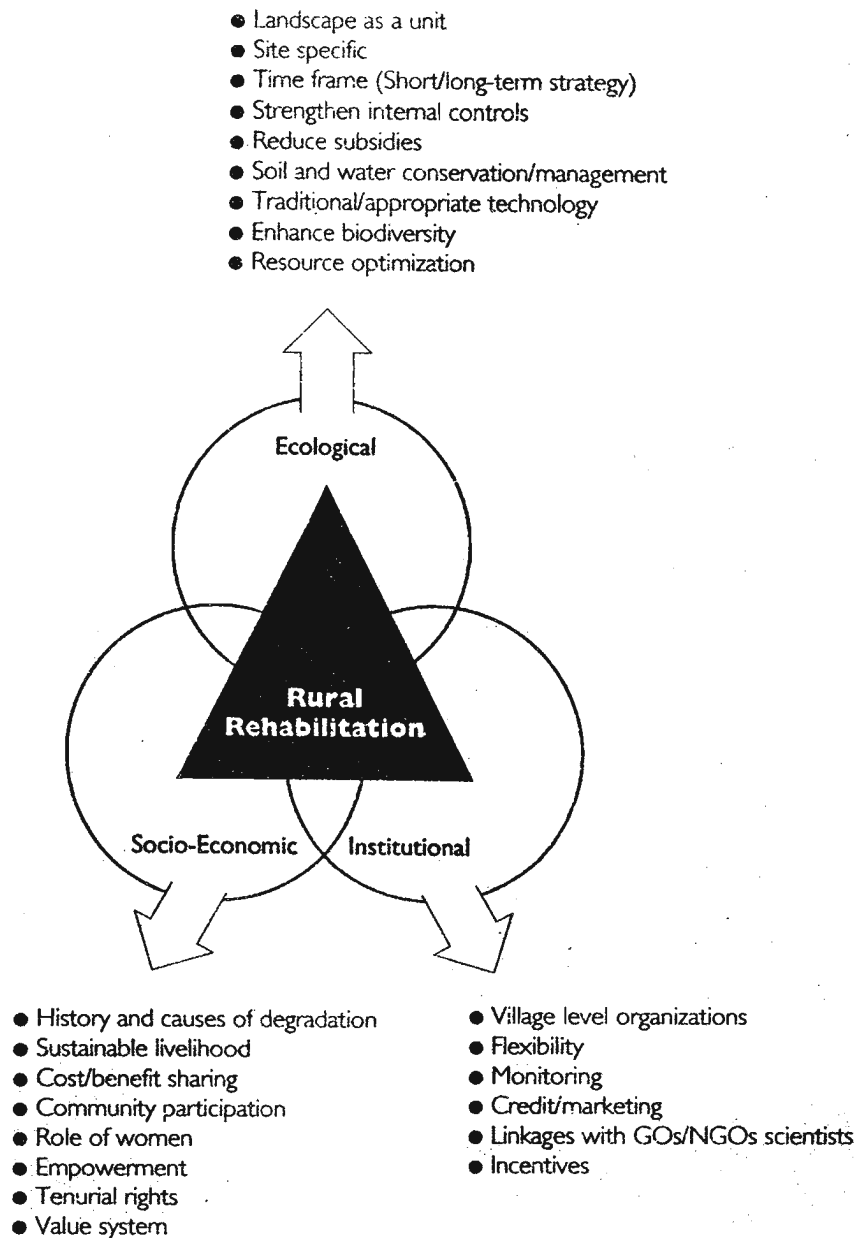
Ecosystem rehabilitation and management will be successful and sustainable if;

- Management systems involve the community and user groups, with costs and benefits being shared by the stakeholders and the long-term ecological benefits matching the needs of the community.
- Without appropriate legal and legislative frameworks which clearly define the rights and responsibilities (tenure, access, etc.) of all the stakeholders, ecosystem rehabilitation will not succeed.
- Without clear operational guidelines and explicit and transparent contractual agreements between stakeholders, rehabilitation efforts will not succeed.
- Ecosystem rehabilitation is viable only if pricing reflects the true value (ecological/economic) of the regenerated resource.
- Effective coordination of different liaising agencies/departments at the village level is crucial for the success of rehabilitation.
- To institutionalize ecosystem rehabilitation, it is necessary to build-up the knowledge base/skills/management capabilities of the stakeholders.



Table 1 : Contd.

- Unless credit facilities, markets and appropriate marketing channels are available and incorporated into rehabilitation and management, rehabilitation initiatives will not be sustainable.
- Appropriate institutional mechanisms should be available at the local level for conflict resolution between different stakeholders, to settle conflicts arising during and as a consequence of ecosystem, rehabilitation.



**Figure 2 : Integrative diagram linking the three major issues and many sub-issues crucial for rural rehabilitation. Redrawn from Ramakrishnan *et al* (1994).**

**Seeking new partnerships with the private sector**

There is a range of perceptions and views on the role of the private sector in the management of tropical forest resources. On the one hand, it is argued that a thoroughly predatory approach characterises the major business companies, no matter how much it may be disguised. In short, entrepreneurs will be as exploitive as they are allowed to be. On the other hand, public concern with such issues as criteria for sustainable management of tropical forests is helping to focus attention on environmental safeguards, and on the need for private companies to seek a balance between short, medium and long-term concerns rather than giving overwhelming importance to short-term time horizons.

The move towards greater co-operation and constructive criticism with the private sector can take many forms, reflecting the diverse functions of private sector enterprises in relation to tropical forest resources. Companies can be classified in four large groups: (a) harvesters/transformers/producers of tropical resources; (b) researchers on tropical forest goods and services; (c) financiers of private and public investments in tropical forest projects; and (d) trade and transport enterprises (Hadley & Dogse 1990).

Harvesters and producers of forest resources range from small family "enterprises" to huge multinational timber companies. The overall impact of a large number of small-scale forest operators is often immense although each firm's impact might be marginal. The fact that small enterprises often rely on large-scale firms opening up intact forest areas, illustrates the importance of understanding the interplay between large and small-scale private enterprises.

Research is crucial for generating increased knowledge on the potential products from tropical forest ecosystems. It may contribute to the identification of valuable animal and plant species which could be used in the development of new marketable forest products (e.g. medicines and in biotechnological research). It is possible, however, that the discovery of new forest commodities in many cases might only lead to increased non-sustainable forest use, as the major problem in the tropics frequently is not the lack of resources but their mismanagement. Private credit institutions play a crucial role in the way forests are being managed by providing investment capital for a wide spectrum of extraction, industrialization, and infrastructure projects. The aggravated debt crisis has also made several heavily indebted tropical countries more susceptible to economic restructuring and development programmes suggested by the creditors. Frequently such programmes have emphasized increases in export oriented activities, such as tropical hardwood logging, so as to earn the hard currency necessary for servicing the debt.

Trade and transport constitute the physical link between the supply and the demand of tropical forest goods. It is therefore of strategic importance for international policy-makers interested in modifying production and consumption trends. This is especially so

for the part of the goods produced in the tropics that is consumed elsewhere (in the North) and therefore passes through transport channels.

Within such a framework of functional relationships of private sector enterprises with forest resources, the question of scale - from the global to the local - takes on considerable importance. An example is that of actions restricting logging in one country, which might well increase the rate at which forests are cleared in other countries, as reflected in the repercussions of the ban on logging in Thailand on timber exploitation in neighbouring countries.

At another scale is the notion of mobilizing private enterprises in respect to the management of natural resources in a particular forested locality. An example from UNESCO's programmes is the Kutai National Park in East Kalimantan (Indonesia), which was established to preserve the largest remaining tract of lowland rain forest in East Kalimantan. Half of the mammal species of Borneo and the majority of the bird species of Borneo still can be found in the park. But fire, logging and mining activities in the past have degraded extensive forest areas and the expanding industrial towns of Bontang and Sangatta have encroached the park boundaries. Under the name of "Friends of Kutai", local industries (coal, petroleum, paper, natural gas and timber) and governmental agencies have accepted to work together towards the conservation and management of Kutai National Park. A critical step was reached in December 1995 when the industries formally committed financial support towards the rehabilitation of the park. UNESCO and UNDP play a role as catalyser and by providing technical advice to the "Friends of Kutai". UNESCO also supports the management of Kutai on a day-to-day basis through the presence of a resident expert and other staff, the purchase of equipment, and the training of the Park staff.

### **Changes in government perceptions and involvement**

There is increasing recognition that the role of government in respect to forest resources needs to change, away from a direct control and management responsibility towards a supporting and facilitating one (Pinbert & Pretty 1994). Within such a context, Fisher (1995) has suggested some specific roles, as follows: facilitating conflict resolution among groups of resource users; providing a back-up when groups of users attempt to implement regulations, but are unable to enforce them, which would apply to conflicts within a user group, and which might be particularly important in enforcing restrictions against outsiders; ensuring that negotiated agreements take into account the interest of diverse groups within communities (i.e. monitoring the equity of sharing costs and benefits among stakeholders; and providing advice on technical matters when required.

Seen from the government side, there are also indications of changing perceptions and attitudes. One reflection of this change, at the international level, are the topics brought

to bear on discussions about forests within the ad hoc Intergovernmental Panel on Forests (IPF), set up by ECOSOC following a recommendation of the Commission on Sustainable Development, with a view to pursuing consensus and co-ordinated proposals for action to support the management, conservation and sustainable development of forests.

Subjects examined by the panel at its two sessions in 1996 have included the assessment of the multiple benefits of forests, sectoral and cross-sectoral linkages related to forest management, development of criteria and indications for sustainable forest development, refinement of forest principles, and traditional forest-related knowledge. Perhaps significant has been the widely based participation of representatives from the non-governmental sector and indigenous peoples associations in the work of the panel. Also noteworthy is the prominence given to considerations such as "culture" in documents prepared for the panel, such as the following extract (United Nations. 1996, para 13).

"As a group accumulates TFRK (Traditional Forest-Related Knowledge), it will develop a culture that is increasingly distinct from all others. Many similarities will persist, however, owing to common cultural and genetic inheritance from other peoples, and adaptation of other groups to the demands of similar ecosystems. Each culture thus contains some traditional knowledge that is uniquely local, and some that is widely shared. The two kinds of knowledge are deeply intermingled and embedded in the culture as a whole. Most elements will make little sense if they are removed from a cultural context - when stored, for example, in a computer database. Many can pass easily into new cultural contexts, however, if the recipient culture is open to new ideas and particularly if it has grown up in a similar environment - one, that is; in which the imported concepts make sense".

"Culture" or "cultural" appears seven times in this paragraph. It is highly unlikely that such mentions of culture in respect to forest conservation and management would have been included ten or even five years ago in the official documents of inter-governmental forestry bodies.

### **Research perspectives on forest systems**

Just as the last decade or so has seen change in the relationships of local communities, the private sector and government agencies to forests, so there have been shifts in the forest research agenda. Driving forces behind that change have included public and policy concern with such issues as climate change, biological diversity and the rights of indigenous and other forest-dwelling communities.

Manifestations of changes in the forest research agenda are many, including the increasing interest in forest systems of scientific groups not usually considered as part of the forest-research community. An example is the climate change community, and those interested in the functioning of the global earth system and the refinement of the global

climate change models. Reflections of that interest are considerations on forests in the work of the Intergovernmental Panel on Climate Change (1996), on such aspects as climate change impacts on forests, the management of wood production under changing climate and land use, and the management of forests for mitigation of greenhouse gas emissions.

Within the research community more traditionally associated with forest systems, there are also multiple indications of shifts in approach and new or reinforced directions of enquiry (Hadley and Schreckenberg 1989, Schreckenberg & Hadley 1991). Examples include the search for promising tropical forest trees as candidates for domestication (e.g. Leakey and Newton 1994) and new approaches to the valuation of the products and services provided by forests (e.g. Godoy & Bawa 1993).

Within a broader societal context, there are also illustrations from many countries of scientific groups becoming associated in broadly based societal initiatives to improve ways in which forest resources are planned and managed, as for example within individual sites contributing to the World Network of Biosphere Reserves (UNESCO 1995) or to the Canadian sponsored Model forest initiative.

## **CONCLUDING REMARKS**

In many parts of the humid tropics, trends in the history of forest management are closely linked to the broader context of government and social and economic development. In India, for example, Hobley (1996) recognizes the four stages of "Colonialism, Commercialism, Conservation and Collaboration". Systematic alienation of forest communities from their resources by the state was followed by increasing commercialism of a relatively narrow band of forest products and natural resource protection against the majority of local resource users. More recently, participatory forestry represents a democratic assertion of people's rights and a move towards decentralized systems of responsible resource use.

A challenge in this process is that of maintaining the skills and knowledge of different social groups as roles and perceptions change. Here, Poore (1995) has commented on dangers 'when the constituencies do not confine their influence to stating what they want, but become involved in determining how it should be done. The management of forest ecosystems is a highly expert matter. Just as one would not allow a panel of the interested public to decide how a patient should be treated but would rely on expert medical opinion, so forest management and its standards is the province of professional foresters. The challenge facing them is to have the knowledge and skill to manage forests for these multiple benefits, and to have the sensitivity and wisdom to recognize, understand and anticipate the changing needs and wishes of the society they serve'.

Another key aspect of this changing universe of forestry management is the need for forest scientists to become more proactive in the national and international forest policy dialogue. To close by borrowing from an address of FAO's Assistant Director General of Forestry, David Harcharik, to the Twentieth World Congress of the International Union of Forest Research Organizations in Finland in 1995. "Often the research community has left it to someone else to translate the results of research into action. This has led not only to an unduly low profile for the research community, but especially to the risk of important decisions being taken in ignorance of good science. The research community should make its voice heard along with the many other legitimate partners in the forest development debate, while also maintaining scientific independence and credibility". (Harcharik 1996).

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