MONASH UNIVERSITY

MONASH PUBLICATIONS
IN GEOGRAPHY AND ENVIRONMENTAL SCIENCE

Number 49

ANALOGUE FORESTRY: AN INTRODUCTION

By

RANIL SENANAYAKE AND JOHN JACK

ANALOGUE FORESTRY:
AN INTRODUCTION

by

Ranil Senanayake and John Jack

1998

Monash Publications in Geography Number 49

Department of Geography and Environmental Science,
Monash University, Melbourne, Victoria 3168, Australia

Department of Geography and Environmental Science
Monash University

National Library of Australia ISSN
ISSN 0313 8410

National Library of Australia Card Number and ISBN
ISBN 0 909685 58 4

Illustrations, Formatting and Design by Gary R.R. Swinton
Published by
Department of Geography and Environmental Science,
Monash University Clayton Campus
Printed by
Monash Print Services, Monash University, Caulfield Campus

CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

ABSTRACT

Forests and other 'natural' areas have been subjected to increasing public scrutiny over the past 40 years; much of this has been associated with a concern for loss of biological diversity including (more recently) the loss of cultural values of native peoples.

A challenge to emerge from the considerations of the operation of the Convention on Biological Diversity is the observation that over 99% of the biodiversity of a forest is contained within its non-tree component, While the ideal way of maintaining the original levels of forest biodiversity is in the scheduling and management of forested land for conservation, there are relatively small resources available for purchase or scheduling of protected areas. The establishment of protected areas and private reserves are not enough for conservation, due to their small area and the likelihood of conflict between conservation values and the human need for resources.

The conservation of standing forest is a priority, but given present population and economic trends the degradation of biodiversity within non scheduled areas of forest will reach exponential rates unless directly addressed in the context of forest biodiversity conservation. For instance, one of the greatest unrecognised areas in tropical rainforest conservation and rehabilitation efforts is the loss of non-woody plant taxa and the subsequent loss of the organisms dependent on these microhabitats. Analogue Forestry is a response that seeks to address both the genetic and cultural issues of biological loss. This paper explores the major ecological processes that underlie Analogue Forestry. A 'forest' in the context of these discussions is distinguished from 'plantation' which latter is basically a collection of trees of the same age and species and with little or no attention to the non-woody species. Similarly 'agroforestry' deals with a limited range of non-woody plants and of those not usually in a conservation context.

It is suggested that it is the diversity of species, functions and structures that distinguish the 'forest' from other collections of trees (plantations, shelter-belts, agro-forests and the like). Much consideration is given to the inter-connectedness of functions within the forest over time and thus the importance of successional changes and adaptability of plants and other organisms of the forest ecological system. It is postulated that much of the undervaluing of forests in Western culture derives from an ignorance among the owner/managers (government and industry) of the wide range of 'products' of the forest, most of these from non-woody plants. In consequence the nature of forest products is dealt with in some depth.

Because of Analogue Forestry's derivation from the practices of forest management by traditional peoples its application requires that the cultural values of its practitioners be fully taken into account in the design and operation of each new project. It further follows that the Analogue Forest will mimic the structures and functions of the most locally relevant native 'forest' (local ecosystem climax) and that it will fit (balance, function and structure) appropriately within the anthropogenic and natural landscape of the region.

Case studies detail how Analogue Forestry has been applied in two locations, one in Sri Lanka and one in Victoria, Australia. The experience distilled from these studies and particularly those of the senior author in numerous developing countries is listed as 'Pre-requisites for successful Analogue Forestry'. The special issues that gene conservation raises and the role of Analogue Forestry in support of traditional conservation measures are also examined.

ACKNOWLEDGMENTS

Department of Geography and Environmental Science for administrative support. Members of the Environmental Management Unit and particularly Dr Clive Coogan, RSA, for their confidence and support. Peter Mathews and Carmen Zerata for their helpful criticism of the early drafts, Anthony Dufty for his detailed editing and scientific criticisms, Gary R.R. Swinton for his careful and skilled production of the figures and David Mercer who oversaw the final editing and production process.

NOTE ON AUTHORS

Ranil Senanayake: Consultant to Environmental Liaison Centre International, Nairobi, KENYA. Advises and directs dialogue between NGO's and governments on biodiversity issues, particularly those relating to indigenous peoples in Africa, East Asia and South America. Ranil directs the NeoSynthesis Research Centre, Mirahawatte, Sri Lanka and works closely with the hundreds of villages engaged in production and sale of organic products by the Analogue Forestry process.

John Jack: Honorary Research Fellow, Department of Geography and Environmental Science, Monash University, Clayton, Victoria 3168, Australia. John directs the activities of the Environment Management Unit. EMU is concerned with developing a global type database for local biodiversity management and enhancement. EMU provides seminars and workshops to inform farmers and other on Analogue Forestry and related processes.

CHAPTER ONE

INTRODUCTION

'We who can call an art "significant", knowing not of what, are also proud to "progress" we know not whither' (Coomaraswamy, 1947, p.33).

Modern, technological society has a short, dramatic history, its growth shadowing the outburst of human populations. During the past 160 years there has been an exponential rate of increase in the global population. The human population grew from about one billion people in the 1830s to two billion a hundred years later. This doubled to four billion in 1975 a mere forty-five years later. The increase has been largely made possible by our ability to control disease and reduce mortality, thus conferring on humanity the greatest asset of a species, its ability to survive and grow. Currently the world population (five billion and growing exponentially) can be seen as a logical expression of the species imperative, to project itself into the future. It can also be seen as a causal factor in the degradation of the very environment that is optimal for the survival of the species. Whatever historical or philosophical perspective is accepted, one fact is real by all scientific measures: the effect of this increasing population has been to degrade patterns of ecosystem stability.

Technological advances have paralleled and been integrally related to growth of human populations. These advances have been powered by non-photosynthetic energy. World growth is defined by goals that had no need to address biological or ecological criteria. Modern technological society has organised itself around the flow of money, the measure of which is economics, which assumes that anything that leads to the growth of this society is good. The energy to power this growth comes from the activity of consumption. Consumption is seen to be the effective engine of economic growth. However, most economic models give a very low value to social and environmental goals. Without assigning significant value to such goals, economic growth can become a mindless rush to increase monetary value. This results in the patterns so familiar through much of the world today, the massive spiral of consumption-driven, environmental and social decay.

The consequence of this type of development was seen by many. It is summarised most eloquently by Mahatma Ghandi, who, when addressing the Indian people at independence, observed that with independence, India came into the modern world and perhaps may wish to become like Great Britain from whom she had just gained independence. He said that 'We should not forget that it took the resources of half this world to make Britain great', and concluded with the rhetorical question 'If we (India) want to be like that how many worlds would we need?'.

Increasing rates of desertification and rainforest destruction have resulted from following the current path to progress. By 2030 most of the tropical forests will be gone and by 2060 as much as a third of all arable land will be desert. These signals suggest an erosion of the systems that are essential for the sustainability of human populations. It means a reduction in our biological potential to survive, due to the fact that a large contribution to the biological quality of life is provided by the living component of the environment. This relationship, of biodiversity and sustainability, is being recognised at the highest international level with the governments of the world directing that links between the United Nations conventions on biological diversity and sustainable development be explored.

The biological quality of life is the state of any individual's environment. Evaluation consists of the relatively simple question: is the environment malign to the individual or is it benign? Any measure of the biological quality of life recognises the fact that biological organisms have finite thresholds. In a biological sense, the most fundamental need is the ability to survive. At an individual level this means to stay alive, while at the level of the genome it is the ability to extend the genotype into

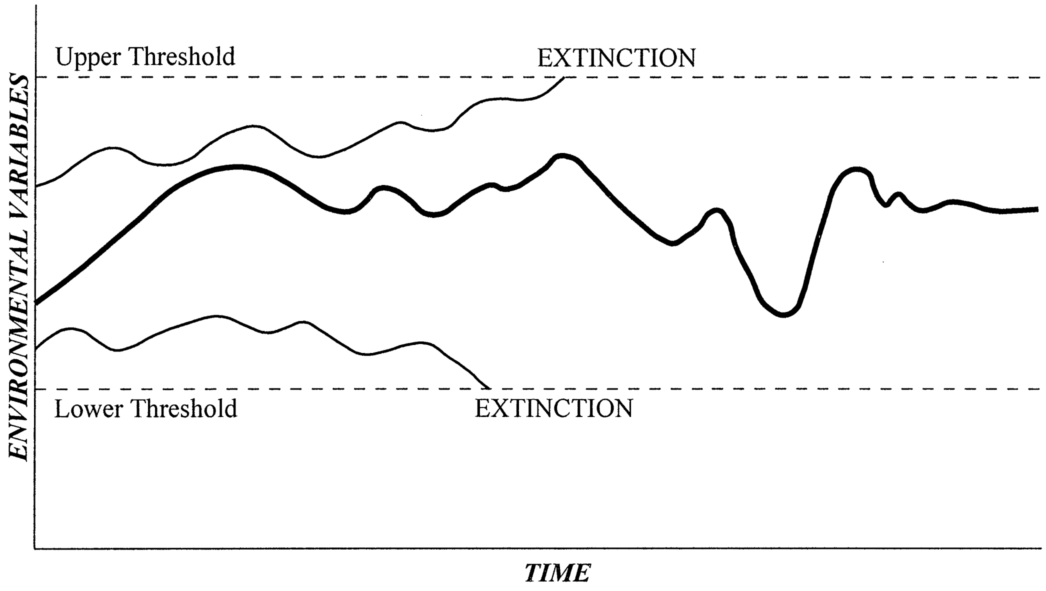


Figure 1: The environmental space of an organism is defined by the threshold variables

the future and at the community level it is the potential to recover from perturbation and stress.

Any biological system or community can be seen as a system which oscillates between inflexible boundary conditions without exceeding any boundary conditions. If the boundary conditions are exceeded, a change in state occurs so that the system loses its current identity and potential. For an individual, exceeding the boundary conditions the result is death (Figure 1). Thus, the sustainability of biological systems is determined by their boundary conditions, as well as by internal dynamics. This exemplifies the fact that biological entities are not abstract.A biological entity is a product of its temporal and genetic history in varying environments operating within set environmental thresholds that cannot be transcended without extinction. While acclimatisation often allows an individual or species to change its measured thresholds over evolutionary time, there exist lethal thresholds, such as toxin concentration or temperature, beyond which an organism cannot transcend (McLeese, 1956).

These boundaries are often easy to quantify and can provide a measure of the most fundamental human right, the right to life.While this subject requires address elsewhere the improvement of environmental stability will most certainly have a positive impact on the biological quality of life by sustaining fundamental human needs such as the quality of land, air and water.

The forest has long been recognised as an important source of these environmental needs, but the immediacy of demand for one of its highly valued products, viz. wood, has obscured the value of these more fundamental needs. In the light of modern knowledge the role of a forest has to be evaluated in wider terms. What is known by science reveals the forest as an ecosystem of tremendous complexity. These environmental needs certainly demand more effective management attention if its effectiveness in environmental stabilisation or biodiversity conservation is to be developed. It also suggests that a forest is not just a collection of trees; it is a complex ever-changing system, a huge array of organisms that continually changes in form and function.

The loss of biodiversity has been examined by many scientists and judged to be reaching a critical state. One measure of this loss can be seen in the current rate of species extinctions. This trend is alarming enough to produce global response, as seen in the Convention on Biological Diversity (CBD), and global action as seen in the work of international organisations such as the International Union for the Conservation of Nature (IUCN), the World Wildlife Fund (WWF), the United Nations Environment Programme (UNEP), the United Nations Development Programme (UNDP), the Food and Agricultural Organisation of the United Nations (FAO) (CGIAR). Recent research suggests that the rate of loss might be a magnitude greater than was generally accepted (Adis, 1988). If adequate levels of biodiversity are to be sustained, a fundamental requirement for land management will be that all ecosystems be managed to conserve the greatest amount of genetic and ecological information. There is also a growing body of knowledge that demonstrates a link between the loss of biodiversity and the loss of forest cover (McNeely *et al,* 1990).

The consequences of the loss of forest cover also need to be addressed in terms of more immediate human needs. Loss of income, loss of water quality and the loss of traditional botanicals (plant sources of food and medicine) are some short-term consequences. The income that a local forest can produce has not been fully appreciated by an administration that sees wood as the greatest asset of a forest and has been weaned in the post-1800 traditions of European forestry. These practices reversed earlier traditions of holistic management and has developed a science of even-aged, short rotation, monoculture plantations for wood production, as a definition of forestry (Robinson, 1988).

Biodiversity is what gives a forest its identity. In this context, a forest must also be appreciated as a constantly changing, growing entity. From the small bushes that grow in an area after fire, to the tall growth fifty years later, the species and architecture go through many changes, all expressions of the growing, maturing forest. This process was modified and simplified to produce even-aged monoculture plantations. While being a very effective response to the need for wood, this type of forest cannot provide all the environmental outputs of natural forests. However, this is the only major response to the phenomenon of forest cover loss to date.

This level of response has compounded the impact on the environment by human population growth to produce the present crisis expressed as a loss of biodiversity and ecosystem stability. One problem seems to stem from the short history of the science of modern forestry. As Robinson (1988) states, scientific forestry began in Germany in the 1790s with the work of Heinrich Cotta and G.L. Hartig. A short time later, Bernard Lorentz and Adolphe Prade started its practice in France. Thus the age of modern silviculture is roughly equivalent to only two or three generations of forest trees. The development of this system to encompass all of global forest loss has been accepted to be logical by a very narrow set of criteria being given value in many economic analyses. The present crisis is an indictment of the assumptions that contributed to such analyses.

The need to develop a scientific system of silviculture that answered to a wider set of needs was expressed by these very pioneers of modern forestry, but its development was eclipsed by economically expedient wood production. The tree planting efforts of humanity span periods exceeding 10,000 years and are reflected in the wealth of traditional knowledge within various societies. The evaluation of this data and incorporation into a scientific system of silviculture began with work such as Smith (1977) on tree crops as a replacement for annual cropping and the extensive work on traditional forestry done by the International Center for Research in Agroforestry (ICRAF) (Nair, 1989).

Recent reports of remote societies suggest that some communities may have very sophisticated forest management systems in terms of biodiversity conservation (Knudtson and Suzuki, 1992). The value of using traditional design to augment modern forestry goals is exemplified by an experiment in the synthesis of Mayanmarese (Burmese) traditions and forestry science in 1806. This experiment produced the 'taungya' method of establishing teak (*Tectona grandis*) plantations (Blanford, 1958). This method of forest establishment was so successful, that it has spread to most of the tropical world and has become the precursor of modern agroforestry (King, 1989). In brief, the method entails the planting of young teak trees among traditional annual crops, such that the sun-loving crops common to slash and burn agriculture could be maintained for the first few years of tree growth. Once the trees had attained enough stature to shade out the annual crops, the land was taken out of annual cropping and devoted to the silviculture of teak.

The need to develop revegetation strategies that tend to provide economic benefits while providing ecological benefits is a need attaining great importance within an increasing percentage of the population in both professional and public spheres of influence. The response to this need is insufficient in much of present silviculture design, even-aged monoculture being the extreme example. In revegetation strategies that seek to provide both economic and ecological benefits, the ecological factors describing the original vegetation will provide many of the design characteristics necessary for continuity of the system. In terms of economic factors, systems of human land use with a long history of tenure on a particular landscape can provide other sets of design characteristics of great importance for sustaining value.

If the evolved patterns of natural vegetation cannot be maintained in a given landscape, the best degree of environmental stability can be provided by vegetation patterns analogous to the evolved patterns. On a landscape scale this is envisaged by patterns of tree covered and open land. Once patterns analogous to the original structure have been addressed, other biological considerations can be introduced. One such will be at the taxonomic level. Here, the identity of the species of plants that constitute the original tree cover would help to determine the required plantings, again patterns analogous to the original would seem to provide optimum benefit.

The ecological identity of forests is set by species presence, architecture, trophic structure and biodiversity. Thus, the design of forest analogues must be guided by such variables. In turn, these variables provide a measure by which the efficiency of the design can be judged. Progress, in terms of forestry, would seem to be the development of most elegant revegetation efforts that include economic, social and environmental goals in the design. The goal towards which such action should be directed is defined by the original formations of vegetation.

Appreciating a forest in all its permutations is an extremely complicated task. To be appreciative of the relative strengths and weaknesses of each variable, be it a tree or a butterfly, requires data collection and processing at a prodigious level. This is where cultural knowledge becomes invaluable. At an indigenous level of resolution and management, societies have demonstrated an understanding of forest processes that allowed for the creation of sustainable, dynamic forests that were systematically planted. These forests are almost indistinguishable from natural forest. This level of silviculture will require a tremendous amount of research and trials to emulate.

The current body of indigenous knowledge in silviculture can provide some valuable models but, due to the legal problems of moving plants and animals across national borders, it seems unlikely that such bio-cultural knowledge can be easily transferred in its entirety outside its historical area. However, though specific plant and animal species cannot be easily transferred, other patterns such as architectural, ecological or cultural can be. Such patterns from past and present cultural experience can be used in similar but remote environments.

To all these ends the fullest appreciation of a forest is the most important step.

CHAPTER TWO

WHAT IS A FOREST?

IMPORTANCE

The evolution of erect plants has had a significant effect on the creation of the terrestrial environment. In fact, the same evolutionary breakthrough that allowed trees to develop also facilitated the formation of organic soil. The formation of organic soil in turn allowed the development of a soil ecosystem that contributed to the rooting ability and the functioning of the trees.

It is known that plants have existed on this planet for a very long time, the earliest fossils dating back to the pre-Cambrian (circa 3500 million years). These plants were largely aquatic and non-vascular. Examination of these early fossils suggest that they contained cellulose and hemicellulose (Barghoon, (1964) but lacked the ability to develop arborescent or tree like forms. Arborescent forms arose much later, in the Devonian (circa 400 million years), and it was during this period that the mechanism necessary for lignin synthesis was developed. Lignin is central to the arborescent habit because it gives strength and rigidity to cell walls. The maintenance of a large, erect, arborescent stem depends largely on the strength of lignified secondary tissue. The importance of lignin in the evolutionary history of arborescent forms is illustrated in the work of Manskaya and Drodova (1968) who examined various plant groups for the presence of lignin in cell wall composition. They found that lignin was absent in algae and non-vascular plants, like mosses, but present in varying amounts in Lycopods, Ferns, Gymnosperms and Angiosperms.

The development of lignin brought about another revolution in forest environments. Studies of the humates (the complex, ubiquitous organic compounds of soil) suggest that lignin may be the precursor of humic acid (Waksman, 1926). Although many other synthetic pathways to the formation of humic acids have been reviewed (Tate, 1989), recent studies that involved labelling specific lignin carbons with C-14 demonstrated conclusively that humic acid carbons are indeed derived from lignin (Martin and Haider, 1978). As soil organic matter changes the nature of the soil substrate to a state with greater water-holding and nutrient-conserving capacity and the evolution of the organic component of soil, it seems likely that humates may have co-evolved with arborescence.

The other physiological features to develop in parallel with arborescence and soil were the tree roots. The roots of trees perform a wide array of functions. They anchor the tree and provide stability to the above-ground component that is constantly subjected to physiological stresses. They collect and provide water to the above-ground parts; they collect nutrients from the soil to be used in the metabolic activity of the tree; they provide shelter and food for the large community of soil micro-organisms that are symbiotically associated with the root system. Thus, tree roots determine the depth of forest soils to the degree that the physical environment will allow for soil formation. However this process is determined by limiting conditions such as bedrock, groundwater or toxic compounds. Thus, the depth of soil formation by roots depends entirely on the ability of a tree species and soil organisms to alter geologic strata. For example, tree roots have been recorded from depths up to 28 m below the surface (Nulsen *et al,* 1986).

WHEN? WHERE?

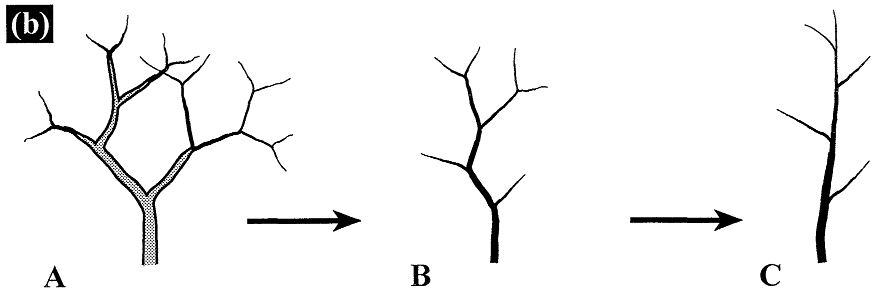
Land plants began to appear in the fossil record around the late-Silurian and early-Devonian. These were small, herbaceous, rootless and leafless plants, dichotomously branched with terminal sporangia (Figure 2a). Examples of these forms are seen in the early genera such as *Cooksia* or *Rhynia.* (Barghoon, 1964). As there was no root structure to utilise soil moisture in relatively drier soils, these plants colonised moist and damp areas. They grew by activity in the apical meristem and had a simple vascular organisation. The stem was leafless and attained a height of about 0.2 m. These early upright plants did not attain any great height. Some of the tallest plants of this period (up to 0.5 m) were seen in genera like *Asteroxylon*, that had a more complex, lobed, primary xylem, together with a monopodal stem with small scale-like leaves (Morley, 1973). As these early plants evolved they began to show the development of rudimentary root structures and a shift towards unequal dichotomous (pseudo-monopodal) and later to monopodal branching (Figure 2b) (Banks, 1970). These adaptations eventually led to the formation of a main trunk with lateral branches, the basic architectural features of a tree. By the middle-Devonian this form was well established. The development of a rooting system is also associated with this period. The 'branches' of these early trees however were still teleome (complete without leaves). The first leaf-like processes arose in the middle- to late-Devonian.

By the late-Devonian the first 'forest' forming trees were established. Leaf-like processes and crowns capable of providing shelter were seen in genera such as *Archaeopteris* (*Callixylon*) (Beck, 1970). For instance, this genus possessed compound fronds up to a metre long and massive stems up to 1.5 m in diameter. These forests had crowns that had monopodial, radially branching growth patterns as seen in today's tree ferns or palms and were associated with stilt roots eg. *Psaroinus*. They also contained many dichotomously branched forms of the arborescent Lycopsids, as well as stilt-rooted, strap-leaved *Cordaites* (Halle and Olderman, 1970). The fossil record demonstrates the evolution of a support structure upon which grew the photosynthetic surface, the crown. Evolution progressed from coarse fibre to wood as support material but the form, that of a crown atop an erect stem, remained constant.

Thus, the tree is an old life form whose origins can be traced back to the Devonian. Trees are also the fundamental component of any forest, irrespective of its history or origin. In order to understand a forest it is important to gain an appreciation of its trees and their function.

Forms of early genera
(after Foster and Gifford, 1959)

Figure 2: First land plants; (a) dichotomous branching. Later development; (b) monopodal branching



A
Dichotomously branching axis

B
A sympodal axis developed

C
A monopodal axis developed by reduction of side branches and straightening of main axis

ARCHITECTURAL FORM


Terminal Decurrent Excurrent

Figure 3: Some crown shapes

In spite of the changes in species composition and morphology of the forest, the architectural form has been maintained through geologic time. In all cases the canopy dominated structure remains. The canopy is achieved by crowns of individual trees occupying the entire photosynthetic surface so that very little direct sunlight penetrates to the forest floor. The structure of the canopy is determined by the nature of crown formation and by the species that comprise it. The crown expression of different species, therefore, is often described in terms of their position in the canopy. Four types are recognised by Smith (1962):

Dominant trees- where the crowns are above the level of the canopy. The crown is well developed, though they can become crowded on the sides.

Co-dominant trees- where the crowns form the general level of the canopy. The crowns are medium-sized and crowded from the sides.

Intermediate trees- shorter than dominants or co-dominants, but extend the upper part of the crown into the canopy. Small crowns crowded on the sides; as a result these crowns receive a little direct light from above but none on the sides.

Suppressed trees- crowns below the level of the canopy. Does not receive any direct light from above, sides or below.

In addition to its position in the canopy of the forest there are three broad categories of crown shape in forest trees (Figure 3). These are; terminal (columnar), excurrent and decurrent (deliquescent). Trees with terminal crowns have one leader surrounded by leaves and do not demonstrate a branching habit. This crown form is common among the palms and arborescent ferns. Excurrent crowns are found in most gymnosperms and some angiosperms. Here the terminal leader grows more each year than the lateral branches below it, resulting in a conical crown and single central stem. Decurrent (deliquescent) crowns are found in most angiosperms. Here the lateral branches grow as fast, or faster, than the terminal leader. Such trees often lose the identity of a main stem in the crown (Kramer and Kozlowski, 1960).

Tree roots tend to exhibit different forms and can be classified into four, broad, morphological types termed: tap-root, heart-root, plate or flat-root and fibrous roots (Figure 4). The earliest form of root was the fibrous root, as seen in lycopsid plants and fern allies of the Devonian. These forms exist up to the present. In modern trees this habit of root-

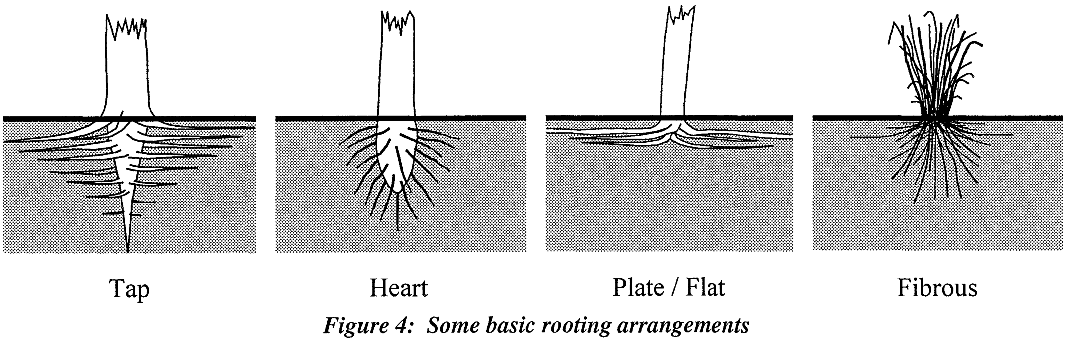
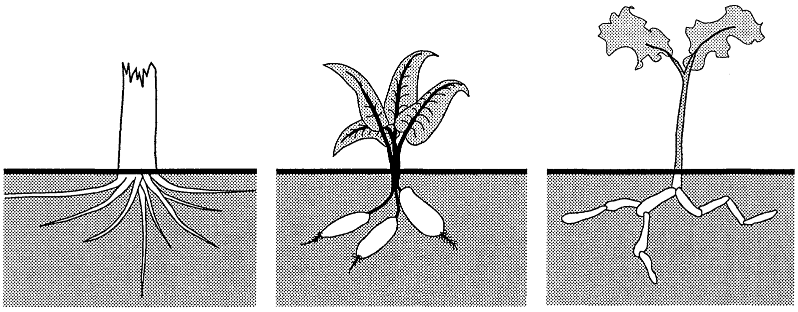

Tap Heart Plate / Flat Fibrous

Figure 4: Some basic rooting arrangements



Roots Tubers Rhizomes

Figure 5: Other ground organs

ing is found in the palms. The taproot and heart root is a development of the more modern flowering plants, but this classical form may be modified into plate root formation in certain soils.

The architectural form of a tree can be divided into two distinct sets of organs. One set is the above ground organs which includes the trunk, branches, leaves, flowers and fruit; the other is the below ground organs which includes roots, tubers and rhizomes (Figure 5). This architectural form differs greatly depending on the species and life strategy (Halle *et al*, 1978). The change in form often reflects a change in ecological function, such as the development of buttress roots in trees growing on shallow soils.

The architectural form of the forest has another component that is significant at the scale of trees. This is exemplified by the vines or lianes; these, when combined with the trees, introduce an homogenising of the different individual species attributes, leading to the emergence of community attributes.

DEFINITIONS

A major obstacle to the care and continuance of forest values, is the current understanding of a forest. A forest, in terms of modern perception is merely a collection of trees. English dictionary definitions of forests illustrates this problem. Forests are defined as: ' A large tract of land covered with trees' (Anon, 1971a). 'A dense growth of trees together with other plants covering a large area' (Anon, 1978), or 'A large tract covered with trees and undergrowth, sometimes mixed with pasture, trees growing in it' (Anon, 1966), or more rarely 'an extensive wooded area, preserving some of its primitive wildness and usually having game or wild animals in it' (Anon, 1971b).

In the broadest sense a forest is the name given to the association of tall plants which grow in dense or open stands and which carry their foliage in a canopy above the ground, on stems which grow large and strong (Broadman, 1986). The degree of canopy cover differentiates forest from woodland. A forest has crowns of trees that form a closed canopy while in a woodland there are many gaps between the trees and trees do not fully dominate (FAO, 1988). The ecological attributes, age, and history need to be addressed if a forest is to be seen as something more than a collection of trees. While the percentage of trees that determine the classification boundaries still needs to be expressed for each type of forest system, it will be seen that at a most general level, a forest can most simply be defined as 'a tree-dominated ecosystem'. The history of a given forest is then reflected in categorisation such as natural and anthropogenic. Anthropogenic refers to tree-dominated ecosystems that arose as a consequence of human activity, and natural, to those that arose without such an influence. Biodiversity provides an ideal measure to differentiate the various monoculture plantations from natural forests and can be used as two ends of the scale representing possible 'tree-dominated ecosystems' for any given area.

ECOLOGY AND CONSERVATION

When considering the historic and present condition of a forest it is important to determine if the forest is natural (wild) or anthropogenic (human created or affected by human activity). A forest ecosystem can be described as natural if it has had no impact of human activities or if it has been disturbed, has demonstrated a propensity for the reestablishment of a natural state. In natural forests that have been disturbed, the intensity and frequency of the disturbance event is what determines stability and the possibility of sustaining natural characteristics. For example, if the disturbance event occurs with a frequency that is spaced far enough apart not to affect the re-establishment of species essential to that system (Figure 6a) it will not affect the sustainability of that system. However, if the disturbance event occurs with a frequency that will not allow the regeneration or re-establishment of species essential to that system (Figure 6b) it will affect the sustainability of the natural system by removing species integral to its stability. A similar process can follow if the intensity of the impact is of such magnitude that the sustainability or identity of the natural system is lost.

Another important variable when considering the perpetuation of a forest is the effect of age. Old-growth forests contrast sharply with early successional stages in composition and life strategies of the species that comprise them. However, the functional differences between old-growth forests and younger forests are often qualitative rather than quantitative (Franklin, 1988). Studies of temperate forests suggest that the younger, plantation forests can function like early successional stages of natural forest, but are unable to mature and attain the ecological quality of old-growth forests.

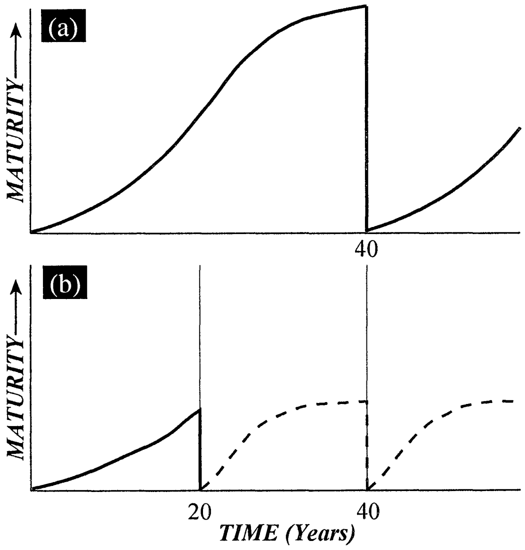
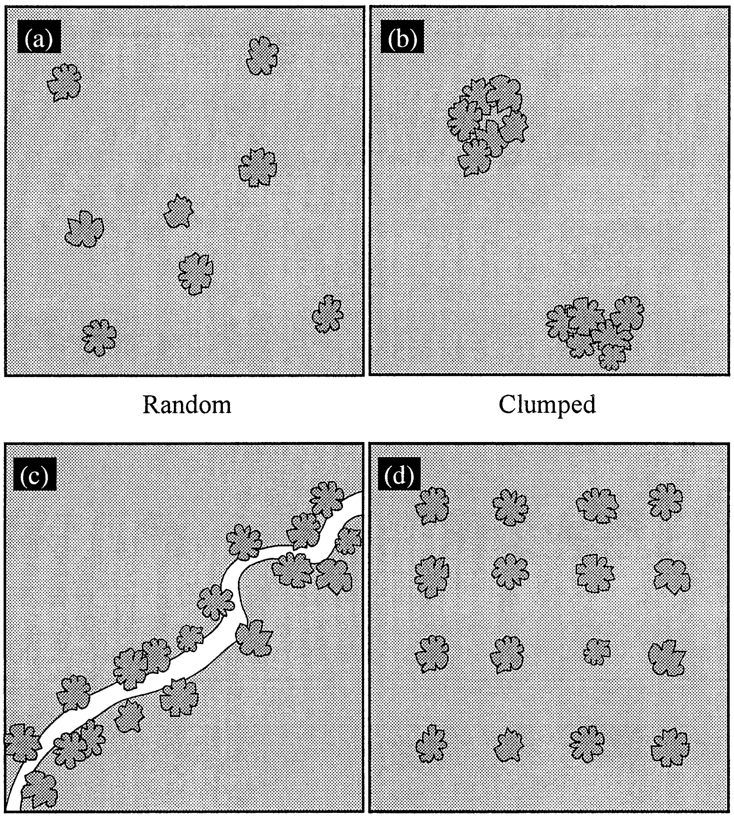


Figure 6: Effect of frequency of disturbance event; shows successful re-establishment of **Eucalyptus regnans** ***after wildfire (a), shows replacement of*** **E. regnans** ***with*** **Acacia decurrens** ***(b)***

The concept of wild or natural is commonly not assigned much value in international forestry investment. Old-growth forest is perceived to be over-mature, requiring replacement with a more productive planting. This has led to the current global situation where monoculture plantations are the major forestry response to forest loss and replacement. These plantations are then promoted as reforestation, afforestation or new forests. The assumption is that the such plantations will provide all the services of the natural forest. This assumption needs to be questioned in the light of modern needs, such as environmental stability and biodiversity sustainability, as monoculture plantations have not been demonstrated to be able to provide the spectrum of products and services generated by the natural forest.

The view that all the local and global environmental services of forests can be provided by any tree-dominated vegetation cover is misleading because a forest is not just a collection of trees, it is also a collection of organisms. This view is exemplified by Sayer and Whitmore (1991) who state '(species) extinctions in our view is the most serious consequence of tropical forest clearance because, although hydrological and climatic fluctuations performed by the original forest can be recreated by man-made community (vegetation), once it has been lost, a species has gone forever'. Therefore, the significant attributes of a forest include: its history, community structure, canopy pattern and ecological functioning.

In public perception, a forest is seen to posses all these attributes. Thus, the predominant cultural perception of 'forest' tends to be associated with wild or natural formations. This may be a reason why there has been an almost automatic acceptance of the view that any collection of trees that is described by the word forest, contains all the attributes of wild or natural formations. The distinction between 'natural forest' and 'man-made forest' has to be emphasised in discussions of forests in future if all services of forest formations are to be appreciated.



Random Clumped

Regular 1 Regular 2

Figure 7: Natural arrangement patterns; random, clumped, and regular

Forests at all stages fix and cycle energy or carbon, regulate hydraulic flows and conserve nu-trients, but some stages carry out these activities more efficiently than others. For instance, studies on nutrient losses from Pacific North-West forests of the United States, suggest that old-growth watersheds have a very low rate of nutrient loss when compared with younger growth watersheds (Franklin *et al*, 1986). In terms of its qualitative effect on precipit-ation, old-growth coniferous forests have been shown to be particularly effective at gleaning moisture from clouds and fog and thus increase local precipitation (Harr, 1982). These forests possess dominant trees that are commonly taller than 75 m and present a very large crown surface to affect this micro-climatic response. A similar effect has been noted in the coastal moun-tain ash (*Eucalyptus regnans*) forests in Australia. Here, fog drip has been measured at about one percent of gross rainfall (O'Connell and O'Shaughnessy, 1975). However Mollison (1988) suggests that condensation drip can be as high as 80-86% of total precipitation in other coastal areas.

Old-growth forests also possess a greater range of tree sizes. This patchiness in canopy cover allows a heterogeneous forest understorey to develop. The other unique feature of this stage of forests is the presence of dead trees and snags (severely leaning/partially fallen trees). These features contribute greatly to the coarse, woody, debris of the forest floor. Thus, old growth forests provide an environment with a high potential for maintaining biodiversity and the structural and functional diversity gained with age becomes a further important attribute of a forest.

In describing a forest, not only the floristic characteristics such as species composition and its age, but also structure and physiognomy are important. The structure of a forest refers to the architectural or spatial pattern of growth forms in a plant community and has to be determined horizontally as well as vertically. In considering horizontal structure the occurrence of individual species or cohorts in random, clumped or regular patterns has to be addressed (Figure 7). Vertical structure includes such features as crown height, leaf density and branching pattern. of each individual plant layer as well as the shape and depth of the root zone (Figure 8).

The physiognomy or the outward appearance of the vegetation (tree, vine, epiphyte, broadleaf or evergreen), provides a very effective shorthand for the description of a plant community (Table 1), as it is the presence and particular proportion of each growth form which gives a plant community its unique character (Perera, 1975). Physiognomic descriptors may prove useful to profile forest structures.

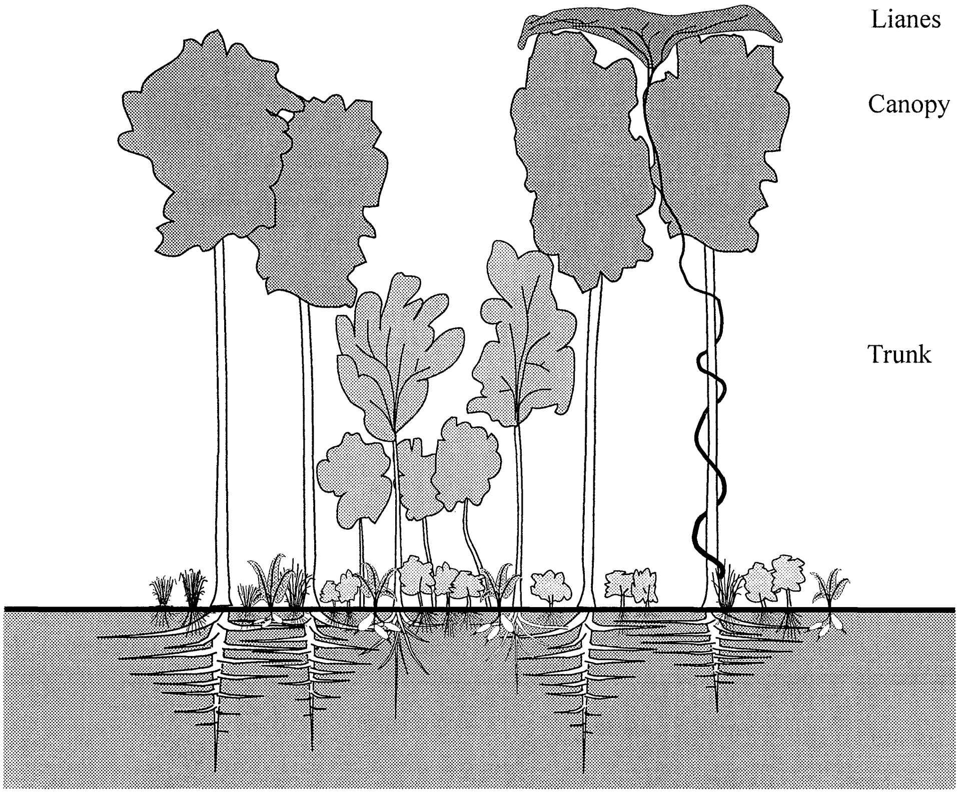


Figure 8: Some vertical structural arrangements

A forest ecosystem can be described as anthropogenic if it displays characteristics that demonstrate human activity. Anthropogenic forests may range from *Pinus* monocultures to the forest-fallow of Papua New Guinea. Many traditional responses to tree cropping are similar to natural systems that existed in the locale. That is, it contains species that were once a part of the local biota or possesses architectural or ecological structures that are similar to the natural system of the area. Sometimes, this response may differ from the natural system and display characteristics that are more similar to natural systems that exist elsewhere, but both responses have to operate within the parameters set by the local environment.

Many modern anthropogenic systems require heavy inputs of energy or resources for their sustainability. These systems do not have any requirement to be constrained by the parameters set by the local natural environment and are termed 'industrial'. They often display characteristics that are not usually found in natural systems, monoculture (even-aged) plantations being a good example.

Irrespective of its origin, a forest is an ecosystem where trees are the dominant organisms. The functional characteristics of a forest are its ability to shelter and create a modified environment within its architectural structure, its ability to regulate water and nutrient flows by biological and physical activity, its ability to build forest soils and its ability to sequester carbon.

The forest is inseparable from its trees, the associated organisms and its ecological history. Thus a sound knowledge of the individual species' attributes together with attributes of the forest as a whole improves the design of forest. For example, the forest as an organised system also provides products and services that cannot be provided by any individual tree. Forest water and forest environment are two good examples of the products of a whole forest. Forest water has always been recognised to have high potability (Langford and O'Shaughnessy, 1977) and forest environments are the structures that conserve biodiversity. In order to obtain the optimum yield from a forest, be it conservation value, monetary value or social value, a knowledge of the functional aspects of trees and forests has to be examined.

Table 1: Physiognomic vegetation mapping
Kuchler and Zonneveld (1988), modified after Senanayake (1989)

A. Growth form categories	
(1) Basic growth forms	
Woody plants	symbol
Broadleaf evergreen	B
Broadleaf deciduous	D
Needle leaf evergreen	E
Needle leaf deciduous	N
Aphyllous	O
Semi-deciduous (B+D)	S
Mixed (D+E)	M
Herbaceous plants	
Graminoids	G
Forbs	H
Lichens, Mosses	L
(2) Special growth forms	
Climbers (Lianas)	C
Stem succulents	K
Tuft plants	T
Bamboos	V
Epiphytes	X
(3) Leaf characteristics	
Hard(sclerophyll)	h
Soft	w
Succulent	k
Mesophyll (>12.7 cm)	l
Notophyll (12.6-7.6 cm)	n
Microphyll (7.5-2.5 cm)	s
Nannophyll (< 2.5 cm)	t

B. Structural categories	
(1) Height (stratification)	
Height class	
8 = > 35 m	
7 = 20-35 m	
6 = 10-20 m	
5 = 5-10 m	
4 = 2-5 m	
3 = 0.5-2 m	
2 = 0.1-0.5 m	
1 = < 0.1 m	
(2) Coverage	
Coverage class	
Continuous (over 75%	c
Interrupted (50-75%)	i
Patchy, park-like (25-50%)	p
Rare (6-25%)	r
Sporadic(1-6%)	b
Almost absent (<1%)	a

CHAPTER THREE

HOW DOES A FOREST FORM?

PRECONDITIONS

A forest can be seen as the tree-dominated phase of a succession of ecosystems, which usually gains biomass with maturity. While the successional process progresses with time, local or climatic events can arrest the process of maturity and hold a seral stage constant for long periods of time, a characteristic that has been utilised in human-designed cropping systems. However, the complete cycle of forest ecosystems with all the long-term ecological or homeostatic information that such a time scale generates seems to be heading towards extinction. A forest regulates major terrestrial dynamics such as the hydrologic cycle, nutrient cycle and carbon cycle. It also provides conditions that are essential to the sustainability of a large proportion of terrestrial biodiversity. In this sense a forest confers stability to the biosphere.

In any environment, the presence of a new species has the potential to produces changes in its character. For example, weeds that are resistant to desiccation rapidly colonise bare fields. The presence of these weeds however, has changed the character of the environment of the bare field. It has begun to moderate the environment by shading the soil and thereby reduces evaporation and increases the humidity of the soil surface. Such moderation is also assisted by the fact that weeds are often C4 or CAM (Crassulacean Acid Metabolism) plants and as such fix carbon dioxide more efficiently than C3 plants. The weedy vegetation has also deepened the biologically active zone of the soil profile by putting down roots to stimulate and extend the soil ecosystem. Thus desiccation and shallowness of the soil becomes a less limiting factor in the environment. This allows the more desiccation-sensitive and specialised species to invade the weed community and to eventually compete more successfully than the original weeds (Figure 9). These processes continue as each stage creates the conditions beneficial for the invasion of another species. These stages are termed seral stages, each stage setting the conditions for a consequent, more mature stage.

If forested land is cleared and left to develop over time with no further disturbance, a forest similar to that which was cleared will form after a period of time. The time required will vary with the degree of disturbance and the proximity of a mature forest, but the process is ubiquitous; it is termed succession. The processes are driven by various forces.

The processes of succession and the resulting plant community structure are also affected by site aspect and slope as well as the proximity to sources of plant reproduction. The aspect of a site affects the intensity of environmental harshness, which in turn affects the rapidity of plant establishment and reproduction. Invasions of different species adapted to the different site conditions affect stand structure and species composition differentially. In the Cascade Mountains of North America, Tesch (1975) found that natural stand regeneration occurs rapidly on north-facing slopes which are generally

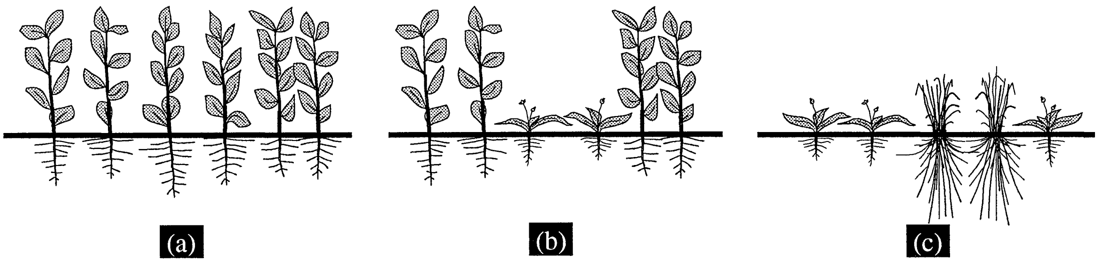


Figure 9: One species prepares the site for the next

wetter and cooler as opposed to the south-facing slopes which were drier, hotter and had longer growing seasons. The regeneration on the north slopes tends to be dense and even-aged. The undergrowth representation in this aspect was negligible due to the density and uniformity of canopy growth. East-facing, west-facing and finally south-facing slopes exhibit progressively longer establishment periods and deviate from even-aged conditions. The greater exposure on the southern slope results in a highly variable canopy structure and composition with a greater understorey growth as a result. While the same pattern may not hold in other environments, such as where the direction with most exposure is from another direction, it is useful to consider this effect on hilly or sloping land. This type of forest community response to aspect has been addressed by Whittaker (1960), who suggested that species richness of a particular stand or community of trees due to community factors, is different from the species richness that occurs as a result of environmental gradients or patterns and labelled these as 'alpha and beta' diversity respectively. Therefore, the aspect of land will also be a determinant of the type of forest that is optimal to a landscape.

There are a series of life strategy characteristics that differentiate the species at the two ends of the seral continuum (Table 2). For example, plants in early successional stages have a low root/shoot ratio. This means that these plants have a greater aerial vegetative biomass and are effective in producing rapid growth and large crops of seeds, while plants of late-successional stages display a high root/shoot ratio, have low rates of growth mostly in stem and root, and have a relatively lower proportion of the biomass devoted to seed production. Annuals generally have root/shoot ratios of about 0.13-0.20, biennials have a ratio of 0.21-0.42, and woody perennials demonstrate ratios of 0.77-4.04 (Monk, 1966). Within these stages, succession will continue until the establishment of new species no longer changes the environment for the community. This stable, mature state of the environment is termed the climax community.

Table 2: General characteristics of plants during early and late stages of succession (after Ricklefs 1973)

Characteristic	**Early**	**Late**
Seeds*	Many	Few
Seed size*	Small	Large
Dispersal	Wind and /or stuck to animals	Gravity and/or eaten by animals
Seed viability	Long, latent in soil	Short.
Root/shoot ratio	Low	High
Growth rate	Rapid	Slow
Mature size	Small	Large
Shade tolerance	Low	High

* This characteristic may not be reflected in some Australian trees

SUCCESSION

Successional processes are driven by two fundamental forces, the biological and non-biological. When biological forces are predominant it is called autogenic succession. Here the general (broad pattern of rainfall, drought and fire) and the (abiotic) chemical and physical aspects of the environment are held constant. The organisms modify the environment so that later successional invaders (species) move in. In such situations two patterns are seen:

> Primary (autogenic) succession - which happens on newly-formed or thrown-up area (eg. after glaciation or volcanic eruption). The environment is relatively sterile with no organisms present. Initially the process often involves the formation of soil organic matter.
>
> Secondary (autogenic) succession - here the disturbance is less dramatic. (eg. after fire, cut fields etc) The environment has not been reduced to a relatively sterile state. This process does not involve the formation of soil organic matter on terrestrial systems.

Autogenic succession in forests begins on newly-cleared land with fast growing, weedy species called colonisers that change their immediate soil and surface environment by their life's actions. Those changes in turn, create microclimates amenable for the growth of more woody, longer-lived species. These latter species in their turn, create microclimates suitable for the seeds and seedlings of larger trees to survive. This process continues until no further changes occur, usually culminating in a mature forest termed the 'climax state' (Figure 10). The appearance of the stages may differ in different areas. For instance, in the south-eastern United States, the grass-shrub stage of fast growing weedy species is usually replaced by pine forest in twenty-five years and if left undisturbed the pine forest is replaced by an oak-hickory climax within 150 years (Oosting, 1942). An orderly progression of community change where a regular sequence of different populations replace each other in any given area, is characteristic of this process. Each stage or identified complex of species along this time gradient or sere, is called a seral stage. The seed germination behaviour of early successional species and late successional species (Rao and Singh, 1989) provides an example of the different ecological requirements of the different stages.

When non-biological forces predominate the process is termed allogenic succession- here the general environment such as the patterns of rainfall, drought or fire events are variable and exert pressure on the ecosystem. The response to this pressure in forest ecosystems can sometimes move the plant community in a reverse direction, towards open grassland rather than closed forest as seen when repeated fires eliminate forests of *Nothofagus cunninghami.* In Australia this can generate cycles of nutrient depletion by invasion with other, smaller species to produce a stable, closed sedgeland composed mainly of tussocks of *Gymnoschoenus sphaerocephalus* (Jackson, 1968), but this process is usually generated by repeated disturbance or by

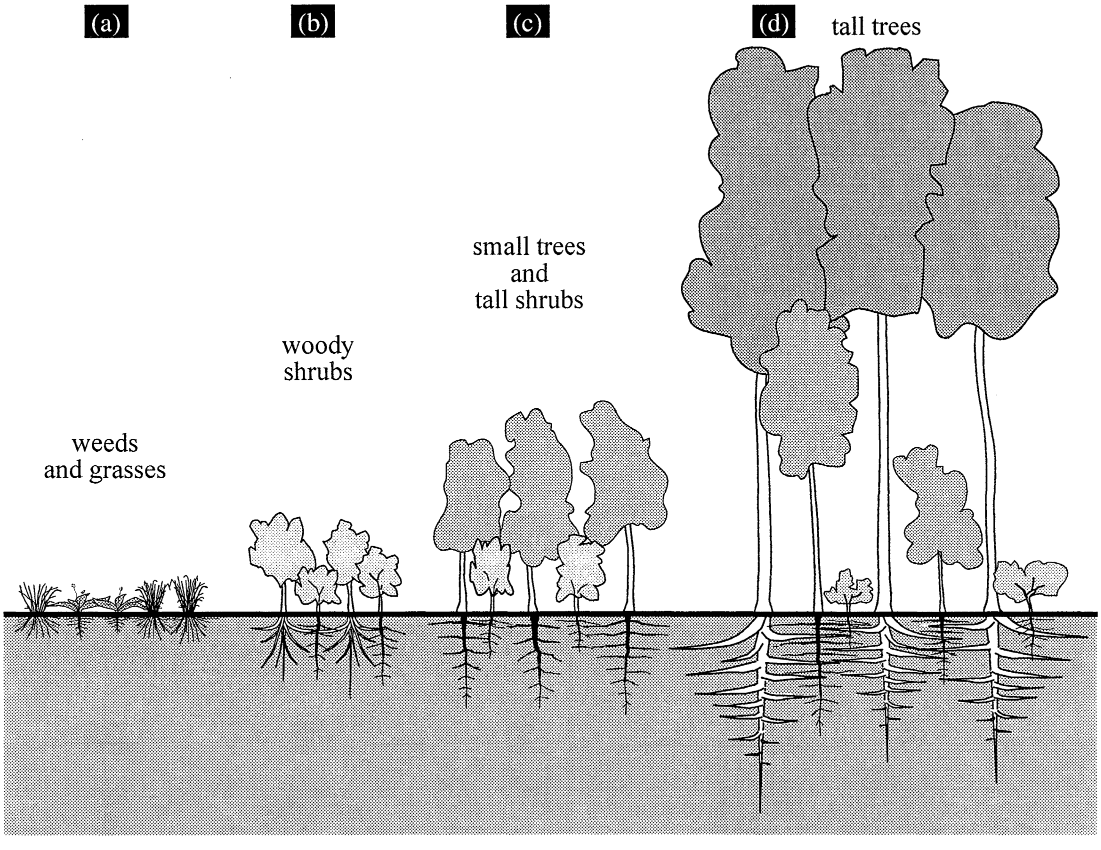


Figure 10: Successional changes from pioneer to climax

a radical change in the environment. In this process changes are time-driven and may be cyclic such as diurnal, seasonal, annual or episodic; or directional such as non-cyclic climate changes.

While succession changes the species turnover rates and architecture of the community, as seen in changes of the proportions of r-selected or weedy and early colonisers and K-selected or specialist and mature species, succession also changes the proportion of canopy closure. As the trees grow taller and more specialist species are present, the biological properties of the community parallel the properties of the species that constitute the community (Ricklefs, 1973). A forest that has the plant families Rutacae and Aristolacae as vegetation components, will have large populations of *Papilio* butterflies, as these are the principal food plants of this genus. A forest without these plants will not have many Papilionids in its butterfly fauna, even though it may be structurally similar. Both forests will change as communities mature, in terms of tree species and architecture. The species complex now attained may be more dissimilar in terms of its butterfly fauna. Similar patterns can be determined for most groups of organisms. However, one feature that is consistent with the progress of forest maturity is an increase in biomass.

In an individual, or in an ecosystem, growth occurs only as long as there is a surplus in productivity. In trees for instance, biomass increases with maturity both above and below ground until a critical stage in growth is reached. This phenomenon is termed maturity. During the early stages of growth there is a surplus in productivity, over and above the requirement for species maintenance. This surplus is used for growth, as growth increases so does biomass. However, this surplus in productivity is soon utilised due to the fact that as biomass increases so does the species maintenance requirement until there is no more surplus to fuel growth. In a community the net accumulation of biomass stops when production within that community is equal to its maintenance (Odum, 1969). This stage signals the start of the maintenance phase in forests (Figure 11) and systems of relative stability that demonstrate no major structural changes within the community. Even though new species may invade and replace others the structure of the community remains unchanged. When species and structure have achieved a relatively stable autogenic equilibrium, a community climax has been reached. As the size of a tree increases with community maturity a higher proportion of community nutrients will be tied up in biomass. In the more mature tree communities, biomass tends to be represented as supportive tissue. Here a greater proportion will be in stems and roots, rather than leaves. Thus a larger proportion of the productivity of mature tree systems enters the detritus food chain rather than the consumer food chain (Whittaker and Woodwell, 1968).

The process of succession has been divided into four stages, pioneer, intermediate, mature and over-mature for forestry considerations (Figure 10). In some forests, however evidence of autogenic replacement by more shade-tolerant species may not occur for a very long time, due to the fact that the dominant canopy species exhibit continuous regeneration and tend towards self-replacement. (Read and Hill, 1988).

Different successional stages have different effects on the environment. In terms of hydrology, the volume of runoff will be greater, and quality lower, if the catchment is covered by early successional stages while the runoff will be reduced and water quality higher in catchments covered with late-seral stages. The early successional stages consist of relatively short annuals which have a low

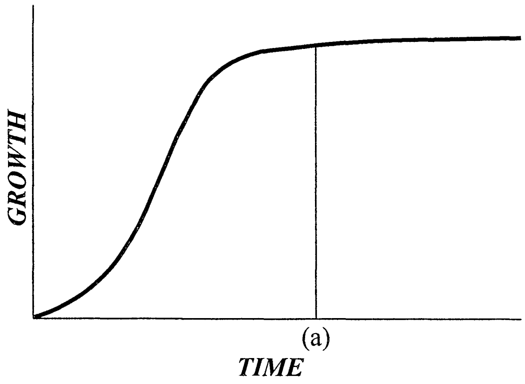


Figure 11: Stability reached when growth is matched by maintenance requirements

rate of rainfall interception, and evapotranspire over a few months of a year. Most of the rainfall is channelled into surface drainage in early-seral stages. There is also a greater degree of erosion with the increase in overland flow, leading to a reduction in water quality. But as the forest grows there is an increase in on-site water use as evapotranspiration and rainfall interception increase; this leads to a reduction in streamflow. The increase in canopy shade and litter cover of the soil, reduces erosion and improves water quality (Gilmour, 1968). The rate of water-use levels off at forest maturity and this stage usually provides the best water quality. The maintenance of forested catchments in a tree-dominated, climax or sub-climax state, has been seen to be highly desirable for the maintenance of high water quality, although in some catchments a dense sub-climax of bracken has been found to yield water of high quality.

DISTURBANCE

Succession would seem to be influenced by the degree of disturbance that the land had been subjected to. In a study of the patterns of plant succession in abandoned pastures in eastern Amazonia, three types of abandoned pasture were examined, namely, lightly-used, moderately-used and heavily-used. In pastures that had been subjected to light use, the forest rapidly regenerated with an above ground biomass accumulation of 10 t/ha/y and tree species richness of about 20 species per 100 m^2. Pastures that had been subjected to moderate use also developed trees but at a lower species richness and the biomass accumulation was 5 t/ha/y. The pastures that had been heavily used did not have many trees, the land being dominated by grasses and forbs. The representation of trees after eight years was one per 100 m^2 with the rate of above-ground biomass accumulation being 0.6 t/ha/y (Uhl *et al*, 1988). Another study that looked at succession in a twenty-year fallow subject to shifting cultivation in India, demonstrated a successional series that began with grasses and weeds, which was replaced by bamboo (*Dendrocalamus hamiltonii*), and was later replaced by a tree canopy. The succession was accompanied by increased species diversity, reduced dominance and increased above-ground net primary productivity at 1.8 t/ha/y (Toky and Ramakrishnan, 1983).

Fire is another significant disturbance factor in the growth of forests. In some communities, fire stimulates regeneration and seed release from the forest trees. These communities benefit from fire events as the process of maturity is arrested at the fire-modified climax. In some instances human activity is identified with such ecosystems. In Australia, the incidence of greatest fire activity and consequently the assertion of sclerophyll woodland is seen to be contemporaneous with the arrival of humans and has been attributed to their actions (Kershaw, 1986). Although climate remained the major determinant of vegetation distribution or change (Clark, 1983), Aboriginal land use particularly burning, could affect the rate of change by reinforcing or opposing the climatically determined direction of change (McPhail, 1980). Thus humans have been identified as an agent in determining the vegetation complex for many thousands of years, so that many landscapes encountered by the first Europeans were 'cultural' landscapes (Clark, 1990).

The regenerative ability of the species represented in these fire-adapted forests has been demonstrated in the differences observed between burnt and unburnt patches of sclerophyll woodland in south-eastern Australia. Burning stimulated the growth of all species represented in the tree and shrub strata during the first year after the burn. Both seedling input and vegetation recovery of populations occurred during the first and second year after burning (Purdie and Slayter, 1976). However, different fire-adapted communities respond differently, depending on their species composition. In a comparative study that looked at the effect of mild fires on litter decomposition by the soil fauna, three forests in Western Australia were examined. Two forests were native with karri (*Eucalyptus diversicolor*) and jarrah (*E. marginata*) as the dominant trees and the third was a plantation of pitch pine (*Pinus pinaster*). This study found that litter decomposition in the pine forest ceases until four years after burning, while it occurs more rapidly in the native forests (Springett, 1976). The soil fauna are fire-adapted and are able to respond by building up populations after fire events but the rapidity of response differs with the dominant tree species of the forest.

Recruitment of new plants after disturbance can be accomplished by input from seed trees as well as buried seed banks in the soil. A study that looked at the seed bank contained in the upper 10 cm of soil in three habitat types in central Idaho, found viable seeds representing 80 different species in the upper 10 cm of forest soil. The most viable seeds (67%) were found in the top 5 cm (Kramer and Johnson, 1986). Forest soils can assist in the re-establishment of disturbed forest by maintaining a seed bank and a dynamic soil ecosystem.

TIME

In this discussion we examine the time taken to re-establish the structure of mature forest. In terms of basal area (i.e. sum of the cross-sectional areas) of the trees of mature forest, the volume of wood or the biomass values found in a mature forest, can be reached in approximately 190 years by tropical forests (Saldarriaga *et al*, 1988). During the early growth phase of these forests, living biomass was found to increase in a linear fashion during the first 40 years and then plateau out, with no significant changes occurring for the next 40 years. This is due to the fact that biomass accumulation by the slow-growing species is offset by the death of long-lived successional species, whose lifetimes are about 40 years. In this study, the number of tree species increased during the early growth stages of succession, with stands at 40 years losing the pioneer species but gaining many species of the mature forest.

The concept of climax as a state that endures indefinitely is misleading as all ecosystems change. For the purpose of design it can be perceived as a highly mature or stable state in seral succession. Each seral stage progresses toward maturity or climax. Brunig (1983) suggests that seral stages be evaluated as a building-up phase (A), a nurturing phase (R) and a die back-phase (Z) with the die-back phase leading through regeneration to new successional stages. In the complete cycle of the boreal coniferous forest Brunig (1983) postulates that there are four building-up phases starting at about 10 years, 75-80 years, 300 years and at about 700 years. In the tropics there are five. The first at year two, the next at year 10, then at 30, 300 and 800 years.

Current knowledge suggests that the entire cycle of forest formation from pioneer to senescent takes about the same time in temperate and tropical systems, approximately 2000 years (Brunig *op cit*). This 2000-year cycle is comprised of many sub-cycles, each with a distinctive growth phase, for example (A), the phase of biomass or information accumulation. This is also the phase in which the ecosystem can yield a surplus and not lose its growth potential. Thus there are many such points along the successional gradient of a forest where cropping at a constant (regular) basis can be sustained over a relatively long time. Studies on the forest-fallow shifting cultivators of Papua New Guinea (Clark, 1971) suggest that early successional stages of the forest may be more useful in producing more crop plants of use to humans than the climax stages. This study also notes that the secondary, or pioneer species, are more productive. In terms of a forest-fallow gardener, it will be useful not to allow succession to proceed towards mature stages but rather maintain somewhat simplified communities, using early- or mid-seral stage species.

Examples of cropping at different seral stages of forest maturity can be seen in disturbed lowland rainforest in Sri Lanka. Here the palms, areca nut (*Areca catechu*) and fishtail palm (*Caryota urens*) are common early-seral stage plants along gullies and streams. The original forest association of *Doona, Dipertocarpus, Mesua* (Gaussen *et al*, 1968) has been greatly degraded by human activities. The landscape is modified so that all low-lying swampy areas have been converted to rice fields. This intensive agricultural system is over 3000 years old. The palm association is maintained in an informal (non-managed) manner at the forest boundary with the rice paddies. This seral stage has been used consistently for product extraction for hundreds of years. As the rice paddies represent a regular pattern of disturbance, this ecosystem cannot mature and the effect of this disturbance extends to the palm association. As other early-pioneer trees, such as *Macranga* or *Trema,* occurring within this association are removed regularly for firewood or small timber, a regular disturbance pattern is maintained, while the palms provide a forest product and are not used for timber or firewood; thus the palm dominated successional stage is maintained throughout.

Another example can be drawn from the mallee bush of Australia. This ecosystem is dominated by trees of the genus *Eucalyptus* that grow to about 3-9 m in height. The growth originates from a large underground, woody swelling composed of stem tissue, called a lignotuber. This structure serves the forest community well. As mallee vegetation tends to be burnt frequently all aerial stems and leaves are destroyed, but the underground lignotuber is rarely affected and the vegetation growth centre is maintained (Parsons, 1981). Fires return the entire community to an early-seral stage and the trees grow back from the dormant buds within the lignotuber. The early response of these trees is to put out a large number of aerial shoots after the disturbance event. As the ecosystem matures, the later-seral stages carry fewer stems. Six months after a fire event a mallee lignotuber could carry 70 shoots. Seven years later this can diminish to 20-30. If the community is allowed to mature without disturbance for 100 years the numbers of stems will be further reduced to 10 (Holland, 1969). In this community, if a disturbance occurred at any time the system will revert to the early-seral stage of lignotuber sprouts and begin again. The eucalyptus oil industry based on the mallee communities maintains the growth on a 7-10 years rotation, essentially harvesting at a mid-seral stage when leaf production is highest. This system has been used on certain stands in Victoria consistently for over 75 years with no apparent ill-effects on the continuity of the forest species.

CHAPTER FOUR

FUNCTIONING OF A FOREST

AERIAL ZONE

The site of primary production in most vegetation is in the leaves. Leaves form the outer area of the crown and are the solar energy-collecting organs of a tree; they are also the surfaces of gas exchange and evapotranspiration. Solar energy is collected in the process of photosynthesis where carbon dioxide is absorbed from the atmosphere and combines with water to yield sugars and oxygen as summarised by the general reaction:

carbon dioxide + water + light -> glucose + oxygen

Light energy is absorbed by various specialised organic compounds, called pigments, such as chlorophyll, carotenes and anthocyanins. These pigments give leaves their characteristic colour. This reaction has far-reaching consequences and has been viewed as the driving force of the entire biosphere (Lovelock, 1988). It has also been hypothesised by Holland (1984) as the mechanism by which the present oxidising (oxygen-rich) atmosphere of this planet was formed and is a major mechanism by which gaseous carbon, as carbon dioxide, is fixed or sequestered into its solid phase during the planetary cycling of this element.

Evapotranspiration, or the release of water vapour from the leaf, is part of the mechanism of water and nutrient transport in the tree and of photosynthetic action. A water release rate of 100:1, where over 100 molecules of water are released for each molecule of carbon dioxide absorbed by the leaf (Jones, 1976), provides an indication of the magnitude of this activity. In order to carry out these functions effectively leaves present an extensive surface area to the environment. For example, 0.5 ha of oak forest with a basal stem area of 5.5 m^2 produces an aggregate leaf surface area of more than 2.03 ha (Rothacher *et. al*, 1954). Cummings (1941) reported that a single specimen of open-grown *Acer saccharum* had over 177,000 leaves giving a leaf surface area of over 0.24 ha. In general, leaf sizes and leaf numbers tend to be negatively correlated; the larger the leaf size the less in number and vice versa. This relationship has been measured for some trees, large-leaved trees such as *Catalpa* spp having about 26,000 leaves while younger, small-leaved *Citrus* spp had over 90,000 leaves (Kozlowski, 1971). The mean mass of leaves produced does not seem to vary much between different plant groups. The measured mean annual leaf production has been reported as 2.8 t/ha/y for angiosperms and 2.7 t/ha/y for gymnosperms. Col-

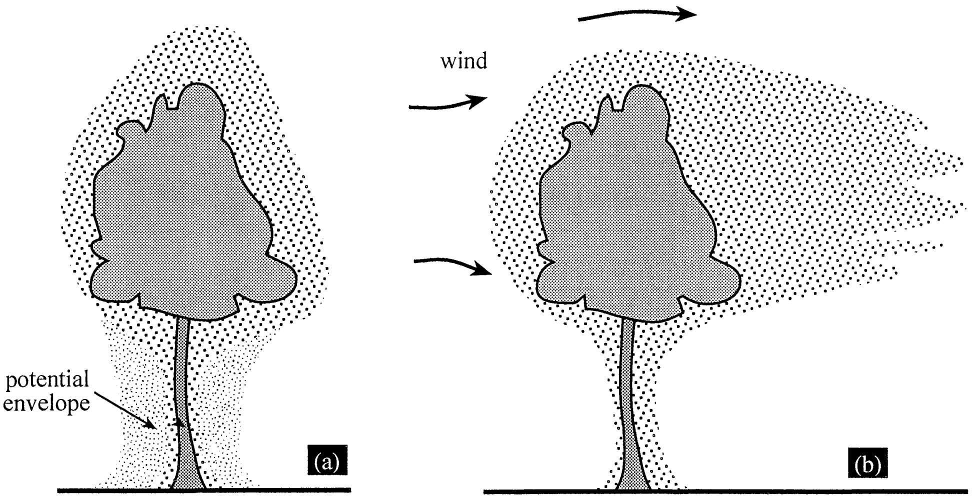


Figure 12: Envelopes of high humidity

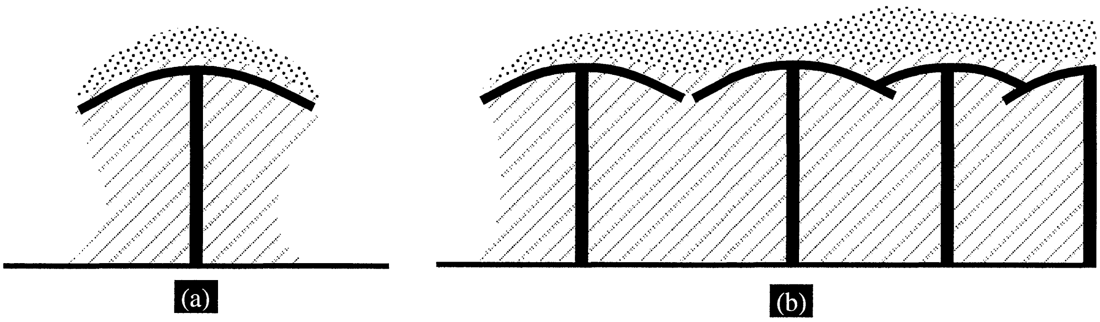


Figure 13: The modifying function of the umbrella: single (a), multiple (b)

lectively they give environmental profiles that extend beyond the physical limits of the foliage.

A tree canopy with leaves affects its immediate environment in three ways. One is by the action of evapotranspiration that creates an envelope or zone of relative humidity higher than the surrounding environment, around the crown of the tree (Figure 12). The shape of this envelope changes with environmental influence such as temperature, wind or pressure. The other similar effect is produced by the action of gas exchange. This produces a higher level of oxygen and carbon dioxide (and other gaseous compounds) at a higher concentration than its immediate environment. This envelope can be expected to dissipate much faster than that of water vapour. The third effect of the tree canopy on its immediate environment is its ability to intercept sunlight, rain, frost, hail and wind and hence provide a zone of shelter below. When groups of trees begin functioning like forests, the collective physical action seems to affect the local climate (Heisler and Dewalli, 1988).

Paravi (1937) performed pioneer experiments on the effect of forests on their external environment. Using a system of instruments attached to suspended balloons, he measured atmospheric temperature and relative humidity of the atmosphere above forests and open lands. This study demonstrates the differential effects of various types of ground cover on the local atmospheric envelope. The effect of forest cover on atmospheric temperature and relative humidity was detectable at 1000 m, while the air above the forest was detectably warmer for a greater height than over bare ground.

The crown shapes of different species may have a wide variety of expression. The different shapes have been described as various categories such as cylindrical, umbrella-shaped, weeping etc (Corner, 1964). Other systems of classification have examined the crown architecture and plant growth habits. For example, Halle *et al,* (1978) constructed a series of models based on these characteristics for tropical trees. Whatever the architecture of a crown, its function is an intercepting surface to sunlight, wind and rainfall. The action of the crown in a horizontal plane is an architectural structure of a shade-providing canopy with columnar vertical support, the most simple model being that of an umbrella. While the permeability of each type of canopy may differ according to the morphology of the species, the environmental effect of its function is to create a modified zone below it (Figure 13a). In a forest situation this architectural structure, with many vertical supports and a large area of canopy (Figure 13b), modifies many other environmental factors within the structure, including relative humidity, soil temperature and soil moisture and thus plant and animal behaviour. The responses to wind, rain and sun change with an increase in size until a predictable, constant environment is achieved. This environment is markedly different from the environment outside a forest. The ability to shade has brought about a distinct change to the natural ecosystem. Thus, the shade afforded by a forest modifies the environment that is under the forest crown. Studies of the differences in air and soil temperature regimes and of relative humidity demonstrate radically different patterns between forested and unforested environments in the same area. For instance, the diurnal/nocturnal fluctuations of surface, soil and water temperature in an open area will demonstrate a strong flux, whereas the flux will be dampened within a forest (Figure 14). In studies of the relative effects between forested and open areas it has also been demonstrated that the evapotranspiration rates of plants also follow similar patterns (Lawson *et al*, 1970). Thus a forest can be perceived as an environment controlled by an organism; that is, this environment could not exist if not for the activity of trees.

The analogy of the tree crown as a permeable umbrella also produces other design considerations. While providing shade the crown also allows the throughflow of wind and water. The dynamics of wind transport patterns through vegetation have been well studied (Rosenberg *et al*, 1983) and used in a landscape management approaches such as the creation of shelterbelts for wind attenuation (Robinette, 1972).

The dynamics of water transport through the crown indicate that there are various individual patterns in individual species. This is seen in the relative proportions of the collected throughfall that reach the ground via leaf drip, and branch and trunk transport. A proportion of water that is collected by the leaves in the canopy is termed canopy interception. This process can enable the evaporation of a considerable volume of rainfall and reduce the volume of throughfall considerably. Studies in Victoria reported that some species like redwood and Douglas-fir can have interception rates as high as 39% and 28% respectively (O'Connell and O'Shaughnessy, 1975).

The crown, especially if the tree is tall, cannot contribute much to erosion control. In fact the crown can concentrate the raindrops into larger drops with more erosive potential. It has been demonstrated that rain water collected in the crowns of tall trees is able to reach terminal velocity, so that the kinetic energy per drop is much larger than free-falling rain in the open (Lembaga Ekologi, 1980). It is canopy that is low enough to the ground that has a compensating reduction on raindrop velocity (Wiersum, 1984). Thus the lower canopies of a forest and the litter-layer of the forest floor are the features that control the erosive force of rainfall on a forest.

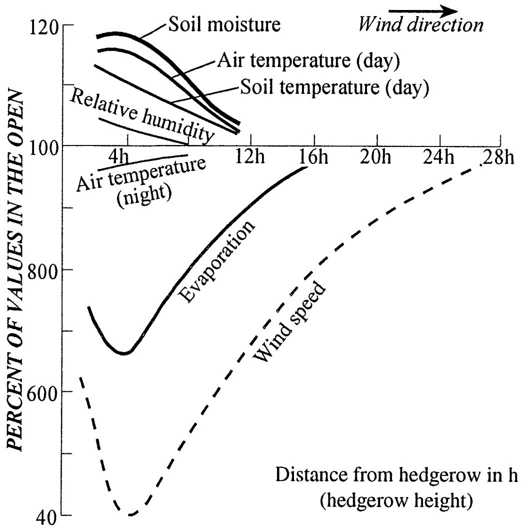


Figure 14: Surface, soil, and water temperatures in the forest and open (after Foreman and Godron, 1986)

The shade afforded by the canopy is also an important factor for the regeneration of forest trees. In many temperate forests the potential seedbed for the germination of tree seeds changes with a variation of shade. For instance most coastal trees in heavy shade (<10% sunlight) regenerate best on coarse, woody debris covered with duff (decaying organic matter). As the effect of shade decreases to light or moderate shade (15-40% sunlight) the potential seedbed area increases, so that regeneration occurs on the forest floor as well as on coarse woody debris. However both substrates become unsuitable as seedbeds if there is a decrease in shade and increase in exposure to full sunlight, as occurs after clear-cutting (Minroe, 1974). Removing the canopy of the forest exposes the forest floor to intense insolation and desiccation. This also results in the destruction of the specialised forest soil organisms, which are replaced with species adapted to life in open lands (Baker, 1950). In more xeric environments, such as the sclerophyll forests of Australia, fire and an ash-bed can be the dominant factor initiating seedfall and germination (Ashton, 1981a; Attiwill and Chambers, 1995). Many species of *Eucalyptus* and *Banksia* release their seed burden after a fire event, while many species of *Acacia* require heating to split the seed coat and initiate germination.

The atmospheric condition under canopy is characterised by a lack of wind movement a high relative humidity due to the evapotranspiration of the plants and persistence of water vapour in the still air and a high carbon dioxide concentration due to high respiration levels of the terrestrial organisms and by the decomposition of organic matter on the forest floor (Pianka, 1974). These conditions are especially pertinent in the case of regeneration of tropical rain forest trees. Young trees grow, but very slowly under these conditions (Halle *et al*, 1978). This stagnant phase of development is changed as soon as there is an increase of light energy or wind penetration reaching the young tree, brought about by the action of the loss of one or more canopy trees. The effect brings about increased photosynthetic activity or higher transpiration rates allowing rapid growth into the space created.

Shade is a dominant factor in the maintenance of aquatic habitats. For instance, clearcut logging can produce large changes in the temperature of small streams. The principal source of heat input at clearcutting is from direct solar radiation. Shade removal may increase radiation loads by six to seven times. In studies of forested streams of the Pacific North-west (Brown, 1971), mean monthly maximum stream temperatures increased by 3.6-6.1°C in midsummer. In one case, where the forest of an entire basin was removed, a temperature increase of 14.3°C was recorded. Buffer strips that provide sufficient canopy cover to give adequate shading is an effective way of minimising increases in stream temperature.

The virulence of many fish pathogens that cause mesonephros disease, furunculosis, vibrios and columnaris disease have been demonstrated to increase as the water temperature rises (Lantz, 1971). In addition, the toxicity of chemicals usually increases with increased temperature so that organisms subjected to toxic materials become less tolerant as temperature rises. This effect is a natural consequence of the fact that both chemical reaction rates and metabolic rates increase with temperature increases.

In addition to the physical effects the forest canopy also provides a large direct input into the aquatic ecosystems. As primary production is low in these heavily-shaded waters, autochthonous production is also low. Many aquatic organisms that live under such conditions are often adapted to live on allochthonous material or food produced outside of the stream ecosystem. Further, the friable, organic nature of the forest floor allows rain water to drain into the stream systems without a heavy sediment load. Increasing the sediment load in forest streams has been demonstrated to be detrimental to populations of stream fish in temperate regions (Narver, 1971) as well as in the tropics (Senanayake and Moyle, 1981) by covering eggs with silt and reducing the recruitment rate of juveniles or by interfering with the breathing of adults by choking their gills.

SOIL ZONE

Forest soils, created by the trees and the shade afforded the forest floor are themselves a unique ecosystem. As Wilde (1958, p.9) states: 'forest soils are that portion of the earth's surface which serves as a medium for the sustenance of forest vegetation; it consists of mineral and organic matter permeated by varying amounts of water and air and inhabited by organisms; it exhibits peculiar characteristics acquired under the influence of the three pedogenic factors uncommon to other soils, forest-litter, tree roots and specific organisms whose existence depends upon the presence of forest vegetation'. Forest soils form by the action of litterfall and by the growth of roots and root exudates. Root systems create a zone of physical stability and high biological activity within the body of soil.

Forest litter is the product of senescence and environmental damage to the trees. Litter is the most conspicuous element of a forest floor in many forests and consists of components that range in size from microscopic leaf or bark fragments to coarse woody debris or pieces of wood more than 10 cm in diameter and one metre in length (Harmon and Hua, 1990). This layer helps to reduce erosion, provides a source of energy and nutrient flow, serves as seedbed, and provides habitat for decomposers and heterotrophs that live on the forest floor. The bark, leaves, twigs and branches of some eucalypt forests can account for annual accumulations of 4-

10 t/ha (O'Connell and Menage, 1982; Walker, 1979). The coarse woody debris is important to consider in the management of forest ecosystems as it is one of the slowest components to recover after disturbance (Spies *et al*, 1988), due to the fact that large branches and trunks are not commonly shed to the litter-layer in young, actively growing forests.

Tree roots usually have a biomass of about 20-30% of the above-ground biomass, the ratio of below-ground biomass to above-ground biomass usually having an inverse relationship (Ulrich *et al*, 1981). In addition the annual loss of fine feeder roots, in a natural 'sloughing off' (loss due to growth) process has been estimated to be about 10 t/ha for a 50 year *Eucalyptus obliqua* stand (Attiwill and Leeper, 1987). This is a greater amount than the annual litterfall from this forest. In North American forests the turnover of mycorrhizal root associations has been estimated to contribute to the soil generation process more than 5 times the input from litterfall (Fogel, 1980).

This input of root excretions and exudates into the soil attracts and stimulates a large number of soil organisms. The majority of soil organisms, in both mass and numbers, are micro-organisms. While their representation in soils may encompass many groups such as viruses, algae, nematodes and microarthropods, the highest representation is found within three major groups: bacteria, fungi and actinomycetes. One gram of fertile soil may contain 1-2 billion individual bacterial cells. This accounts for a mass of about 350-7100 kg/ha of bacteria in the upper 15 cm of soil (Allison, 1973). In infertile sands the populations may drop to hundreds of thousands of individual cells per gram. Similarly it has been found that actinomycetes may reach populations of 200 million or more individuals per gram of soil. This group which falls between the bacteria and fungi is able to decompose organic matter at moisture levels too low for either bacteria or fungi to operate effectively and produces antibiotics of high toxicity to other organisms including pathogens (Waksman, 1952). The fungi are present in similar numbers and often have a kilometre of hyphae in a gram of soil. Fungi are divided into three major divisions depending on their mode of nutrition; saprophytic, parasitic and symbiotic. At any forest location there are dozens of different species from each division.

Saprophytic fungi are responsible for decomposition. Practically all plant matter that falls to the forest floor has some part of its decomposition accomplished by fungi. Fungi are decomposers of proteins, cellulose and other carbohydrates and lignin. They are tolerant of a wide range of acid and alkaline soils and are able to tolerate periodic droughts. Their distribution in the soil is restricted by two factors. One is the fact that fungi are generally aerobes and cannot survive in the regions of the soil with a deficiency of oxygen. As the soil profile gets deeper more anoxic fungal populations tend to appear. The other limiting factor in the distribution of fungi in the soil ecosystem is the presence of arthropods, which feed on mycelia and spores and thus control fungal populations. The end product of this fungal activity is the accumulation of highly nitrogenous mycelial residue in the soil. Species of saprophytic fungi in forest soils are often correlated with soil types and with the distribution of distinct types of vegetation (Tresner *et al*, 1954), suggesting a response to the different phytochemical regimes of different species of vegetation.

Parasitic fungi depend on living tissue for their nutrition. These fungi, too, are common in forest soils. They may kill their host as seedlings or as adult trees, or may infect plants and maintain sublethal infections weakening in the host for a long time. Sometimes parasitic fungi can act as a factor limiting the distribution of certain tree species (Wilde and White, 1939). It has also been suggested that certain plant communities modify the forest soil so that a degree of control from parasitic fungi is obtained. In Western Australia, jarrah (*Eucalyptus marginata*) is very susceptible to infection by the dieback fungus (*Phytophthera cinnamomi*) when associated with a proteaceous understorey, but when the understorey is changed to legumes (as after fire) the susceptibility of *E. marginata* to the dieback fungus is greatly reduced (Shea *et al*, 1979). In North America, the fungus *Poria weirii* (a root rot) is a major disease in Douglas-fir and other conifers. The best control of this disease in conifer forests is inter-planting with alder. *Poria* is effectively controlled by inhibiting compounds produced by alder as well as being suppressed in the soil ecosystem by the large population of bacteria and fungi that are stimulated by the organic nitrogen fixed by the alder's root nodules (Trappe, 1971).

Fungi that live in a symbiotic relationship with plants are known as mycorrhizal fungi. These fungi produce a mycelium that enters into, or envelopes, roots creating certain modifications in the living plant tissue. These modified roots are termed mycorrhizae. This modification has profound consequences for plant growth as it permits the plant to provide the fungi with synthesised sugars and starches, while the fungi extract minerals from the soil and supply them to the plant. The extensive spread of fungal hypae through the soil also increases the effective feeding zone of the tree roots. Many species of trees, especially the conifers, cannot grow efficiently or compete successfully without these fungi. Often it is these fungi that help plants adapt to specialised environments. However, these organisms are still poorly known. Robinson (1988) records 360 new species collected in a single day from a single site in New Mexico. The inference to lesser studied systems such as rainforest soils is tremendous.

Mycorrhizae occur in two forms: Ectotrophic and Endotrophic. 1) Ectotrophic mycorrhizae are commonly associated with trees. They form a smooth mantle of mycelium around the root and penetrate the intercellular spaces of the root with their hyphae. 2) Endotrophic mycorrhizae contain mycelium that develops within the cell. The hyphae penetrate epidermal and cortical cells, forms vesicles, or bladder-like organs in the intercellular spaces and arbuscules, or cauliflower-like organs within the cells. Hyphae spread widely from the infected root.

Both forms of mycorrhizae usually stimulate intense branching of the lateral feeder roots. This effect together with the surface area gained from the fungal hyphae, greatly increases the efficiency of nutrient uptake by the plant. The building up of a good mycorrhizal population in the forest soil appreciably reduces the need for fertiliser input into nurseries and arboricultural plantations (Wilde, 1958). The relationship between tree roots and soil organisms is very intimate and reflects their long history of co-evolution.

Forest soils, then, are unique ecosystems which depend upon the activity of tree roots and the fall of forest litter for their maintenance. The surface soil and the litter layer fall into two distinctive groups, termed mull and mor, reflecting the integrity of the horizons. In forests with a mull litter the transition between the litter and the mineral soil is indistinct. A mor litter, in contrast, has a very distinct and clear transition zone. The mor litter can easily be separated from the mineral soil below. In both instances there is a large diversity of soil animals that live by disintegrating and digesting plant residues, breaking the debris into its organic and inorganic constituents and finally, dispersing the end products into the body of the soil. The most important of these macro-organisms are earthworms, millipedes, mites, wood-lice, termites, springtails, crustaceans and larvae of beetles and flies. In temperate zone forests their combined populations may weigh more than 1000 kg/ha (Edwards, 1969).

In physical action the root systems of a forest can serve as cohesive binders of the soil mass. In addition, if they penetrate entirely through the soil zone, they can anchor the soil mantle to the substrate, providing an effective stabilising influence. Tree roots, by adding to the shear-strength of soils are effective in providing a reduction of shallow slope failures or landslips (O'Loughlin and Ziemer, 1982). In some extremely steep areas tree roots may be the dominant factor in shear-strength of the slope soil (Swanston, 1971). This has been evidenced in areas where forests were removed from landslide prone areas. In many cases the incidence of landslides has increased greatly 5-20 years after clearcutting, due to the fact that a part of the strength of the soil mass came from the anchoring effect of the tree roots. As the roots decay, susceptibility to landslides gradually increases (Rice *et al*, 1972).

In certain species (*Eucalyptus pileata* and *E. eremophila*) tree roots have been traced to a depth of 28 m (Nulsen *et al*, 1986), illustrating the structural potential of roots.

Good friable forest soils are also an important factor in controlling erosion, while the presence of a canopy can slow the erosive force of rain droplets. The permeability of the soil has been demonstrated to have a significant effect on retarding surface flow. Farmer (1973) simulated rainfall on soil types to determine which factors are the most important in the detachment of soil particles by raindrops. In this study slope and rainfall intensity were found to be far less important than the presence or absence of water on the soil surface. Soil particle detachability was found to increase greatly when a thin layer of water covers the surface, such as when overland flow occurs. This fulfils a major need in land management. As Pereira (1967) argues that one of the major effects of forests is to prevent runoff and overland flow and by infiltration and percolation regulate flow in stream canals. Infiltration is also affected by the structure of the tree. Nulsen *et al* (op cit) record that 25% of intercepted rainfall ran down the stem as stemflow. This flow caused saturated conditions around the bole of the tree and dye tracing showed that the water penetrated the soil via annular pathways of the soil-root interface.

A forest, therefore, is an essential feature in maintaining the quality of soils, in terms of biomass input and protection from desiccation. The ability of the forest to create and maintain a modified environment beneath the canopy provides the potential for the development of ecosystems and species that contribute to its unique nature as well as to the stability of that ecosystem.

Trees, in addition to their differential effect on soil biota, also have the ability to affect the nutrient status and the pH of the soil that they grow in. A comparative study of *Acacia albida* and *Kigelea africana* growing in woodland, demonstrated that the nutrient status in regard to N, P, K and C was higher under the trees than in open grassland, but the soil below *Kigelea* had a higher level of P and was less acid than the grassland soils, while *Acacia* had a lower level of P and soils were more acid than grassland soils (Dunham, 1991). Further, trees have been demonstrated to be capable of accumulating various elements. Studies in Russia suggest that oak (*Quercus* spp) and Beech (*Fagus* spp) have been shown to accumulate Be, Co, Zn, Cd, Sn, Pb, Mn, Ni, Ce, As, Ag and Au in their leaves and in the humus layer under the tree (Remezov and Pogrebnyak, 1969); the levels of all these metals are substantially higher than in the soil surrounding the tree. This ability of trees to bioconcentrate metals may become useful in controlling the ground movement of certain toxins.

KEYSTONE SPECIES

The ecological identity of a forest often can be defined by a few keystone species. These are species without which the equilibrium, and thereby the nature, of any ecosystem changes. Keystone species in some non-forest ecosystems have been extensively studied to illustrate the functioning of this principle. In a forest situation keystone species are those which provide architectural or biological stability to that forest ecosystem. The relative height of mature redwood and the forest ecosystems that are replacing them (Figure 15) is an example of architectural keystone. The redwood can be replaced by Douglas-fir of similar structure to conserve architectural form, but replacing it with pine, or maintaining it on a very short rotation, will change the forest architecture radically and produce changes in the forest ecosystems.

The architectural or structural keystone is only one aspect; the other is trophic. The biological system is maintained by species which provide and regulate the flow of energy within the ecosystem. Every stage of forest succession contains its keystone species. In early, seral stages of tropical forests, species like *Erythrina, Cecropia, Macranga and Trema* are pioneer species. They are fast-growing, invasive and have leaves that are of great palatability, usually pock-marked with holes made by herbivorous insects (Ewel, 1976). They also produce great quantities of nectar in floral and extra floral organs that feed a wide diversity of insects. These support populations of insectivorous vertebrates such as birds and reptiles, which in turn support their predators. The observations of the feeding activity of bird species in an *Erythrina*-dominated forest patch in Sri Lanka (Table 3) demonstrate the strength of this tree as a keystone species in creating an ecosystem that could be used by forest obligate species. Every forest has its own complex of such seral keystones that lend it stability.

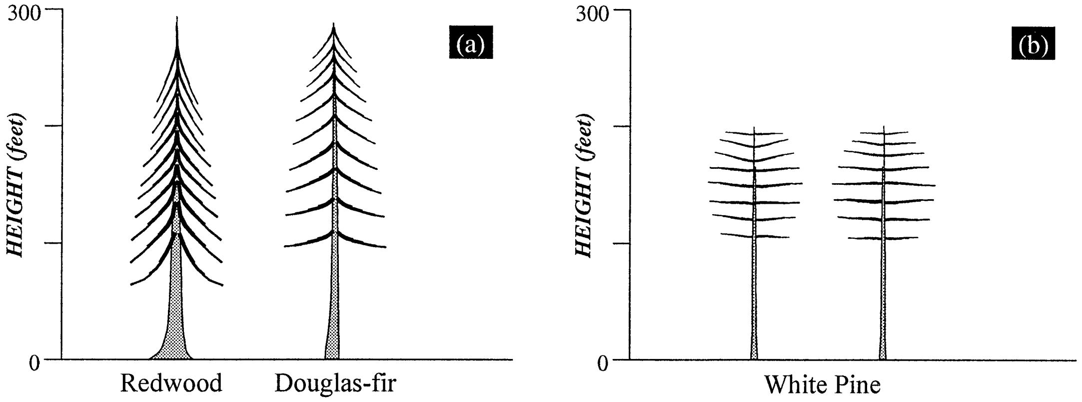


Figure 15: Effects of replacement of redwood or Douglas-fir keystones compared with white pine

Table 3: Species of birds recorded visiting* Erythrina lithosperma *trees at Bandaraewela, Sri Lanka. (NSRC data.)

Species	Food	Season	Frequency
Black headed oriole	omnivore	flowering	regular
Blossom headed parakeet	fruit/seeds	flowering	regular
Brown headed barbet	omnivore	all year	regular
Ceylon gray tit	insects	all year	regular
Ceylon iora	insects	flowering	regular
Ceylon lorikeet	nectar	flowering	regular
Ceylon paradise flycatcher	insects	flowering	regular
Ceylon tailorbird	insects	all year	regular
Flowerpecker	nectar	flowering	regular
Grey headed flycatcher	insects	all year	regular
Indian paradise flycatcher	insects	winter	rare
Little minivet	insects	all year	regular
Lotens sunbird	omnivore	all year	regular
Orange minivet	insects	all year	regular
Pied shrike	insects	all year	regular
Red vented bulbul	omnivore	all year	regular
Rose ringed parakeet	fruit/seeds	all year	regular
Scimitar babbler	insects	all year	regular
Small white eye	insects	all year	regular
White browed bulbul	omnivore	all year	regular
White browed fantail flycatcher	insects	all year	regular
Yellow eared babbler	insects	flowering	rare
Yellow fronted barbet	omnivore	flowering	rare

CHAPTER FIVE

FOREST-ADAPTED ORGANISMS

A forest is not just a collection of trees cycling nutrients and growing in a mature soil. It is also a vast collection of other organisms varying from birds to lichens that are components of interlinked trophic webs. A knowledge of forest-adapted organisms is important to forest design, especially in the context of biodiversity conservation. Forest-adapted organisms are also good indicator species, that can warn of negative trends or signal positive changes to a forest. The forest-modified environment has provided the conditions for the evolution of a vast array of species whose niches (Hutchinson, 1965) are confined to forests. These organisms are often referred to as forest-specialists or forest-obligate species. They cannot maintain populations outside the specialised environment that a forest supplies.

STRUCTURES

The forest as a structure that provides a modified environment has varied little throughout the millennia. It remains the major terrestrial refuge for species with primitive characteristics. It also provides the greatest focus of biodiversity. For instance, Australian rainforests possess a large proportion of litter-dwelling species that bear primitive characteristics (Mattson, 1976). Similar patterns have been observed in biodiversity of plants, birds, beetles and mammals (Wilson, 1988). The organisms that occupy climax forest communities exhibit more K-type life strategies (Table 4) or represent the more 'rare' element of the forest biota. The concepts of r and K selection arose from work in population biology (Pianka, 1970) and are identified by the life strategies of the organism.

The forests that create a modified environment for forest-adapted biota range from temperate to tropical formations. The forest as a tree-dominated ecosystem remains while the species composition changes. The associated biota may or may not change smoothly along gradients. For instance, a certain bird or mammal species may be found from pioneer to more mature seral stages, the same species being found in grassland and forest. However, the changes in community structure and function will be different enough at two ends of a scale, from pioneer to climax to be clearly observed. While this change is seen as succession towards a more mature state, the responses of tropical and temperate forests are different. As a forest moves from pioneer to mature stages, species composition changes with the maturity in both types of forest. The species diversity remains relatively constant in temperate forests, while species diversity increases in tropical forests.

Table 4: Some characteristics of pioneer (r selected) and climax (K selected) organisms

r selected organisms	**K selected organisms**
adapted to uncertain climates	adapted to certain climates
good colonisers	poor colonisers
mortality density independent	mortality density dependent
population stability low	population stability high
rapid population development	slow population development
small size	large size
short lifetimes	long lifetimes
high fecundity	low fecundity

Bowles (1963) ranked different species of birds in a Washington Douglas-fir forest into common (>21%), fairly-common (11-20%) and rare (<11%) categories based on frequencies of observation. In his study he looked at three different types of forest (Table 5). He found that twice as many 'common' species occurred in a salvage logged blowdown area when compared to old-growth forest, but twice as many 'rare' species occurred in the old-growth when compared to salvage logged blowdown areas. Similar studies in other temperate forests (Harris *et al*, 1982) suggest that it is the structural diversity provided by fallen logs and snags that occur in old-growth forest that gives it greater habitat value. In S-E Australia Recher (1969) demonstrated that bird species diversity was correlated with the complexity of the vegetation as measured by the vertical distribution of the foliage. In a 80-100 year old dry sclerophyll mixed eucalypt forest Neumann *et al*, (1995) recorded in the litter-layer, 109 species and 30 families of the order Coleoptera, over a four year period.

Table 5: Number of species of birds ranked as common, fairly-common and rare, occurring in the three types of Douglas-fir forests in western Washington (after Bowles 1963)

	Common	**Fairly-common**	**Rare**
Salvage logged, clearcut	16	12	8
Partially logged, mature stand	15	5	11
Old growth	7	5	17

The patterns in tropical rainforests are somewhat different. As the forest matures into old-growth there is an increase in species diversity and richness with forest maturity (Forsyth and Miyata, 1984). The diversity of different organisms in these forests is illustrated by Wilson (1988), who recorded 43 species of ant belonging to 26 genera from a single leguminous tree in a climax forest in South America, and 700 species of ant in 10 selected one-hectare plots in the rainforests of Borneo. The canopy of tropical forests provides a series of habitats that have yielded over 3,000 species of beetles from five 12 m^2 plots in Manaus, Brazil (Erwin, 1983). In these plots the canopy is occupied by over 150 species/ha of trees and vines. Also, there is an intermingling of leaves between two or more species of trees, between vines and the trees and between one tree overshadowing the other, resulting in the creation of micro-environments and the tremendous biodiversity observed in these canopies (Erwin, 1988). This heterogeneity in the environment allows for specialisation. In a completely uniform environment only one species could occur at any trophic level. Thus, much of the animal diversity in tropical forests can be attributed to structural heterogeneity (Ricklefs, 1973).

The architectural structure of a tall-tree dominated ecosystem has allowed for the development of many species specialised for arboreal life. In terms of utilisable space, the forest environment can be divided into canopy space, branch space, and terrestrial space (Figure 16), most pronounced in tropical forests.

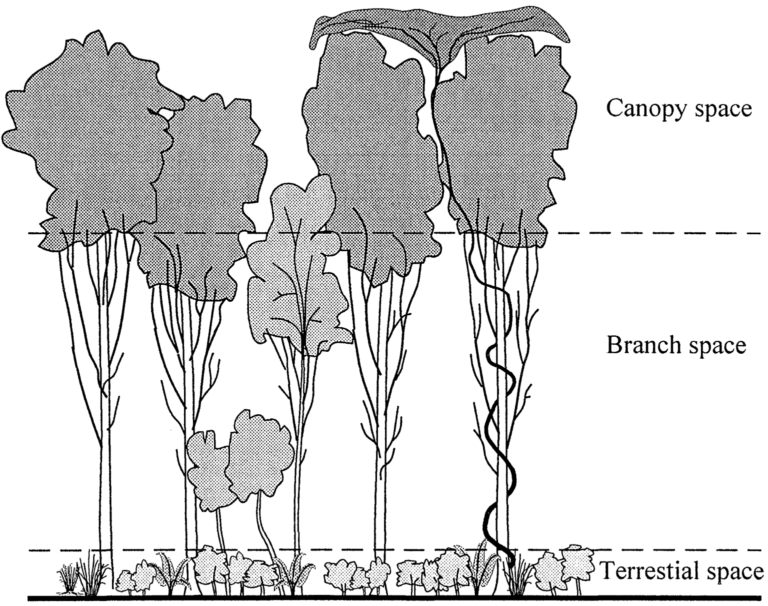


Figure 16: Categories of forest space

The canopy space is most complex where the organisms tend to be small due to the restricted nature of the spaces available for movement. The canopy space is also the region of greatest productivity and supports a tremendous population of leaf-eating or phytophagous organisms. Many species of birds, small mammals, (e.g Humbolt's wooley monkey *(Lagothrix lagotrichia)),* arboreal reptiles, (e.g. flying snake *(Crysopelea ornata)* and flying lizard *(Draco volans))* and amphibians, (e.g. gliding frog *(Rhacophorous reinwardti))* occur in the upper canopy. The branch space usually lies below the canopy and supports it. The spaces here are much larger and support many large mammals like gibbons (*Hylobates* spp), spider monkeys (*Ateles* spp) or orang utans (*Pongo pygmaeus*) and birds like forest owls and eagles.

The terrestrial space, allows for the development of specialised ground-dwelling organisms ranging from forest mice to rhinoceros, or from rails to cassowaries. The extent of undergrowth affects the quality of this habitat greatly. Furthermore the height and age of the forest determines the size of the organisms that can utilise these spaces. The primates provide good examples. Many species such as the forest-dwelling spider monkeys, gibbons, orang utan or the lemurs (*Lemur* spp) (Mittermeier, 1988) are confined to life in tall trees, but are unable to maintain populations in young growth or smaller stands. This requirement means that such species may become endangered due to the loss of mature habitat. These large animals require old-growth forest, as they are not adapted to terrestrial life or pioneer vegetation. Others, such as the aye-aye (*Daubentonia madagascarensis*) or tarsiers (*Tarsius spp*) which are tiny, still cannot utilise pioneer vegetation as they are specialised for living on the complex habitat found on the surfaces of old-growth trees.

Another array of habitats used by tree dwelling organisms is the spaces created by shedding bark, tree stags and rot holes. As tree bark begins to die it shrinks and the layer between the bark and sapwood is quickly colonised by saprophytic fungi and the organisms that feed on these fungi. The presence of these small organisms attracts larger predatory forms such as spiders or reptiles specialised for life in these environments. The geckoes, especially the cryptic forms like the leaf tailed gecko (*Phyllurus cornutus*), are an example of species adapted for life in these habitats. Tree stags and fallen logs have long been recognised as valuable habitat for forest species. In Oregon forests it was found that 14 species of reptiles and amphibians, 115 species of birds and 49 species of mammals used fallen logs and stags as habitat (Thomas, 1979). Holes in trees are formations found in old-growth, where water collects in cavities formed by the action of micro- or macro-organisms these habitats support a highly specialised group of organisms ranging from crabs (Senanayake, 1975) to frogs such as the microhylid (*Ramanella palmata*) (Zoysa and Raheem, 1990). These rot holes have been identified from forests in every continent except Antarctica (Fish, 1983) and contain a characteristic, specialist fauna of insect larvae, mites, microcrustaceans, annelids and anuran tadpoles that demonstrate robust food webs. In a study of water filled treeholes in Australia, food webs involving 45 species operating at four trophic levels have been identified (Jenkins and Kitching, 1990).

SUBSTRATES

Aerial

Forest trees provide three major habitat areas for organisms specialised for life in a forest environment. They are: the living substrates as exemplified by the active growing components; this is the habitat for organisms that live on the trees like epiphytes or in the trees like parasites. The second habitat area consists of the non-living or inert substrates characterised by litter, debris or minerals which harbour decomposer communities. The third is the space created by the architecture of these substrates. This forest space, which lies below the canopy is used by many forest-adapted organisms from arboreal mammals to birds, reptiles and insects.

The living substrates of forest trees offer three distinct surfaces for colonisation by other species: the trunk and branches, the leaves and the roots. The trunk and branches of the trees provide the substrate for the development of epiphytes such as mosses, liverworts, lichens, ferns and the higher plants such as orchids or bromeliads. The specialised nature of these epiphytic ecosystems can be seen both from a perspective of time and scale. The initial colonisers of the surface of the bark and branches are the algae, mosses and lichens. These groups begin to demonstrate characteristics of ecosystem maturity within themselves. For example, lichens demonstrate successional processes when they colonise a new substrate (Yarranton, 1972). As a community these epiphytes form suitable substrates for the establishment of higher plants, much in the manner of successional maturity of the forest itself. One study in the Himalayas found that bryophytes produced the most biomass on most trunks; next to them were the lichens on the smallest trunks, and flowering plants on the largest (Tewari *et al*, 1985). However, it should be noted that the nature of the substrate, (ie the species of tree on which these communities form) often provides differential benefits. Some trees have a short-lived bark that sheds in large flakes or strips and affects the establishment of a stable community (Peard, 1983). The physical nature of the bark is not the only factor affecting the distribution of epiphytes. Some species of trees support a particular suite of epiphytes. In the rainforests of Sri Lanka epiphytic orchids preferentially colonise certain species of trees (Quyn, 1991) and their range may be restricted by the availability of these tree species (Table 6). A similar pattern has been demonstrated for epiphytic bryophytes and lichens in the dry evergreen forest of Guyana. Here many species, particularly the foliose lichens were found exclusively on the trees *Eperua grandiflora* or *E. falcata* (Cornelissen and Ter Steege, 1989). Even within a single species of tree, effects of bark chemistry on epiphytes can be detected. An examination of the epiphytic species composition on the lower trunk of *Acer macrophyllum* in Canada found that the epiphytes responded mainly to microhabitat differences in relative humidity and light conditions but bark chemistry accounted for some of the variation (Kenkel and Bradfield, 1986).

Table 6: Record of epiphytic orchids and hosts, at Corbett's Gap, Rangala, Sri Lanka (Data from Quyn 1991)

Epiphytic orchids	Host trees
Aerides cylindricum	*Callophyllum* spp
Cirrhopetalum grandiflora	*Callophyllum* spp
Dendrobium heterocarpum	*Callophyllum* spp, *Semecarpus* spp
Eria bicolor	*Semecarpus* spp
Josephia latifolia	*Callophyllum* spp
Liparis viridifolia	*Semecarpus* spp, *Eugenia* spp
Octarrhena parvula	*Callophyllum* spp
Sarchochilius spp	*Callophyllum* spp

These epiphytic communities in turn harbour specialised life forms that require such ecosystems to sustain their populations; the life history of the poison arrow frog (*Dendrobates* spp) which uses the water held in the 'cup' of epiphytic bromeliads to rear its tadpoles is such an example. In a study the factors affecting the population status of *Dendrobates pumilio*, the availability of bromeliads was seen to be the strongest control factor (Donnelly, 1988). In some forests the epiphyte substrate provides habitat for more species than are found on the forest floor (Paoletti *et al*, 1991). Laessle (1961) recorded 68 species of animals and plants in the water retained in Jamaican bromeliads. Epiphytic communities can account for a large biomass in some environments. In forests of the Colombian Andes the epiphyte biomass was estimated at about 12 tonnes dry weight per hectare (Veneklaas *et al*, 1990).

Epiphytic lichens and lichen communities are also useful in identifying old-growth, or relatively undisturbed forest area (Rose, 1976), as they establish long-lived populations late in the non-vascular plant succession. In Thai forests Wolseley and Aguirre-Hudson, (1991) have demonstrated that the size of lichens can provide evidence of fire and disturbance in dry dipterocarp forests. Old-growth Douglas-fir forests have been reported to have over 125 species of lichens that inhabit treetops. Here a succession in fauna and flora occurs as a twig grows into a branch (Dennison, 1973). These old growth Douglas-fir forests are typically poor in nitrogen and rely on the lichen flora that is present to assist in nutrient cycling. The most abundant species, a foliose lichen, *Lobaria oregana,* serves as an indicator species of old-growth and fixes atmospheric nitrogen at the rate of 2-11.2 kg/ha/y (Franklin, 1988).

The leaves of the tree also provide a growing substrate for many species. Leaves that are usually short-lived often have associations of decomposer fungi that develop into active communities at time of leaf fall. These communities of fungi begin the process of decomposition just before, or at, leaf fall. The longer-lived leaves such as those of *Wilkiea spp*, often support active colonies of lichens. Here, the classical seral process seen on the trunks of trees is not evident. Instead, new species move towards a gradual replacement of the initial flora by competitive exclusion (Conran and Rogers, 1983).

Many bird species are confined to a forest habitat due to environmental factors such as nesting or feeding requirements. The spotted owl (*Otus trichopsis*) of north western America, which cannot nest outside forest formations, or the bower birds (*Ptilonorhynchus spp*) of Australia that require a clear forest floor for their courtship ritual, are examples. Other species cannot compete with non-forest species or are pre-dated upon once the habitat has degraded, as exemplified by the blue magpie (*Urocissa ornata)* of Sri Lanka. This species inhabits mature forest and cannot maintain populations in disturbed habitat due to the pressure of cuckolding by species of cuckoo that inhabit early-seral stages of the forest. All nests within mature forest remain safe from this nest parasite while over 90% of all nests outside the forest are parasitised (Karunaratne, 1993).

The diversity of tree species in a forest has a direct bearing on the biodiversity of its component fauna. Many species of forest insects are highly specialised to live on a particular species or genus of plant. Often the food plant is confined to a single species. In Australia, there are about 70,000 species of phytophagous insects, of which over one quarter depend on different species of eucalypts or acacia for food (New, 1983). The fact that there is strong tree/host specificity to phytophagous insects was illustrated clearly by Erwin and Scott, (1980). Collections of beetles from tropical forest canopy in Panama have changed the estimates of the insect species present on earth from 1.5 million to 30 million (Erwin, 1988) and underscores the value of the canopy vegetation in maintaining biodiversity. In addition, the diversity of forest trees is an important factor determining the soil chemical status because leaves of different species decay and release their nutrients at different rates (Evans, 1984).

Below Ground

The roots provide a substrate for colonisation by various species of bacteria and fungi with many specifically adapted to live in a symbiotic relationship with specific tree species. They also provide food or habitat for many species of plants that have specialised to inhabit forest soils beneath the forest floor at fossorial or sub-fossorial levels. These can range from the giant root parasite possessing the worlds' largest flower (*Rafflesia*) found in the rainforests of Malaya to the tiny ground orchids (*Dipodium spp, Calochilus spp*) of the eucalypt forests of Australia. The litter that collects between the roots retains moisture for a longer time than the litter in open areas. The moist, deep litter supports specialised forest organisms. For instance, in a study of the forest floor litter dwelling frogs of the rainforest, it was found that populations were positively correlated with litter volume and moisture (Almon, 1991).

The non-living substrates are composed of coarse woody debris, dead trees, soil litter and exposed rocks. The litter and coarse, woody debris characteristic of old forests contains large populations of wood-decaying fungi. The commoner types are *Echinodontium spp, Philiota spp, Phillinus spp* and *Hericium spp.* Studies of the action of these fungi demonstrate that they are all associated with bacteria capable of fixing nitrogen (Aho, 1974). This is yet another source of nitrogen input to old-growth forests that are nitrogen-poor.

The forest soil biota live by disintegrating and digesting plant residues. There are many species of bacteria, fungi, worms and microarthropods specialised in using forest debris. They break the debris into its organic and inorganic constituents and work the end-products into the body of the soil. These animals provide the food for animals at a higher trophic level, such as scorpions, spiders or beetles, that are food for a yet higher trophic level, building up a complex community of organisms specialised for life in forest soils. At each level there are organisms specialised to forest life that can be driven to extinction by the loss of the environments. For instance, the wood ants (*Formica spp*) of spruce-pine forests and birch-aspen forests of Russia have been so severely depleted by loss of habitat that forest reserves were established in 1977 to ensure their protection (Wuorenrinne, 1988). Similar studies on the megalomorph (trap-door) spiders in Australia suggest that most of the surviving species are confined to soils in patches of remnant natural vegetation (Main, 1987).

The other major non-living substrate that a forest offers for colonisation is the rocks. The rocks that protrude into forest space harbour communities of lichens, mosses, ferns or other pterophytic plants. They also generate cavities that provide habitat for a wide range of organisms specialised for life in these microhabitats. The rocks also provide a regular input into forest soils by the action of weathering and by biological activity such as decomposition by lichens. The mineral element of the parent soil also provides a specialised substrate for soil micoorganism communities, the action of which is essential for the creation of the body of soil (Jenny, 1961). However, the formation of the mineral part of soil also depends on the temperature, climate and age, as noted by Wilde (1958, p.34), 'The ecological effects of the parent soil material are like concentric ripples from a stone cast in a pool of water; its influence diminishes with distance'. In other words, the influence of the parent soil on the ecosystem diminishes with the effect of temperature, climate and age.

Forest soils frequently contain very specialised macro-organisms that reflect the unique character of these soil ecosystems. The numbers of organisms can often be large; 42 million arthropods species per hectare were calculated for a Seram rainforest, the vast majority living in the soil and leaf-litter (Stork, 1988). The animals that live in these soils, range from the legless sub-fossorial skinks (*Nessia spp, Acontias spp, Anomalopus spp*) to legless sub-fossorial amphibians (*Ichthiophis spp*). The size of organisms that live in forest soils can extend in size from microorganisms like bacteria to macro-organisms like mammals such as moles and shrews (Wilde, 1958). The loss of these soils often lead to the loss of these specialised organisms. Gans (1973), working on the earth snakes of Sri Lanka and India, demonstrated that the present populations were restricted to remnant forest patches or to anthropogenic ecosystems that have the propensity to create deep organic soils which are similar to the original forest soils. The distribution patterns indicate a wide range where the forests and forest soils once existed. But, as most of the forests and their soils were lost to coffee and tea plantations in the 18th and 19th century, the present distribution is confined to small remnant patches of forest that act as refugia today.

REVIEW

Thus forest environments are essential for the sustainability of many specialised communities of organisms, at various trophic or scalar levels. However the habitat quality of the forest has an important effect in its ability to sustain biodiversity. In studies of the comparative effects of exotic pine monocultures with eucalypt stands in Australia, Ahern and Yen (1977) found significant differences in many invertebrate groups, while studies on more vagile groups such as birds (Driscoll, 1977) and beetles (Neumann, 1979), do not show such a pronounced variation. Thus indicators of habitat quality may have to be drawn from more sedentary groups (Forster and Wilson, 1973). Other comparative studies between exotic plantations and native forests confirm the pattern that habitat quality is greatly reduced in exotic monocultures in terms of soil fauna (Senanayake, 1987b) and less vagile macrofauna (Wilson and Johns, 1982). The quality of the forest environment can also be affected by a reduction of the quality of local climate. Meher-Homji (1989) suggests that poor forestry practices can have a negative effect on habitat quality by initiating changes in established hydrological patterns.

A major ecological drawback in afforestation or reforestation with monoculture plantations is their poor ability to sustain the native biota (Budowski, 1984). These considerations are important when biodiversity conservation, species conservation or genetic conservation are considered

(Henning, 1991). It can also have a great impact in terms of the local economy or social structures.

The potential value of forest-adapted plants is just beginning to be realised. The value the genes from a single wild plant collected in the mountain forests of Peru has been estimated at an increase of US $M8 per annum to the tomato industry (Iltis, 1988). Similarly, the value of forest-adapted plants for the pharmaceutical industry, chemical industry and cosmetic industry is now being appreciated and translated into the need to conserve this resource (Plotkin, 1988).

CHAPTER SIX

FOREST PRODUCTS

In general parlance, product refers to goods or services that have validity in the economic system. Forest products might therefore be seen as economic goods or services that are created by forests.These products can be classed into two broad categories. One category contains the products that can be attributed to specific species such as wood, fruit, gums and the like. The other category contains products that can be attributed to the functioning of the forest as a whole. Here, products such as water and services such as aesthetics or soil erosion control, are seen to be valuable outputs of a forest. Although the value of individual products has been recognised for a long period of time, the value of a forest as such, though long appreciated, is only just beginning to gain economic recognition.

The most recognised product of a forest has been the wood in the trees. Different species produced timbers of different quality. Some species were rarer or more difficult to obtain than others. Thus timber is categorised into different classes reflecting its quality and rarity. The differential in price between pine and walnut in temperate zones or between *Albizzia* and ebony in the tropics serve as good examples. In addition, the age of the tree also has a bearing on the quality of the wood within a species. Tree-age is seen to have importance in setting value because a greater amount of low-density sapwood is generally found in young-growth trees and because, with increasing age, vascular cambium produces longer and thicker walled cells, a feature important in the modern market (Resch, 1967). In this study it was shown that as a tree matures and grows in girth, there is an increase in fibre quality as well as in the specific gravity of commercial wood.

Wood is also important in terms of its energy potential. In much of the world wood provides the primary domestic energy that is used for cooking. Approximately 86% of the fuel-wood consumed from the world production is consumed in developing countries (Peck, 1984). It has a heating value of approximately 5,000 kcal/kg dry weight (Grantham, 1974). It could be used effectively in institutional heating, where newly-developed wood burning furnace technology can deliver energy at over 80% efficiency (Riley, 1976). When converted to charcoal, wood-derived fuel becomes one of the best solid fuels known as it is clean burning without any sulphur emissions and has the capacity to be blended with oil or coal to increase the burning efficiency of these fuels (Anon, 1979). However wood is poorly suited for the generation of electricity because the energy losses of 65-75% in generation and transmission at the current level of technology make it uneconomic.

The development of wood-based industries that allowed low grade wood to be chipped and used to produce industrial process steam, chipboard, fibreboard, chemicals and paper pulp (Goldstein *et al*, 1978), has created new markets for wood thought to be unmarketable previously. It also creates a demand for those parts of a tree usually returned to the environment in the practice of traditional timber harvesting.

The basic products that markets concerned themselves with for a long time were wood and fibre. This aspect is clearly demonstrated in research studies such as, 'The Forest and its Products' (CSIRO, 1986) or the 'Master Plan' for forestry in Sri Lanka (Anon, 1986), which begins by defining a forest as unprocessed wood. In fact all other forests products receive little attention and are designated as Minor Forest Products (MFP's) by most forestry departments (Rao, 1991). As a result, the development of fruits or nuts as a crop has been left to horticulture and confined to orchard production. The collection of gums, waxes, honey and other minor forest products has been left to licensees. These trends in forestry have led to trunk condition, wood biomass or timber value becoming major criteria determining species selection and forest design.

The potential for tree crops to yield substitutes for products such as cereals that were considered outputs of annual cropping systems was first discussed in the scientific community by Smith (1977), who based his arguments on many examples around the world. The comparison of two land management systems in similar climates, one in Corsica and the other in west China, provides one example. Visits to both areas during the early 1900s saw productive agricultural systems. But on return about twenty years later one was still productive while the other was eroding badly. The difference was that in the stable system (Corsica), large stands of orchards, chestnut groves and other forests, had been preserved while in the unstable system (China), the hillsides had been ploughed and left treeless. These observations have evoked a greater interest in tree crops and movements towards developing non-timber products as a primary crop, especially in providing substitutes for annual cereal and pasture crops (Sholto Douglas and de Hart, 1985).

Although there has been an on-going interest in non-wood products from forests (Smith, 1977; Macmillan, 1935), research and development of these species have been driven by horticultural needs rather than forestry. However, these trends may be changing. In a recent evaluation of non-wood forest products by Asian foresters gathered together under the auspices of the FAO (Rao, 1991), the list in Table 7a has been suggested.

Table 7a: Non-wood forest products (List A)

- Fibre products
  - - Bamboos and rattans
- Food products
  - -Edible fruits, nuts and spices.
  - -Oil seeds
  - -Honey
  - -Mushrooms etc.
- Medicinal products
  - -Medicinal plants
- Extractive products
  - -Gums, resins and oleoresins
  - -Tannins and dyes
  - -Essential oils
- Miscellaneous products
  - -Sericulture
  - -Wildlife products

All products listed in Table 7a fall into the individual species category. In considering the range of products to be evaluated the modification proposed by Schery (1972) may be useful (see Table 7b).

When individual species are considered, each seral stage of forest has a different suite of species that produce optimally. For instance, pawpaw (*Carica papaya*) may be very useful in the early-seral stages of a tropical forest but be very poor in late-seral stages. Similarly durians (*Durio spp*) may not be as useful in early-seral stages but are very important in late stages. In a temperate situation blueberry (*Vaccinium spp*) will perform well during early-seral stages but not under shade, while persimmon (*Diospyros kaki*) will do better in a more mature, late-seral stage forest. Therefore, in evaluating species for potential of non-wood products the ecological attributes of the species must also be considered.

Table 7b: Non-wood forest products (List B)

- Fibres
- Cell exudates and extractions
- Latex products
- Pectins, gums, resins, oleoresins and similar exudates
- Vegetable tannins and dyes
- Essential oils for perfumes, flavours and industrial use
- Biodynamic Plants : medicinals, insecticides, growth regulants, etc
- Vegetable oils, fats and waxes
- Carbohydrate extractives : sugars and starches.
- Plants used for food, medicine or beverage
- Cereals
- Food seeds and forages
- Vegetables
- Fruits
- Beverage plants
- Other organisms
- Fungi and micro-organisms
- Bees and other invertebrates
- Vertebrates

FIBRE PRODUCTS

The extraction of fibre from non-wood components of plants, yields fibres of fine quality, the most famous non-wood plant fibre product being cotton. These fibres are classified botanically as bast (inner bark) fibres, leaf fibres and floss fibres.

Bast fibres come from a range of quick growing annuals or perennials such as flax (*Linum usitatissimum*), jute (*Corchorus capsularis*), ramie (*Boehmeria nivea*), hemp (*Cannabis sativa*) and rozelle hemp (*Hibiscus sabdariffa*). These plants are usually pioneer, early-seral stage species.

Leaf fibres are extracted from perennial plants usually stemless with strong leaves such as, Manila hemp (*Musa textilis*), Mauritius hemp (*Furcraea gigantica*), sisal hemp (*Agave sisaliana*) or bowstring hemp (*Sansevaria spp*). These plants are long-lived and are often found in environments hostile for the establishment of trees. However, they do maintain good populations in woodland type shade.

Floss fibres are found surrounding the seeds of certain fruit like kapok (*Eriodendron anfractuosum*) and silk cotton tree (*Bombax malabaricum*). These plants are medium-aged trees and form canopy during mid-seral stages.

Other fibres are the coir type fibres that come from the fruit or stems of palms and the fibre composite represented by bamboos (*Bambusa spp*) and rattans (*Calamus spp*). These plants are mid- to late-seral plants, although there are exceptions (especially within the bamboos and palms). The canes do especially well in mature forest, often attaining lengths of 80-180 m. The potential of these two widely-used groups of plants is illustrated in the present role of bamboo in the global economy. Bamboo mats woven from culm strips and bamboo veneers form the basis of a large industry in China. Over a million tons of bamboo culms are used every year by the paper industry of India accounting for over half the paper pulp requirements. Bamboo culms also contain a higher percentage of better fibre for paper pulp than most hardwoods. It is also suitable for making high quality particle and fibreboard (Hsiung, 1988). Bamboos are also very valuable food plants. In more temperate regions like China and Japan the species *Phyllostachys pubescens, P. bambusoides, P. vivax, Dendro-calamus latiflorus, D. oldhami* and *Bambusa beecheyana* are commonly used for shoot production. Under intensive management bamboo farmers have produced more than 15-20 t/ha/y of fresh shoot. In tropical countries species like *Dendrocalamus asperatum, Schizostachyum brachycladum, Gigantochloa levis* and *Bambusa vulgaris* are used for food. Edible bamboo shoots contain 2-4% sugar, 0.2-0.3% fat, 2.5-3.0% protein, 16-18% amino acids and other elements.

EXUDATES

Exudates and extractive products of plants are either cell exudates that occur under natural conditions or extractions from plant tissue through artificial means. The products can be classified into seven broad groups.

Latex products

Latex products from tree species play an important part in the modern economy. The products from latex fall into two broad categories, rubber latex, which contains a high percentage of an elastic polymer, and balata latex in which the principal hydrocarbon is an inelastic polymer. Both classes of products are a result of coagulation, where a solid coagulum is precipitated from the liquid serum. Examples these two types as consumer product are rubber as automobile tyres and balata as chewing gum. For example, natural rubber from the rubber tree (*Hevea brasilensis*) accounts for over 30% of the world rubber market (Anon, 1979). Plant latex hydrocarbons such as rubber are found in many species of trees, the families Euphorbiacae, Ascelepiaeceae, Moracae and Sapotaceae possessing the largest number of potential species (Nielsen *et al*, 1977). The authors also suggest that many of these plants can be possible sources of fuel substitutes. A study on the potential for higher plants to provide sources of petroleum substitutes (Coffey and Halloran, 1979) suggests that in addition to providing sources of chemicals presently derived from petroleum, latex-bearing plants like some hydrocarbon oil producing Euphorbiacae can also provide liquid fuel to meet industrial needs.

In addition to industrial products, species such as *Brosimum utile* yield a potable, milk-like latex which can be drunk fresh like cow's milk (NAS, 1975). The potential of potable latex has also been recorded in *Couma rigida* and *C. macrocarpa* of tropical America where it is used as 'cream' in coffee (Schery, 1972).

Gums

Pectins, gums, resins, oleoresins and similar exudates are cementing substances between cells, stem and root exudates or decomposition products of cellulose. Pectins are used widely in the food and pharmaceutical industry. Most commercial pectin is extracted from citrus and apple fruit wastes, but with increasing demand other tree crops can be considered. Species that have good pectin yields are guava (*Psidium spp*), pink shower tree (*Cassia nodosa*) and tamarind (*Tamarindus indica*).

Gums are usually plant exudates, except for seed gums like that extracted from the Guar plant (*Cyamopsis tetrogonolobus*). The most prolific gum yielding trees are those of the family Leguminosae. Genera such as *Acacia* and *Astralagus* have been supplying gum as a commercial product for many centuries. Today gums are used in the preparation of food and medicines, as well as in industry uses such as sizing of paper and to stabilise drilling mud.

Resins

Resins are found in special ducts or canals in a wide variety of plants. Typically, they are exuded following damage to the stem or root. Unlike gums that are soluble in water, resins are insoluble in water. This characteristic was valued in waterproofing fabrics and boats. Many, such as balsam of Peru (*Myroxylon pereirae*), Copaiba balsam (*Copaifera spp*) or dammar resins (*Diptero-carpacae*), come from large forest trees and are rare or very valuable. They are used as medicine, incense or in specialised industry. Resins are also produced in an industrial scale in even-aged monoculture forestry where resins of *Pinus spp* are used in the production of turpentine.

Vegetable tannins and dyes

Tannins are a group of astringent substances extracted from the bark, leaf, root, fruit and wood from many species of trees. The major use of tannin is to combine it with the proteins of animal hides to form leather. It is also mixed with iron salts to produce ink. Tanning of leather using vegetable tannins has a long history, with artifacts from Egypt dating 3300 BP.

Although over 100 genera of plants have been identified as sources of tannin (Uphof, 1968), the most productive genera are *Acacia* and *Quercus*. Other trees that provide good yields of tannin are chestnut (*Castanea dentata*), hemlock (*Tsuga canadensis*) and mangrove (*Rhizophora mangle*).

Dyes are compounds often found associated with tannins. Dye substances have been extracted from leaves, bark, wood, roots and exudates. Although vegetable dyes have lost some of their commercial value due to the development of synthetic aniline dyes there still exist substantial local markets for some products; for instance annatto (*Bixa orellana*) is used as a colouring agent in the production of dairy products and logwood (*Haematoxylon campechianum*) that is used as a histological stain and as a special purpose dye in America. Plant dyes come in a variety of colours.

Essential oils for perfumes, flavours and spices.

Essential oils are frequently found as floral essences although bark, leaves, fruit, wood and roots of certain plants are also used. The oils are secreted into special glands or into spaces between the cell wall and cuticle of epidermal hairs. This allows the fragrance to be released at the slightest touch. These oils are highly volatile and easily oxidised. They are collected from the parts of plants where they occur by solvent extraction, cold-fat extraction where the essential oil is absorbed into lard or tallow and by steam distillation.

Tree crops that yield essential oils for perfumery are trees such as the sandalwood (*Santalum spp*) of India or (*Eucarya spicata*) of Australia, both yield sandalwood oil. The flowers of the forest tree *Michelia champaka* of Asia yield the essential oil champak.

Spices also owe their properties to essential oils, but are used more for food and industrial needs. Many spices originate from forest tree species the most famous being cloves (*Syzygium arom-aticum*), cinnamon (*Cinnamomum zeylanicum*) and nutmeg (*Myristica fragrans*).

Vegetable oils, fats and waxes

Oils and fats are called fixed oils as opposed to essential oils and are usually contained within the cells of plant tissue. These oils are extracted by breaking and crushing the cells, under heat or pressure, although sometimes solvent extraction is also used. Most fixed oils are derived from seeds, although some waxes may be expressed from plants or leaves.

Oil-yielding trees in the tropics are often palms like coconut (*Cocos nucifera*) or oil palm (*Elaeis guineensis*), although tree species like caryocar (*Caryocar spp*) have also been identified as a promising species for the tropics (Mendelsohn, 1993).

Oil-bearing trees from the Mediterranean zones include species such as olive (*Olea europaea*) and tung (*Aleurites fordii*); both are small, long-lived trees that are grown as orchard crops.

Waxes occur in almost all plants to a greater or lesser degree, as a protective coating on the epidermis. Thus waxes are generally obtained from the leaves or bark or whole plant. The most valuable wax of commerce, carnauba wax, is obtained from the leaves of the palm *Copernicia cerifera.* Other forest plants, like *Calethea lutea,* and desert plants like *Euphorbia antisyphylitica* also contribute to the international trade in plant waxes.

Carbohydrate extractives: sugars and starches.

Sugars have been extracted from tree species in many countries. The most famous temperate example is sugar maple (*Acer saccharum*) of North America. Another lesser-known syrup-yielding tree from the temperate zone is the cider gum (*Eucalyptus gunnii*) from Tasmania. In the tropics sugar has been extracted from the inflorescence of many types of palm, coconut (*Cocos nucifera*), fishtail palm (*Caryota urens*), palmayrah (*Borassus flaballifer*) and the Indian date (*Phoenix sylvestris*).

Starches are commonly extracted from forest floor dwelling plants such as *Marantha arundinacea* and *Canna edulis.* Palms and cycads also contribute greatly to the production of tree-derived starches, for example the sago palm (*Metroxylon sagu*) of east Asia.

BIODYNAMIC PLANTS : MEDICINALS, INSECTICIDES, GROWTH REGULANTS, AND OTHERS

Some of the most valuable of forest products of traditional people have been medicinal plants. Many of these plants have demonstrable effectiveness based on phytochemical constituents. Many species of traditional medicinal plants are used in the modern pharmaceutical industry; quinine (*Cinchona ledgeriana*) is one such example. All traditional societies possessed their pharmacopoeia of medicinal plants. The native people of eastern Canada used over 400 species of plants for medicine (Arnason *et al*, 1981). The Aboriginal people of Australia have been recorded to have used over 115 species of medicinal plants (Cribb and Cribb, 1981) and 625 species have been recorded as being used by the Ayurvedic medical system of Sri Lanka (Jayaweera, 1979).

Insecticides

The increasing resistance to accepting food contaminated by artificial insecticides has resulted in a growing market for botanically derived insecticides such as rotenone, a derivative of *Lonchocarpus nicou* of South America and *Derris elliptica* of Asia. Other forest plants such as *Quassia amara* of Africa or the neem tree (*Azadirachta indica*) of the Indian sub-continent suggest that effective new insecticides can be derived as a forest product. In the case of the neem the leaves and seed oil have been used for pest control in traditional agriculture for many centuries and are beginning to be used in western agriculture today as a standardised product (Anon, 1992). This is creating another large market for a non-timber product, neem seeds.

RITUAL AND RELIGIOUS

In addition to medicinal properties, ritual and religious practices centre around a wide variety of forest plants. For example *Psychotria spp*, *Banisteriopsis spp* and *Virola spp* of the Amazon are taken by the shamans in the ritual of obtaining supernatural guidance (Schultes, 1969).

ORNAMENTALS

Many forest plants are found as domesticated plants in ornamental horticulture. The ornamental shrubbery plants, such as the needle-leafed *Taxus, Juniperus, Picea* and *Pinus* or the broad-leafed *Rhododendron, Camellia* and *Ilex* were originally temperate forest plants. Similarly, tropical trees such as *Plumeria,* or epiphytes like the orchids and bromeliads, have large markets as plants and cut-flowers.

PLANTS USED FOR FOOD, OR BEVERAGE

Cereals

Cereals are usually plants that are annuals and come from the grass family, the *Gramineae,* although other families such as *Polygonaceae* and Amaranthacae are often included. The use of tree species to provide cereal substitutes has been suggested by Sholto Douglas and de Hart (1985) who argue that trees like Algaroba (*Prosopis spp*) can yield large crops of cereal-substitutes. Algaboras are found all over the Americas and flour or meal prepared from their pods formed the basis of a majority of aboriginal diets.

Food seeds and forages

Tropical

Ground nuts (*Arachis hypogaea*) are produced by a small, annual bush with trailing branches that attains a height of 0.6-0.9 m, suited to light soils in early-seral or pioneer stages of succession. After pollination the flower stalk elongates and forces itself into the ground where the fruit is formed.

Country almond (*Terminalia catappa*) is produced by a medium-sized, fast growing, spreading tree with large leathery leaves. It grows in both light and heavy soil as an early-seral tree, forming canopy for the more shade-tolerant species. The fruit contains a single kernel which tastes somewhat like an almond. The tree is deciduous twice a year and produces two crops a year. Fruit is produced in the third year after planting. The tree is fairly short-lived and declines after about 25 years.

Brazil nuts (*Bertholletia excelsa*) are produced by a slow-growing, tall climax or late-seral tree that attains about 33 m. It grows best on deep soils and requires light shade during the seedling stage. The fruit is large and woody about 10-15 cm in diameter. It contains 12 or more large, angular, closely-packed seeds that are the source of the 'nuts'. Usually this species takes about 15 years after planting to produce fruit and yields one crop per year.

Temperate

Hazel nuts (*Corylus avellana*) are produced by a small, quick-growing early-seral bushy tree that attains about 7.6 m in height. For cropping it is usually pruned and maintained at a height of about 1.8 m. The tree grows well in cooler climates and prefers deep soils. The fruit is borne on the lateral branches. This tree is usually propagated from root suckers.

Oak (*Quercus spp*) is generally a slow-growing tree that has over 300 known species. It is generally a late-seral species growing best if it has good soil and light shade during the seedling stage. The fruit or acorn has good food value and has been employed as human and animal food by many societies.

Vegetables

Trees have also been a source of edible leaves used in a cooked or uncooked state in many traditional societies. This feature of trees has been generally overlooked during the application of modern forestry. It has also been neglected in agriculture as this science concentrated on the use of annuals for the supply of green vegetable dietary input. Those few species that have been trialled show great promise. An example is the small tree or shrub, chaya, or tree spinach (*Cnidoscolus chayamansa*). This early-seral stage species has been domesticated in Central America for many years and is now a hedge or backyard plant in many households (NAS, 1975). It produces edible shoots and leaves that are cooked and used like spinach. The potential of trees to supply green vegetable dietary needs provides more meaning to Smith's (1977, Intro. xii) observation that 'the crop yielding tree offers the best medium for extending agriculture to the hills, to steep places, to rocky places and to the lands where rainfall is deficient. New trees yielding annual crops need to be created on these four types of land'. The potential of tree crops to provide annual crops of green vegetables is illustrated in a study that examined the vegetable crops of Indonesia (Ochse, 1977). The listing includes a large number of tree species from all height classes and seral stages. Table 8 lists some useful species. The development of this aspect of trees, as tree vegetables, can provide immediate relief for human communities capable of growing trees. The output of edible product from this system can be as fast as 2-3 months, as was recorded in the case of chaya (NAS, 1975).

Fruits

Tropical

Papaya (*Carica papaya*), a fast-growing, small herbaceous tree, attains a height of about 4.6-6.1 m with a crown of large palmate leaves. It grows best in deep, organic, or loamy soils. It is a pioneer species that is suited for early-seral stages and open sun. Fruit-bearing begins about 10-12 months after planting out and fruit is produced throughout the year. This tree is short-lived and begins to deteriorate at the age of 3-5 years.

Table 8: Some tree vegetables used in Asia

Species	**Stage**	**Height**	**Part Used**
Alsophila glauca	E/L	5-15 m	shoots
Altinga excelsa		40-60 m	y leaves
Anacardium occidentale	E/M	7-20 m	shoots/nuts
Anona muricata	E	3-8 m	shoots/fruit
Antidesma bunius#		15-30m	y leaves/fruit
Bouea macrophylla		10-20 m	y leaves/fruit
Cycas rumphii	E	2-6 m	shoots
Elateriosperma tapos		10-20 m	nuts
Gnetum gnemon	E/M	5-22 m	y leaves/fruit/seed
Hemitelia latebrosa	E/M	3-7 m	shoots
Lannea grandis		15-20 m	y leaves/bark
Mangifera caesia	M/L	20-40 m	y leaves/fruit
*Moringa pterygosperma**	E	4-12 m	leaves/fruit
*Nothopanax pinnatum**	E	2-5 m	leaves
Oroxylon indicum		5-15 m	leaves/bark/flower
Pangium edule	M/L	20-40 m	seed
Parkia javanica	E/M	20-50 m	seeds
Planchonia valida		15-50 m	y leaves/shoots
*Schefflera aromatica**	E	5-12 m	leaves
Spondias	E/M	10-25 m	y leaves/fruit
*Trevesia sundaica**	E	3-10 m	leaves/flowers

* Trees that can be grown from cuttings # Trees suited for wet or streamside areas.
E= early seral; M= mid- seral; L= late-seral

Rambutan (*Nephelium lappaceum*) is a relatively fast-growing small tree and attains a height of about 12-15 m. It grows in a variety of soils preferring deep soils. It is a late-pioneer species and does well in full sun. In nature this species is usually found at the edge of forest or around forest clearings. Fruit production begins about 5-6 years after planting out. The tree attains about 50 years in age before deteriorating.

Mangosteen (*Garcinia mangostana*) is a small, slow-growing, conical-shaped tree that attains a height of about 9-12 m. It grows best in deep, rich, organic soils under light shade. This is a suppressed canopy species and a late-seral stage species. Fruit bearing begins 9-10 years after planting out. The tree is long-lived, specimens of over 80 years of age being relatively common.

Durian (*Durio zibethinus*) is a slow-growing, very large, upright tree that attains a height of over 30 m. It grows best in deep alluvial or loamy soils. It is a climax community emergent canopy species and in its early life grows best under light shade. Fruit bearing begins 7-10 years after planting. This tree is long-lived and specimens of over 150 years have been recorded.

Temperate

Strawberry (*Fragaria virginiana*) is a fast-growing ground-cover that inhabits woodland and colonises open disturbed areas. It is a perennial prostrate herb with a leafy crown from which prostrate stems with small leaf clusters or runners are produced as the new plants. It is suited to the pioneer stage and likes full sun. Fruit bearing begins from the first year and will continue every year as long as the new runners are allowed to grow.

Blueberry (*Vaccinium corymbosum*) is a quick-growing bushy shrub that attains a height of about 3-4.6 m. It grows best in moist, acid, sandy or peaty soils and does well in full sun. It occurs as a early woody bush in forest succession. Fruit-bearing begins at about three years after planting. The bush produces fruit for about 20 years.

Mulberry (*Morus nigra*) is a quick-growing deciduous tree that attains a height of about 9 m with a short rugged trunk. It branches crookedly to form a broad, dome-shaped crown. It grows well on most soils and does well in full sun. Fruit bearing begins at about 3-4 years after planting. The tree is fairly long-lived bearing good crops up to 35 years.

Persimmon (*Diospyrus virginiana*) is a slow growing tree that attains a height of about 9-12 m. It grows in a range of soil types and conditions and does well under light shade. Fruit bearing begins at about 4-5 years after planting. In the native state it has a sub-dominant canopy and produces large quantities of fruit.

Beverage Plants

A beverage or drink can be expressed from most juicy fruit. However, in this discussion beverages will be confined to diffusions and decoctions from processed plant parts. Beverages can be divided into two groups by the presence or absence of alcohol.

Non-alcoholic beverages are prepared from plants such as tea (*Camellia (thea) sinensis*) or coffee (*Coffea spp*); both are small trees that occur in early-seral stages in their native environment. Other beverage yielding plants such as cacao (*Theobroma cacao*) which supplies cocoa and cola (*Cola nitida*) which supplies the cola drinks are understorey plants of more mature forests and requires much denser shade.

Alcoholic beverages are produced by the fermentation of fruits such as grapes (*Vitis spp*) or apples (*Malus spp*). The fruit of many forest trees such as *Artocarpus* or the sweet sap of palms such as *Caryota* or *Nipa* has also been recorded to yield a beer-like beverage that is sometimes distilled into a spirit.

OTHER ORGANISMS

Fungi and microorganisms

All forests contain fungi; the forest environment provides essential microhabitat for many species. As mushrooms they are also one of the most valued of forest products. The truffles (*Tuberales spp*) of France and the morels (*Morchella spp*) of North America are examples. These mushrooms command very high prices on local and international markets. Similar delicacy mushrooms are found in most forests. The development of a special market for wild mushrooms in Geneva has listed 53 species (Table 9) from Switzerland (Weber, 1964). This suggests the potential for the development of mushrooms as forest product in all other countries.

Fungi, bacteria, yeasts and other microorganisms present a very large source of material for future industry. Antibiotics, foods and many precursors to the modern chemical industry are being supplied from microbial sources (Table 10). The growing and maintenance of a good forest soil will conserve much of this potential in forest soils.

BEES AND OTHER INVERTEBRATES

The collection of bees, honey and wax is a feature of many traditional societies. The practice of maintaining and moving hives to flowering crops or forests has developed into agricultural industries in many countries. A forest with its component of flowering trees provides the ideal environment for

Table 9: Checklist of mushrooms which may be sold in the markets of the Canton of Geneva (after Weber, 1964)

Amanita caesarea
Boletus aereus
B. appendiculatus
B. Aurantiacus
B. edulis
Cantharellus cibarius
C. lutescens
Clitocybe cyathiformis
C. geotropa
C. gigantea
Clitopilus prunulus
C. orcella
Coprinus comatus
Cortinarius praestans
Craterellus clavatus
C. cornucopioides
Fistulina hepatica
Gomphidius glutinosus
Hydnum imbricatum
H. repandum
H. marzuolus
H. obrusseus
H. puniceus
H. virgineus
Tuberales spp.
Laccaria laccata
Lactarius deliciosus
L. sanguliflous
Lepiota excoriata
L. procera
L. rhacodes
Marasmius oreades
Morchella spp
Mitrophora spp
Pholiota aegreita
Polyporus confluens
P. frondosus
P. umbellatus
Psalliota arvensis
P. augusta
P. campestris
P. silvatica
Tricholoma aggregatum
T. colombetta
T. georgii
T. irinum
T. nudum
T. paneolum
T. personatum

Table 10: Partial list of chemical substances derived from moulds (after Gilbert and Robinson, 1957)

Acids	**Alcohols**	**Enzymes**	**Polysaccharides**	**Sterols**
Acetic	Ethyl	Amidase	Capreolinose	Cholesterol
Aconitic	Glycerol	Amylase	Galactocarolose	Ergosterol
Garlic	Mannitol	Catalyse	Glycogen	Fungisterol
Citric		Dextrinase	Gums	Phytosterol
Formic		Dipeptase	Mannocarolose	
Fulvic		Enulsin	Polygalactose	
Fumaric		Erepsin	Polymannase	
Fusarinic		Insulase	Rugulose	
Gallic		Invertase	Selerotiose	
Glauconic		Lactase	Starch	
d-Glauconic		Lecithinase	Trehalose	
Glycolic		Lipase	Varianose	
Itatartaric		Maltase		
Iatonic		Nuclease		
Kojic		Protease		
Lactic		Raffinase		
Luteic		Rennet		
Malic		Sulfatase		
Malonic		Tannase		
Oxalic		Urease		
Penicillic		Zymase		
Pyruvic				
Stipitatic				
Succinic				
Terrestric				

apiculture.

There are three components of a forest that are useful in honey production. One is the availability of physical habitat for the establishment of hives. The other two, nectar and pollen come from the flowering parts; the nectar being used for the making of honey and the pollen being used as food by bees. Most broadleaved species have flowers suitable for nectar collection, while coniferous species are often used as a source of pollen (Brown and Hall, 1968).

Other invertebrates from the forest are also being cultured for international markets.An example is the forest farming of butterflies in Papua New Guinea (Parsons, 1992). The brilliant butterflies of the Papilionid and Nymphalid families are farmed by growing their larval food plants together with, or close to, the agricultural fields.

VERTEBRATES

Game has been a traditional product of forests.The creation or preservation of forests for game species has been recorded in medieval Europe as well as in the traditional societies of the 'Kayapo' of Amazonia (Knudtson and Suzuki, 1992).The maintenance of large trees to provide nesting habitat for grackles, which are fitted with artificial nests from which fledglings are harvested for the pet-bird markets, is a common practice, recorded in India, Malaysia and Sri Lanka.

WHOLE-FOREST PRODUCT

Other authors have addressed the whole-forest product that refers to the output of the forest ecosystem. For example, Baur (1974) considers the following products of a forest:

Beautification of the landscape
Drugs, oils, honey
Educational material
Habitat for native animals
Outdoor recreation
Preservation of sites of particular scientific importance
Protection for water catchments
Rough grazing for domestic stock

To appreciate the full potential of forest products, both categories, viz. individual species product and whole-forest product, need to be addressed. Further, some trees may not provide any product of direct anthropocentric utility but may provide stability to the plant community in which they occur. Leguminous trees that fix nitrogen in the soil through the agency of their root nodule associated bacteria are a good example (BOSTID, 1979), as are trees that supply beneficial phytochemicals like those of alder (*Alnus spp*) that control the soil borne root disease *Poria weirii* in other plants (Trappe, 1971).

Whole-forest products can be treated as products or services. Perhaps the most widely accepted example of a whole forest product is potable water. The ideal protection for water catchments designated to the production of potable water is forest cover. Experiments with logging (Kriek and O'Shaughnessy, 1974) and fire (Kuczera, 1985) suggest that, in the mountain ash (*Eucalyptus regnans*) forest in Victoria disturbance can have a negative effect on both water quality and yield. The market value of water from these catchments is not only for the supply of good quality water to the domestic market, but also to export markets.

Grazing

Woodland has been traditionally used for rough grazing for domestic stock by many societies. Where forests are used for such purposes grazing can be considered a forest service, with an appropriate value.

Habitat

Habitat for native animals, conservation of biodiversity and genetic diversity is another tangible service of forests.The concern over the erosion of biodiversity is a global issue. This concern may translate into the economic recognition of the value of conservation areas. If value is placed on the conservation of biodiversity then investment in environmental rehabilitation is encouraged. This also applies to the preservation of sites of particular scientific importance.

Education and research

Forests of all kinds continue to provide insights into bio-chemical, biological and ecological processes. In fact much of future research will be thwarted if there is no control on the erosion of biodiversity. A similar effect will follow if local forests disappear. Communities that do not have access to forests are deprived of an invaluable teaching resource.

Recreation

Forests provide a large economic input into local and national economies by providing a focus for outdoor recreation and tourist visits. The role of national parks, wildlife and historical reserves in the rapidly expanding industry of global tourism has been recognised by many countries. The wildlife parks of Tanzania, for instance are the major tourist destinations in that country. Surveys in Australia reveal that 42% of the major activities in which visitors participated were outdoor 'nature' oriented (Anon, 1990). In fact bushwalking, an activity often performed in forested areas accounted for 15% of all outdoor activity in Australia. The value of forest to visitors is also expressed by the fact that while 2.6% of the land area ofAustralia is dedicated to national parks and conservation, these parks attracted 41.2 million visitors in 1990 (Westcott, 1991). In the United States the visitor rate to the national park system increased fourfold from 1960-1983 (Anon, 1985) and reached 267.4 million by 1991 (Anon, 1994). The provision of a high quality product for the tourist industry, such as forested landscapes, as opposed to deforested landscapes, can be designed by siting forests effectively. Ecotourism is also being recognised as a potential revenue earner in many countries and is providing value for forest reserves. In a study on the Costa Rican rainforests, Tobias and Mendelsohn (1991) found that the annual tourism value from rainforest reserves, based on foreign and domestic visitor use, was 1-2 magnitudes greater than the purchase price currently paid for acquisition of new land to be developed into reserves.

Soil Conservation

Forests help soil conservation by controlling wind and water flow. However forests also contribute to the body of the soil by building the organic substrate that allows the functioning of a good soil ecosystem. This organic substrate, or soil organic matter, is obtained by microbial action on litterfall and root exudates. Soil organic matter helps retain nutrients and moisture and helps to stabilise soil erosion. Soil organic matter plays two major roles in the operation of the soil ecosystem. It has a proportion of a chemically reactive molecules that supply nutrient to the soil biota as well as possessing a proportion of chemically stable molecules that resists attack by soil microbes and plays a part in providing water-stable aggregates that resist erosion (Attiwill and Leeper, 1987).

The action of tree roots in creating soil goes beyond the output of root exudates. The physical action of the roots, by penetrating into the anoxic zone of the subsoil, creates a new set of conditions in this zone. The change in physical conditions allows colonising microorganisms to move further down the soil profile, creating a greater volume of fertile, organic soil. Organic soil, in the current world of diminishing primary resources, is a product of tremendous importance.

Carbon Sequestering

Carbon sequestering, or the locking up of carbon in a solid state, is becoming an increasingly important mechanism to consider given the present increases of carbon dioxide in the atmosphere. Consequences of this increase have been predicted to be a change in global climate and temperature (Pearman, 1989). The only responses available are to reduce the new additions by lesser consumption of fossil fuels and to take carbon dioxide out of the atmosphere. The most effective way to do the latter is through photosynthesis.

Trees have been widely appreciated as a useful tool in sequestering carbon from the carbon dioxide of the atmosphere. However the value of a forest ecosystem in enhancing this effect by the differential sequestering value of different tree species has not been fully appreciated. In a growing forest the processes of sequestering carbon may have two distinct pathways. One is by photosynthetic activity which ties up, or sequesters, atmospheric carbon in living biomass. In this process, the effective rate of sequestering is confined to the life of the individual organism. The other is by respiration activity, which uses the energy fixed by photosynthetic activity, such as in the synthesis of humates. Here, the effective rate of sequestering is dependent on the nature of the respiring ecosystem. Richards (1969) provides us with some idea of the distribution of carbon within the soils and vegetation of various global ecosystems (Figure 17).

The photosynthetic activity of plants takes carbon dioxide out of the atmosphere and fixes it in a solid state as organic matter. This act of sequestering carbon is what provides forest biomass. Its quality, in terms of sequestering value, has to be measured in time. While all plants sequester carbon, trees and woody plants are most efficient as they produce resistant compounds such as lignin. Consider the fate of two photosynthetically derived objects of similar biomass - a large pile of seaweed and a log lying on a beach. Both are plant products, but one (the tree) is strengthened with lignin. The same biological, chemical and physical forces will impact both. The seaweed will have disappeared within a few weeks, the log may remain more or less the same for years.

An important attribute of the wood in terms of its sequestering value is its durability. Natural durability is a reflection of the wood's ability to withstand the attacks of decay organisms (Schery, 1972). Archaeological finds often demonstrate wooden construction items dating back about 1000 years. In the United States a durability standard has been devised by using white oak as the standard. In this method of evaluation white oak is given a rating of (100). Wood with higher scores such as red cedar (150-200) or black locust (150-250) is more durable. Woods with a lower score such as hemlock (35-55) or birch (35-50) are less durable.

The rate at which a forest can sequester carbon is a product of its primary productivity (Figure 18). The rate of production is reported as net annual volume-growth in stemwood (m^3/ha/y). Different tree species have timber of different densities, such that a cubic metre of softwood weighs about 0.43 t.

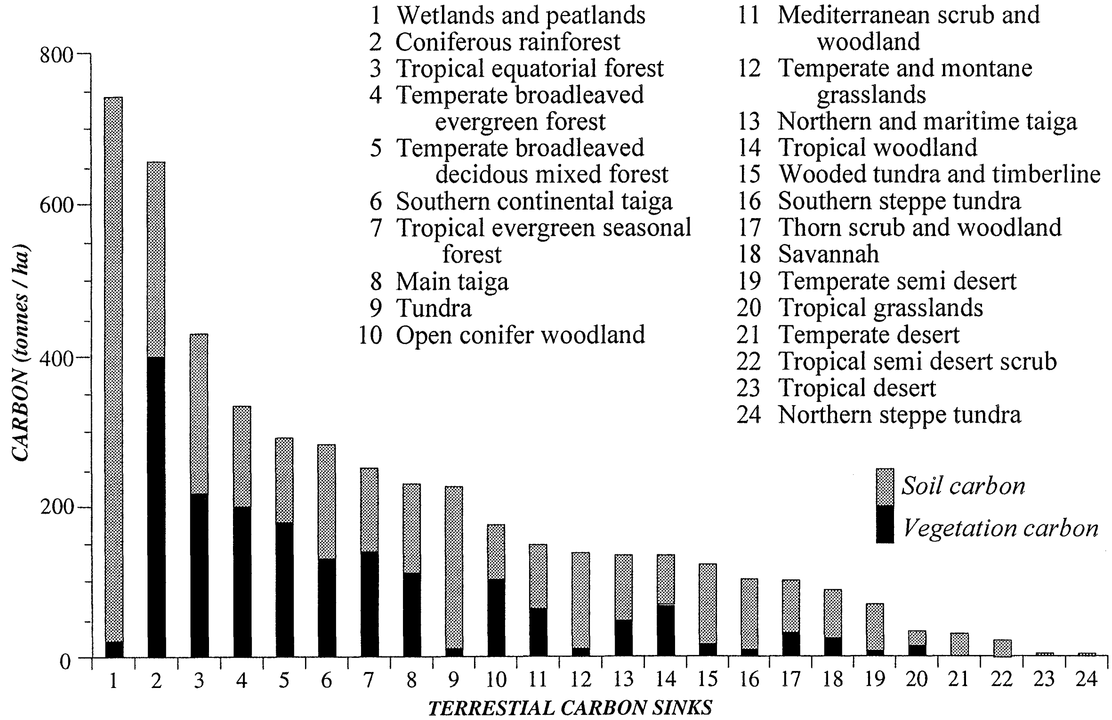


Figure 17: Amount of carbon sequestered by various terrestial ecosystems

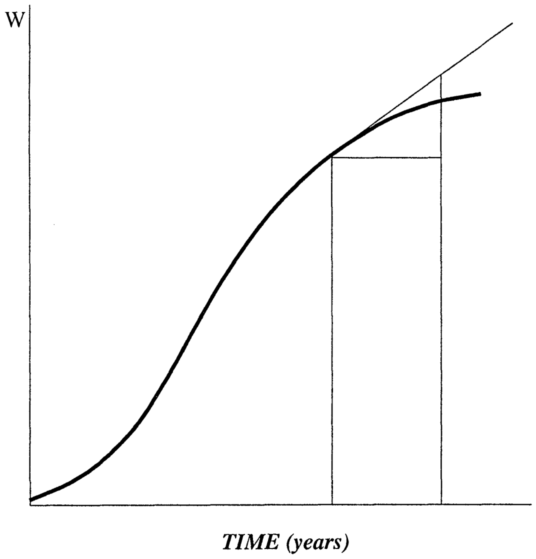


Figure 18: Accumulation of carbon in a typical terrestrial ecosystem

and hardwood about 0.63 t. (Stewart *et al,* 1979). An asymmetric sigmoidal function has been described to approximate the pattern of carbon sequestration into organic matter as a forest grows (Richards, 1969).

$$A \exp(-b \exp(-kt)) \tag{1}$$

Here W is the amount of carbon sequestered at any time t (years), A is the asymptotic value of W; b and k are constants (Richards, *op cit*).

A design that incorporates carbon sequestering as a goal will also tend towards long rotation tree crops. This is due to the fact that the active sequestering or growing phase of any timber is longer and the total biomass is greater (Figure 19). Such designs will allow many species of trees determined to be 'marginal' to be brought into culture.

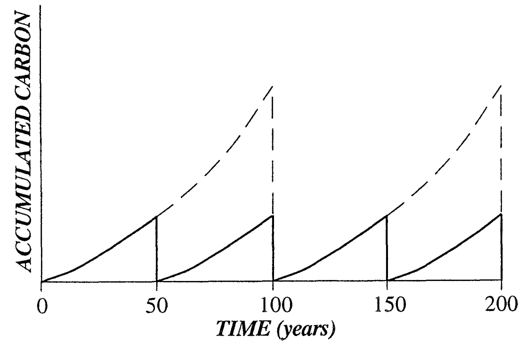


Figure 19: Simplified model of carbon accumulation in forests with 50 and 100 year rotations

Present approaches to controlling carbon dioxide largely have been directed towards controlling release (CDIAC, 1990). The development of terrestrial sinks has been directed towards the growing of trees (Barson and Gifford, 1990). While this is the most logical approach at present, the dynamics of the tree growing process needs to be examined more closely in order to obtain the maximum benefit.

The output from growing trees in terms of sequestering carbon can be stated as Wt.

W or the carbon sequestered +T+L+R where;
T = Timber, trunk and branch material over y cm in diameter
L = Leaves, bark and stems under y cm in diameter
R = Roots and all other underground parts.

In addition to producing the photosynthetic products listed above a growing tree also contributes to the creation of soil organic matter. As a forest product, soil also has great value as a carbon sink, the process of biochemical distillation of photosynthetic products can keep atmospheric carbon dioxide tied to or sequestered by the biological system for periods exceeding 4000 years (Beckermann and Hubble, 1974). About 16% of the long-lived fraction identified as 'old carbon' can have lifetimes from 5700 - 15,000 years (O'Brien and Stout, 1978). The role of soil in sequestering, or tying up, atmospheric carbon dioxide needs to be recognised. An evaluation of the sequestering potential of various forest ecosystems suggests that forest soils contain a large proportion of the carbon pool. These long-lived compounds are a product of the biochemical distillation of photosynthetic products and tie up about 20-30% of the organic matter reaching the soil from the above-ground environment (Kohlmaier *et al,* 1983). This long-lived matter (LSc) component can be represented as a ratio of plant production, where the sum total of the plant production is its total biomass (Wt). The ratio LSc/Wt will vary according to the efficiency of a particular soil to sequester carbon into the long-lived pool and the end-use of the forest. In the case of tree crops the contribution to the soil will be only from the roots, leaves and branches such that $Wt = L+R$, as the timber is expected to be removed from the site or used for an anthropocentric purpose.

The variable (T), representing timber, will have a sequestering value equal to the time of growth and biomass attained. At harvest, the value of the clear-wood as a carbon sink will depend on its end-use. Therefore (T) must be described with a multiplying factor dependent on the durability and end-use of the wood. For instance:

End-use	Firewood	Pulpwood	Chipwood	Constn. Timber
Multiplier (z)	.05	1.0	1.75	2.5

The value Tz can then be added to LSc to give some approximation of the carbon sequestered into the long-term pools so that:

$$Tz + LSc = p \qquad (2)$$

Similar calculations can be made of the short- and medium-term pools to obtain an idea of the value of various forestry approaches to address global greenhouse.

Thus when considering the decay function, the values of the long-term pools should be reflected to provide a set of relative values for different types of forestry. The exponential decay function proposed by Barson and Gifford (1990) states that:

$$Wr + Wo \exp(-dt) \qquad (3)$$

where Wr is the amount of carbon remaining after decaying for time t. Wo is the carbon sequestered into the forest at the time of felling and d is a decay constant. The inclusion of the long-term pools as primary values can make this function more sensitive to the type of forest grown. Thus a decay function that incorporates the long term pools will state:

$$Wr = Wo \exp(-d/p\ t) \qquad (4)$$

For the purpose of sequestering carbon the most productive forests are those that have a long-standing life as well as a high potential to develop deep organic soils. Commercial monocultures have a disadvantage in this respect as they are harvested for timber after a set period of time and very rarely develop deep organic soils. A better model is provided by a polyculture with long rotation times, such as that seen in some forms of traditional forestry, where a high diversity of tree species with a good development of organic soil has been recorded. Further, as the trees used in this approach to forestry are crop species that produce large crops as the trees mature, there is a disincentive to fell the trees unless they are diseased or very old. The development of this type of forestry in some temperate and tropical regions can provide a very efficient method of sequestering carbon that also provides social, ecological and economic benefits.

As the various ecological and social needs of human society begin to reflect wider needs from forests, an ever-wider set of considerations will determine 'best design'. As the variables increase so will be the demand for accurate synthesis. Fig forests that have the potential to be used in the management of atmospheric carbon dioxide are one model worthy of examination.

CHAPTER SEVEN

HISTORY AND CULTURAL RESPONSE

HISTORICAL

The growing of trees and forests is more important today than at any other time in human history as the loss of forests has precipitated a crisis in biodiversity and environmental stability. Therefore it is useful to consider the human response to this crisis. The domestication of plants is synonymous with the movement from a hunter-gatherer to permanent settlement. While cereals like wheat have great antiquity, so do the woody perennials. Grape (*Vitis vinifera*) for instance, has been recorded under cultivation over 6000 years BP. In the forest environment, the movement from forest-gatherers to the incorporation of valuable forest trees within the village or other social context has been a common pattern of human behaviour in many societies. For example, the planting of fruit trees around households where the trees benefit from nutritive additives to the soil from domestic garbage, ash and manure has been a common aspect of land use in the tropics (Ruthenberg, 1980). As the practice developed, tree crops became the basis for larger-scale, commercial, or community tree gardens. The maintenance of these trees became the basis of silviculture and forestry.

Forestry has been defined as 'The science of planting and taking care of forests' (*Webster's New World Dictionary*) or 'The science and art of cultivating, maintaining and developing forests' (Anon, 1978) or 'The science and art of managing forests' (*The Oxford Dictionary of Current English*). Forestry therefore, is all to do with humans. It is the art and science of managing forest ecosystems. As human impact on natural ecosystems increases, the heavier becomes the burden upon the practitioners of this science to ensure that the stability conferred on the biosphere by natural forests continues uninterrupted.

The domestication of trees and other perennials has an ancient history. The early references to the creation of plantation forests date to about 250-150 BC such as the many references to the establishment of trees and forests recorded in the edicts of King Asoka in India, who decreed that trees be planted as forests or along avenues (Sagreiya, 1967). Similar references to the establishment of fruit trees, nut trees and flowering trees in parks and public lands around 200 BC have been recorded in Sri Lanka (Senanayake, 1983). This suggests that the impact of local deforestation was acknowledged even at these early times. The historical record certainly suggests that many civilisations such as those of Babylonia and central China perished with the loss of the native forest and consequent desertification. Many nations developed their individual responses to forestry based upon social or cultural needs. These responses were also tempered by the tree species available in the local environment.

The response that developed in Europe, for example, was to clear-fell derelict forests, burn the slash, cultivate food crops for varying periods on these cleared areas and plant or sow tree species before, along with, or after the sowing of the agricultural crop (King, 1968). This system was widespread among the commoners and was in use in Finland and Germany until the end of the last century. The institution of forestry in Europe had different roots. This arose from the protection and maintenance of forests that belonged to the nobility. For instance the timber-getters and gamekeepers of medieval Europe evolved to become the officials responsible to the king (Magna Carta of King John 1215 AD) and thence to the nobleman who controlled the forest. The principal function of these forests was to provide game rather than provide timber. The early foresters were more akin to gamekeepers and had a different set of priorities in managing forests. The forests that provided wood and timber to the community were 'common' forests and could be accessed by the general public. These forests were utilised for timber extraction without very much management or replanting the trees with good timber characteristics as these were selectively removed. Eventually, this practice of removing all the good trees in the forest and leaving the poor trees had degraded many European forests to a point where selection management had become impractical. In order to remedy this situation and meet with the growing need for timber, Heinrich Cotta of Germany developed a system of clearcutting to remove the poor stand and replanting the area with good stock. The work was begun in the 1780s and met with great success, but Cotta cautioned that his proposal was as a one-time response only and that it should not become standard practice because of the hazards of monoculture. Nonetheless clearcutting and replanting with even-aged stands has today become standard forestry practice (Robinson, 1988). History demonstrates that this cautionary note was not considered. Soon after Cotta, another influential German forester, G.L. Hartig, in the early 1800s, became a strong proponent of even-aged, single species crops. Even though Hartig warned against planting 'off-site' his work led to the establishment of large plantation areas in Norway and Sitka Spruce throughout Saxony and the northern states of Germany (Baker, 1950). The value of a forest was seen as a source of timber only. This perspective is illustrated by the words of Fernow (1902, p.50) a pioneer of the American forest industry. He noted that 'The first and foremost purpose of a forest growth is to supply us with wood material; it is the substance of the trees itself, not their fruit, their beauty, their shade, their shelter, that constitutes the primary object.' This model of single-use forestry was brought not only to North America, but also to Australia, New Zealand, Japan and India by European foresters (Behan, 1975). Given this historical scenario it is hardly surprising that the response of modern forestry is commonly deficient in considerations other than those of producing wood (FAO, 1988, Wood *et al*, 1982).

The advent of the industrial revolution and the rise of economic expediency determined that the primary goal of 'industrial forestry' was to strive for maximum yield of timber over the shortest rotation period. This established even-aged forestry as the most important management strategy for producing large quantities of commercial timber. This view of forestry, based firmly on European traditions and developed in North America, ensured that industrial (wood) goals became the international response to tree loss throughout the world and has led to the present impact of modern forestry on the landscape. The social, environmental and commercial benefits of this effort in terms of providing fuelwood and timber are not to be gainsaid. However, the full potential of the ecological and social benefits of forests has not been harnessed, as these variables did not enjoy effective economic recognition.

The application of economically-driven models on a global scale has seen monoculture and even-aged plantings of fast-growing species being the major response to deforestation worldwide. While these models have contributed greatly to the burgeoning need for wood and fibre, the negative impact of these plantings on both social and ecological levels has also been well documented. It is now becoming apparent that the natural forest cannot be replaced with exotic monocultures nor can these plantations provide solutions to the concerns of biologists or of traditional peoples. In addition, such forests provide no solution to the local and global concerns of overpopulation.

During the period of colonial expansion Eurocentric forest management was applied to many countries throughout the world. Traditional knowledge was rarely incorporated into forestry design. This exclusion may stem from these historical roots of forestry, but examples where other traditional knowledge has been used to design forestry responses often demonstrate a greater measure of success in meeting many social and ecological needs. The development of teak forest plantations using human-created, early-forest, seral stages was developed from the forestry traditions of Myanmar (Burma). Known as the Taungya system, it has been an important design feature used to establish teak forests in many countries. For example, in Thailand, villagers are allowed to cultivate and grow annual crops on a temporary basis in teak plantations and they agree to protect and look after the growing teak during their occupation. When the trees begin to overshadow the crops the land is given to forestry control (Boonkird *et al*, 1984). This system was introduced into South Africa in 1887 (Hailey, 1957) and to India in 1890 (Raghavan, 1960).

However, this system was used solely for the establishment of forest plantations. As King (1989, p.5) states 'It cannot be over-emphasised, however, that for more than a hundred years, in the period 1856, to the mid-1970s, little or no thought appears to have been given in the practice of the system, to the farm, to the farmer and to his agricultural outputs. The system was designed and implemented solely for the forester'.

SOCIAL AND RELIGIOUS

This tradition of forestry tended to foster a professional style of educated, objective, benign forester-aristocrats. They saw their role as a protector of forests from fire, insects and the greed and short sightedness of the public and politics (Koch and Kennedy, 1991), and the automatic assumption of superiority in all matters European. During the colonial period the more traditional forestry methods that differed from the European model were ignored. In many non-European societies throughout the world the protection or growing of forests took on different social or religious meanings. The examples of sacred groves, or Deorais, exist in many traditions. In India, these forests are usually located at the origins of fresh water springs. They are associated with spirits, often a mother-goddess, deity (Paranjpye, 1989). Their belief system, in the swift and immediate retribution meted out by the deity if the forest is disturbed, has served to protect these forests even today. The forest in turn provides the social functions by having a place of religious focus and community activity, as well as economic functions such as providing medicines or famine food or the ecological functions of stabilising water and protecting genetic diversity (Paranjpye, 1989). A study of various forest formations in north-east India suggests that sacred groves may be the last refuge for remnant populations of certain species (Bhadauria and Ramakrishnan, 1991).

A similar concept of sacred grove was followed by the Trobriand Islanders (Malinowski, 1935). This tradition was seen as the only force protecting the kaboma or sacred groves that were the only areas of uncut forest remaining on the islands. To cut the rainforest species of trees that compose such sacred groves was believed to be dangerous because the angered sprits would bring human illness or crop failure. The highly-evolved traditional responses to forest management are seen in the forest agriculture of Papua New Guinea, where the taller structure of the forest was recognised as a feature to be retained, while the smaller growth was cleared for agriculture (Clark, 1976). Further, the social and cultural recognition of the differential planting patterns of village tree gardens in west Java (Achmad *et al*, 1979) suggest that cultural responses to forestry may contain useful design elements for modern application.

The traditions of the Australian Aboriginals demonstrate another significant relationship. Every person received his or her identity within the totemic system, their authority, position, social prestige, and relationships from the area from which they were born or conceived (Strehlow, 1964). This produced a love for the land that was not only an emotional response but even more, in the sense that an individual and his/her soul was indivisibly tied to it in a physical and spiritual unity (Rudder, 1978). This concern is always voiced when there is a perceived threat to the land. Davis (1983, Appendix 2, 9) records traditional custodians commenting 'We are worried. We need our land. We want it to stay spotless. We don't want to see a tree cut down.' Such observations are common in his document. To Aboriginal people the land has a vital life-giving importance. As with many traditional people land is not perceived as a tradeable commodity. It provides the sense of the sacred that has been used to identify 'civilisation' (Schuon, 1976; Coomaraswamy, 1979). They have a special relationship with the land, and that relationship is dynamic requiring an on-going commitment to maintenance and care (Downing, 1988).

A well-designed forest will not only have meaning in ecological and economic terms but also in social terms. In this context social is used in an anthropocentric, non-monetary sense. The Shola of India and the Mukalana of Sri Lanka are forests recognised locally as the source of plant material for their pharmacopoeia and religious functions. The loss of these forests reduces the quality of health, nutrition and spiritual life in the local area. The Kayapo of the Xingu River watershed in Brazil also have similar uses for their forest patches (Knudtson and Suzuki, 1992). These forest patches are planted and tended by the Kayapo to produce some of the 250 species of wild fruit and over 650 species of medicinal plants used by them.

Traditional systems of forestry often demonstrate great sophistication in land management. The Kayapo of Brazil face the same management problem as the Yoruba of western Nigeria (Ojo, 1966) in having to maintain the space so 'laboriously won' from the ever-advancing forest. In addition to their skill in maintaining early-seral communities within the forest, they also demonstrate great skill in growing back native forest in treeless savannas. The regeneration of these forest islands has been reported to follow an established pattern, the success of which is attested to by the reported results. This pattern consists of creating active compost reduced to a size that will facilitate microbial activity. The compost is then mixed with clay and fine, nutrient-high nests of termites. Macro-organisms in the form of termites are added to the pile. Tradition dictates the use of a mixture of insects from mutually exclusive colonies, the rationale being that they are so engaged in battling one another that they leave the plant shoots alone. This mixture is placed in mounds 1-2 m across and about 0.5 m deep. A variety of young plants from the rainforest nearby is planted into this soil. The plot is visited at regular intervals and developed with further plantings until canopy cover is obtained.

In Costa Rica it was found that when a new patch of regeneration was created in a rainforest the initial establishment of seedlings was random. This changed rapidly to a strongly, non-random pattern by the selective mortality of seedlings (Brandani *et al*, 1988). This effect seems to be utilised by the Kayapo system.

While some of these techniques are known to modern forestry science, others, such as the use of arthropods are still unknown. The benign and malign neglect of such traditional information has precipitated a crisis, where much of this information could be lost by the turn of the century. In the development of sound forest management, techniques from many traditions must be evaluated. Recent work, such as Hughes (1990), which demonstrates the impact of ants in the dispersal of seed in sclerophyllous vegetation, or of Berg (1975) which demonstrates specialised ant attracting structures called ealisomes in about 1500 species of Australian plants, suggest that certain organisms may have strong ecological links with the vegetation.

It is also a fact that many traditional societies that rely on non-timber forest products find it difficult to participate in a cash economy. The patterns among the various traditions suggest that the more intense the participation the more difficult to maintain the original forest ecosystem. Forest trees that are unproductive are replaced with productive exotics. For instance, the Kayapo of Brazil maintain the species of the original forest (Knudtson and Suzuki, 1992). The traditional forestry systems of western Java have about 33 tree species (Michon *et al*, 1986) of which six are exotics. The Kandyan forest gardens of Sri Lanka have 20 reported species (Jacob and Alles, 1987) of which 18 are exotics. The structure of all three systems is similar; the species are different. However, the demand for ever higher levels of productivity often threatens the sustainability of traditional responses. The traditional forest garden of Sri Lanka is giving way to a greater proportion of open spaces for annual crops (Everett, in preparation). The introduction of new tree crop species into traditional forest villages can help stabilise this trend. Also, the enrichment of existing village vegetation can be designed so that both crop output and ecological benefits are increased. Many traditional systems of forest management can be developed effectively with modern knowledge.

In some societies the planting of trees and forests has been carried on for the sake of spiritual merit only. At various times in history societies in Asia have paid attention to the sutta in which the Budda declares that 'those who plant trees in temples, forests and aranayas (forest monasteries), will gather merit (karma) by both day and night.' As merit making karma is considered to be the highest priority for Buddhists (Sponsel and Natadecha, 1992, p.4). The planting of forests confers spiritual benefit and has a high non-monetarist value in these societies. This teaching, which required every able person to plant and maintain one tree every five years, did much to ensure the tree cover of ancient India (Schumacher, 1973).

In this sense the social aspects of forests must convey the same meaning to the local community and the designers, so that there will be a consensus on the validity of the design. This means a greater degree of local consultation in both implementation and management.

In terms of non-traditional goals, local education is crucial if the community is to assume a greater degree of responsibility over its resources. Local participation in the setting of long-term goals is essential. Otherwise problems such as the social and political disruption in India, Thailand, Portugal and Spain over the planting of *Eucalyptus spp* cannot be meaningfully addressed. In Spain, for instance, farmers have begun to pull up eucalypt seedlings from plantations and initiate civil disobedience actions to prevent further planting (Mantalbano, 1990). In Sri Lanka, farmers uproot pine seedlings from plantations and replace them with *Artocarpus spp* that they perceive as having greater utility value, with the unfortunate consequence of being jailed for interfering with government property.

PRESENT RESPONSES

Responding to the loss of forests is accomplished by two routes. The first is by the conservation of natural forests, the other is by creating human-made forests. However, the nature of such human created forests, as well as the needs for the conservation of nature, has to be carefully designed if all the values of a forest are to be conserved. In terms of the conservation of natural resources, the art and science of conservation forestry has concentrated on the management of scheduled species or regions as well as the identification of threats to the biodiversity of that forest estate.

Commercial industrial forestry, as it is commonly practised today, consists of silviculture which is the art and science of growing trees, and forest management, which is the economic and financial side of silviculture (Robinson, 1988).These aspects of forestry are comprised of four basic silvicultural systems and two forest management systems. The silvicultural systems are clearcutting, seed-tree, shelterwood and selection systems. The two forest management systems are even-aged management and uneven-aged management.

Silvicultural Systems

Clearcutting system

This system involves the removal of all the timber from the cutting site by the end of the designated time period; this requires species that are able to regenerate on bare soils in full overhead light. Regeneration of these forests may be from the seed burden in the litter, from surrounding trees, by coppice (stem and root suckers from cut stumps), or by replanting with chosen species. The regeneration of such clearcutting systems is managed to produce largely even-aged stands.

Seed-tree system

This is similar to clearcutting systems, except that carefully selected healthy trees or groups of trees are left in a random or patterned order, adequately spaced so that they provide the seed for natural regeneration after logging. The seed trees are harvested after regeneration is established and an even-aged stand results.

Shelterwood system

This system removes all the trees in a phased series of cuts. Typically the first cut in a virgin forest will be designed to remove what is termed overmature or high risk trees; this is referred to as the sanitation or salvage cut. The second cut follows relatively soon after and is designed to open the canopy so that enough sunlight penetrates to the forest floor to stimulate the germination and establishment of seedlings from the seed shed by seedbearing trees. This cut is normally made in a good seed-bearing year and healthy seed bearing trees are retained for the final cutting.The final cuts are made as the new stand develops and the final crop trees grow to optimum market size. At this final cutting all of the remaining old trees are removed so that the new stand will grow at optimal rates.

Selection system

This system differs from the other three in that the end goal is not even-aged silviculture. Rather it aims to establish or maintain an even distribution of trees of various age and size classes throughout the forest. Single trees or groups over a certain stem diameter, as well as diseased or damaged trees under this diameter, will be cut. The size of the patch created in the forest is a function of the seedling requirements for regeneration. Thus this system may be applied with species that do not regenerate successfully in shade as well as those which need shade for regeneration. In general, this system maintains a forest that is dense and has an irregularly profiled, though relatively continuous, well-closed canopy.

Forest Management Systems

Even-aged management

This system of forest management is applied to the first three silvicultural systems discussed above. Cutting areas are relatively large, ranging from 6-120 ha, or more. The forest inventory is maintained by mapping techniques. Under this system of management the forest area becomes a series of even-aged stands. Planning for this type of management readily can be done from sites remote from the forest under management.

Uneven-aged management

This management system can utilise all four silvicultural techniques described above, but the size openings created by logging and the size of the areas given silvicultural treatment are relatively small openings (diameters of 1-2 times tree height). Therefore the management decisions have to be made locally and the treatments are usually too small to be mapped. Thus the forest inventory is maintained in terms of the number of trees by species, age, size and condition.

Forestry has a long and varied history and a multitude of responses, reflecting the environment, the social context and economic pressures that led to each type of response. Many of the early models of forestry in both European and non-European societies demonstrated a sensitivity to the natural systems (Robinson, 1988). The dominance of monoculture plantations managed as clearcutting systems of silviculture is recent and may be a consequence of the economic order that arose after the Industrial Revolution. The various forestry practices arose as a response to the needs for particular forest products. The narrower the definition of product, the narrower the possible response. Thus, it is useful to consider the various types of forestry practised today in terms of their origins and goals. The responses have been compressed to six categories for ease of discussion.

Industrial Forestry

Industrial forestry commonly refers to the fastest and most cost-effective way to produce a growth of trees to provide fuelwood and timber on a large scale. Selection criteria, such as low maintenance needs, where young plants do not require extensive management and rapid growth rates, have produced the present response of mono-cultural plantations with a few 'high yield' species. Thus, industrial forestry is characterised by even-aged silviculture with low species diversity; these systems often yield monoculture plantations. In all these systems of management the production of wood or fibre is seen as the primary product.

This approach to forestry often provides the fastest response to the growing need for timber, fibre and wood products. Species are used that have been identified as having suitable timber or fibre characteristics and developed to grow fast in a range of sites, including degraded agricultural lands. By producing wood in a relatively short time this type of forestry assists in reducing the pressure on the remnant stands of natural forest.

In design the plantings are formalised, usually even-spaced and even-aged. Most industrial forests are comprised of monocultures with relatively short rotation periods. The consistent removal of large volumes in terms of biomass from the ecosystem normally requires the input of fertiliser after the first or second rotation to maintain output levels of the site.

Traditional Forestry

Traditional forestry (Figure 20) encompasses the diverse forms of tree farming termed Village Forest, Forest Gardens, Mixed Tree Farming etc. This type of activity is recorded in many traditional societies. It seeks to develop models based on the functional or utilitarian features of trees. This form of forestry is widespread and accounts for a large proportion of land use in some countries. In western Java for example, these tree gardens account for over 240,000 ha of land representing 20% of current land use (Wiersaum, 1982). In all cases the local natural forest provided the model from which these responses to tree cropping or silviculture developed. In observing traditional gardeners of Papua New Guinea Rappaport (1971, p.128) comments that 'It is to establish temporary associations of plants directly useful to man on sites from which forest is removed and to encourage the return of forest to those sites after the useful plants have been harvested. The return of the forest makes it possible, or at least much easier, to establish again an association of cultivated plants sometime in the future'.

Throughout the world, it had been the custom to cultivate tree species and agricultural crops in intimate combination. In central and northern Europe it was the general custom to clear-fell derelict forests, burn the slash, cultivate food crops for varying periods on the cleared areas and plant or sow tree species before, along with, or after the sowing of the agricultural crop. This practice declined in favour of semi-permanent crop or pasture at the end of the Middle-Ages (King, 1989). In tropical America many societies still practise traditionally simulated forest conditions on their farms in order to obtain the beneficial effect of forest structures. Farmers in Central America, for example, have long imitated the structure and species diversity of tropical forests by planting a variety of crops with different growth habits (Wilken, 1977). In Asia, some areas practised a

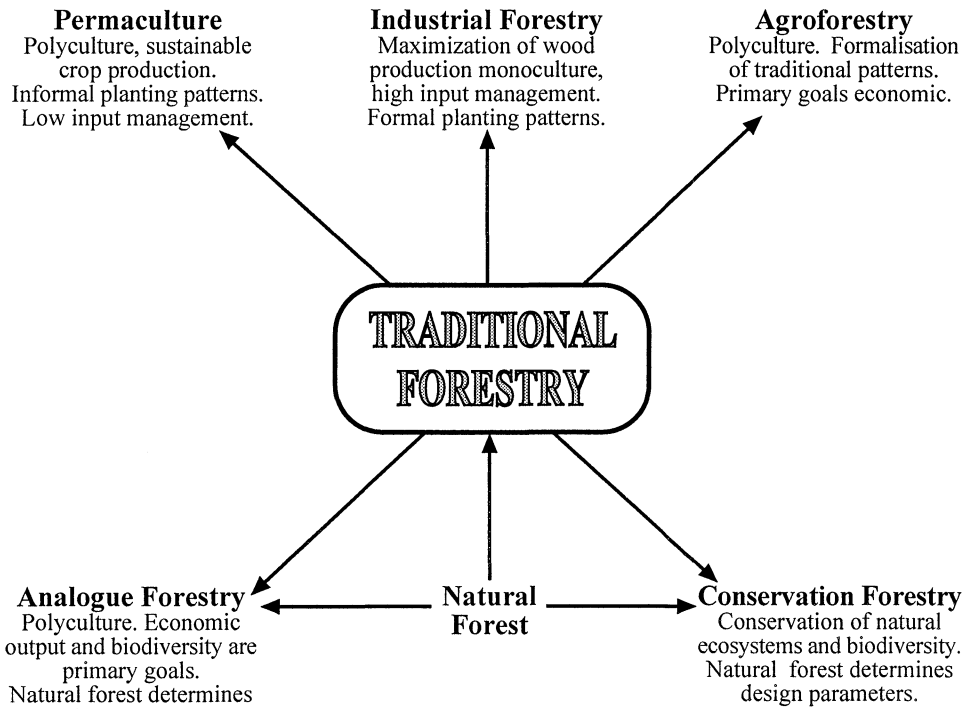


Figure 20: The relationship between the natural forest that provided the model for traditional responses and the model from which all modern responses developed. Arrows indicate the flow of design considerations

sophisticated system of shifting cultivation where certain species of trees were deliberately protected to provide shade and shelter for the maturing crop. Trees were also planted in these areas to provide food, medicines, construction wood and cosmetics (Conklin, 1980). In Nigeria, intensive systems of mixed herbaceous, shrub and tree cropping is practised so that human energy can be conserved by making full use of the limited space laboriously won from the dense forest (Ojo, 1966).

Conservation Forestry

Conservation Forestry refers to the management of wild or natural areas, the conservation of endangered taxa, the preservation of threatened habitats, the planting of forests to control erosion or run off, restoration ecology and all related research, development and extension work.

Conservation Forestry seeks to protect the valuable genetic stock present in natural forests and in imminent danger of being depleted. It is this genetic stock that makes modern agriculture possible and has the potential to produce much of the future needs of humanity. Further, the act of conserving natural areas in this manner, yields ecological benefits such as soil stabilisation and the provision of habitat for many species of plants and animals that cannot survive without natural forests.

Agroforestry

Agroforestry arose as a science from observation and study of traditional forestry systems. In fact, traditional forestry practices increasingly have been identified as sub-systems of integrated farming systems under the name agroforestry (Peck, 1984). However agroforestry is more than traditional responses to forestry needs. A modern definition is given by Lundgren (1987, p.206) who states that: 'Agroforestry is a collective name for land-use systems and practices where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. In agroforestry there are both ecological and economical interactions between the woody and non-woody components.' However the direction of development for this practice tends to be governed by economic goals. For instance, it has been seen as the alternative to the 'highly productive and profitable monocultures that are dependent on fossil fuel subsidies in countries where such subsidies are not possible' (Gholz, 1987, p.1). Agroforestry has also been described as a land use practice where agriculture and forestry are combined and managed to produce both commercial forest products and agricultural produce (Garland K.R. *et al*, 1984). A recent survey of the agroforestry literature would seem to confirm these trends (Nair, 1989). The descriptions of traditional forestry systems demonstrate a complex, diverse, uneven aged, non-formal tree planting system, while the descriptions of agroforestry applications suggest a formal, even-aged planting system of reduced complexity and diversity. For instance, the Kandyan garden de-

Table 11: Crops grown in the Kandyan gardens

Name of Crop
Areca (*Areca catechu*)
Avocado (*Persea americana*)
Black pepper (*Piper nigrum*)
Bread-fruit (*Artocarpus incisa*)
Cacoa (*Theobroma cacoa*)
Cardamom (*Elettaria cardamomum*)
Citrus (*Citrus spp*)
Cloves (*Syzygium aromaticum*)
Coconut (*Cocos nucifera*)
Coffee (*Coffea spp*)
Durian (*Durio zibethinus*)
Flowers
Fodder grasses
Ginger (*Zingiber officinale*)
Jak fruit (*Artocarpus heterophylla*)
Kitul (*Caryota urens*)
Mango (*Mangifera indica*)
Mangosteen (*Garcinia mangostana*)
Nutmeg (*Myristica fragrans*)
Papaya (*Carica papaya*)
Passion-fruit (*Passiflora edulis*)
Pineapple (*Ananas comosus*)
Plantain (*Musa spp*)
Rambutan (*Nephelium lappaceum*)
Rice (*Oryza sativa*)
Rubber (*Hevea brasilensis*)
Tea (*Camellia sinensis*)
Vegetables
Yams (*Dioscorea spp*)

scribed by Jacob and Alles (1987) is summarised in Table 11.

The above traditional response contrasts with the proposed agroforestry model for the same area (Table 12) and therefore it may be useful to separate traditional forestry practices from agroforestry practices. In countries with no prominent history of traditional forestry, such as Australia and New Zealand, agroforestry is seen as the superimposition of tree-cropping systems on traditional agricultural systems and serves to provide a greater structural and ecological diversity to treeless farming systems. Ideally, an agroforestry system is seen as a result of the interactions between the five major components of the system (Reid and Wilson, 1986). These are identified as:

Land
Environment
Agricultural component
Forestry component
Management strategy

The concept of Forest Farming, as proposed by Sholto Douglas and de Hart (1985), which was a precursor to agroforestry, is accommodated under this description as its goals and design techniques are similar.

Permaculture

Permaculture, is a crop management system that was designed as an integrated, evolving system of perennial, or self-perpetuating, plant and animal species useful to man. It is in essence, a complete agricultural ecosystem, modelled on existing but simpler examples (Mollison and Holmgren, 1978). Permaculture (**perma**nent agri**culture**) is more a system of agriculture than forestry as it is the conscious design and maintenance of agriculturally productive ecosystems which have the diversity, stability and resilience of natural ecosystems (Mollison, 1988). It has sometimes been addressed as a system of forestry as it is often includes production systems dominated by trees. This system places a strong emphasis on the ecological phenomenon known as the edge-effect. The transition stage, or edge, between two stages of a succession is the most productive zone. Although permaculture does not address interior species or forest ecosystems, this method does encourage the conservation of agricultural genetic diversity and the building of organic soil. In terms of a synthesis between agriculture and forestry permaculture addresses more variables than agroforestry. In design this system of land management tends to be more informal, the landscape design being determined by local conditions and local needs (Figure 21).

Table 12: Proposed agroforestry plants

Name of Crop
Avocado (*Persea americana*)
Black pepper (*Piper nigrum*)
Bread-fruit (*Artocarpus incisa*)
Cloves (*Syzygium aromaticum*)
Coconut (*Cocos nucifera*)
Coffee (*Coffea spp*)
Jak fruit (*Artocarpus heterophylla*)
Lime (*Citrus spp*)
Mango (*Mangifera indica*)
Nutmeg (*Myristica fragrans*)

Analogue Forestry

Analogue Forestry is a system of silviculture that seeks to establish a tree-dominated ecosystem that is analogous in architectural structure and ecological function to the original climax or sub-climax vegetation community. It may be comprised of natural or exotic species in any proportion, the contribution to structure and function being the factor that determines its use. The ecological function of the system can be measured by a number of variables. For instance, the ecological function of providing microhabitat, keystone species, or stabilising nutrient cycles, involves the use of the original tree or an analogous species that can provide these functions. For example, the replacement of a tree species that provides food for local wildlife, with another that has greater economic value but is analogous in terms of food production for the same local wildlife is an example. The forest community so formed will also be analogous in terms of **whole forest product** and services, such as the production of clean water, environmental stability or biodiversity conservation. Recognition of these functions and designing to meet with their needs, will be an important feature of this system of silviculture.

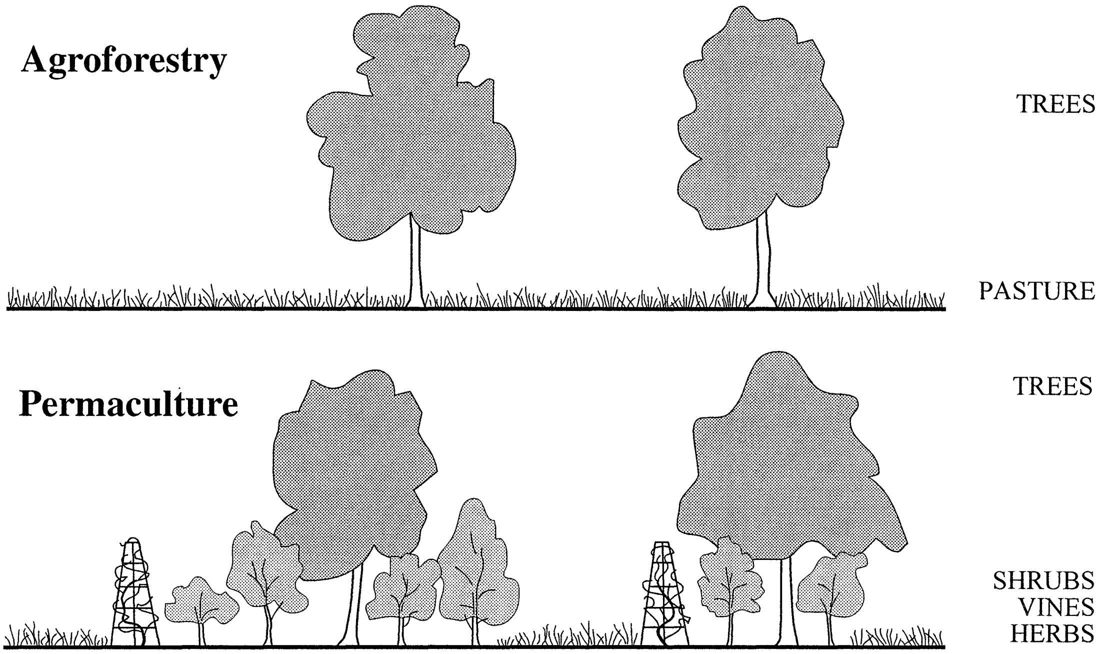


Figure 21: Agroforestry design vs permaculture design

This approach draws on the strengths of the traditional paradigm. Many traditional responses to forestry mimic the structure or successional process of the local forest vegetation. The use of the successional stages of the natural ecosystem to design a cropping system was first reported by Hart (1980). Analogue Forestry is a technique that further develops the structure of the cropping system, so that it is even closer to natural forest and recreates a similar modified environment allowing many species of the original forests to extend their ranges either by design or effect. The traditional response to forestry concerns the functional use of tree crops. This may involve using native species as in the case of the farmers of the puna zone of the Peruvian Andes, or a mixture of native and exotic species as in the case of the farmers of the west coast of Sri Lanka. However each particular use of tree crops provides the highest degree of agricultural sustainability for that environment.

Building on these models, Analogue Forestry attempts to create a physical structure and a set of ecological relationships that is analogous to the natural vegetation represented in the ecological process termed succession. The trees and plants will be similar to the natural structure, but are able to supply human needs. Such forests come under the classification of synthetic plant communities. These plant communities are admixtures of native, naturalised and exotic species or, rarely, combinations of natives atypical of that landscape. Bridgewater (1988) argues that these synthetic communities are often no less stable than native communities and with appropriate management become part of the landscape matrix.

The environment created by such silvicultural processes will support the optimum biodiversity and ecosystem diversity. Further, by increasing crop diversity, risk of a market glut and peak labour demand are reduced.

Future Needs

If the practice of forestry is to provide an effective answer to forest loss it has to be a discipline that extends to all human endeavour that seeks to establish tree crop-dominated ecosystems on any landscape. To ensure a more equitable distribution of attention to the various aspects of forestry, a redirection of the present administrative, research and funding structures may be useful. One suggestion is to create a forestry sector with three departments,

Table 13: Forestry needs at a national level

NEED	FORESTRY TYPE		
	Conservation	**Analogue**	**Industrial**
Sustainability of genetic information	high	high	low
Sustainability of the environment	high	high	low
Potential of non-timber income	medium	high	low
Potential of fuelwood production	low	high	high
Potential of timber production	none	high	high
Potential of human habitation	none	high	none
Potential of timber production over the shortest time	none	low	high

one dealing with conservation forestry, another dealing with industrial forestry and the third dealing with analogue forestry (Senanayake, 1991b). The utility of such an approach to the forestry sector is summarised in Table 13. The attributes of multi-species or diverse tree cropping systems, such as agroforestry, are summarised as analogue forests for ease in comparison.

As Figure 20 demonstrates no single approach to forestry can provide much of the needs expressed by modern society. Another fact to be considered is that short rotation forestry will provide timber and fuelwood but high-quality solid wood that requires long rotation times cannot flow from this process. Robinson (1988) argues that industrial forestry is seldom a lucrative business'. It can be argued that it never was and never will be, because it takes longer than a lifetime to grow high-quality timber, longer than anyone can wait for a return on investment. It takes 75-150 years to grow high-quality wood for fine furniture and musical instruments. Trees can be mass produced for pulp, rough lumber and construction grade plywood under sustained yield in 50-75 years. However, it takes much longer to grow high-quality solid wood; a forest being managed for this purpose will seem uneconomical because it will always contain a large inventory of lower-quality timber that could be sold. Given these conditions the production of high-quality solid timber may have to be designed into other areas of forestry.

CHAPTER EIGHT

FORESTRY IN THE CONTEXT OF LANDSCAPE MANAGEMENT

If forestry is to manage the structure, form and process of the forest to meet community needs without diminishing the diversity and extent of the biota then more comprehensive documentation, measurement and design practices need to be undertaken. This chapter explores some of these considerations.

DOCUMENTATION

Human Needs

A forest or even a collection of trees has strong effects on its environment. Different types of forests have different effects. The differences between pine monoculture and tropical montane forest are obvious in this context. Thus a primary need in terms of managing forests as a part of a landscape is to identify the types of forest needed by various human interests. This is especially pertinent in setting parameters that address the needs of environmental stability and biodiversity conservation; for instance, the need to identify natural forests in a landscape is urgent because re-establishment of natural forest occurs on a minute scale when compared to deforestation, a trend that is increasing consistently (Jenkins, 1988).

Often, the most effective conservation action will be to identify and schedule areas for conservation, a daunting task given the fragmented nature of forest remnants today. One promising approach is the cataloguing and data management systems being developed by the Nature Conservancy of America. In addition to the U.S. database, their Latin America Biogeography Project assembles parallel databases on the biota, ecosystems and conservation areas through the Western Hemisphere. The central databases are in Spanish, allowing the exchange of information between Latin American Conservation data centres (Jenkins, 1988). Many other countries have also begun cataloguing processes. For instance, in Sri Lanka the forest patches usually represent the only habitat for rare, indigenous or endangered species. Most remnant forest patches will go unrecognised because they are not a part of any scheduled or protected area and are cut over or ploughed up. The ability of the area presently scheduled or under protection, to provide habitat for all the species represented in Sri Lanka is poor, due to the fact that there are so many different ecosystems arising from past geologic history (Senanayake, in press). Many relict ecosystems still exist as small patches of refugial forest; they are scattered over the landscape and are not scheduled, recognised nor included in areas under protection. Small patches of refugial forest in Papua New Guinea, Indonesia, India and many other countries suffer a similar fate to those in Sri Lanka. These remnant forest patches abut village land. The development of silvicultural systems analogous to the natural forest can provide a land development technique that can expand their effective area. However, the first priority in terms of endangered or restricted forest ecosystems is to identify the resource. The forest patches on a landscape have to be identified and catalogued if any significant potential for future ecosystem rehabilitation work is to be retained.

One technique to address this problem is the Tropical Forest Register (TFR) whose format has been accepted by a large group of non-government agencies working on tropical forest loss (Senanayake, 1987a). The Neo Synthesis Research Centre (NSRC) has initiated the registering of tropical forest patches in Sri Lanka. Their data demonstrate the utility of this system to tropical ecosystem conservation effort. On a mapping scale of 1:10,000, the resolution allows forests of 1 ha or over, to be clearly notated. Interrogation of the TFR database provides output at many levels. For instance, the level one information presents a physiognomic description of the vegetation following Kuchler and Zonneveld (1988) classification. This is discussed more fully in Senanayake (1989).

Such detailed approaches to forestry are new and arise as a consequence of modern human activity and the destruction of large areas of natural forest. The realisation that natural habitats are being confined to ever decreasing patch sizes has also evoked a scientific response in defining optimum strategies of management as in Conservation Biology (Soulé, 1986). This also raises an issue of fundamental importance for natural ecosystems, viz. biodiversity (Wilson, 1988).

Edges and Flows

Many, if not all, ecological processes have thresholds below and above which they become discontinuous, chaotic, or suspended. Genetic and demographic processes have thresholds below which non-adaptive, random forces begin to prevail over adaptive, deterministic forces within populations.

Nature reserves are inherently disequilibrial for large, rare organisms.

The patches wrought by human activity vary in the degree of disturbance. The most ubiquitous anthropogenic or cultural landscape feature is agriculture. This creates a new ecosystem with different characteristics to the natural ecosystem. The term 'agro-ecosystem' is used to describe these new systems.

Odum (1983) has identified the characteristics of these systems. They include auxiliary sources of energy such as human, animal and fuel energy, to enhance the productivity of particular organisms.

Diversity

Once the distribution of the forest has been mapped out on a landscape, its use can be gauged by examining other fundamental patterns that can be determined for a landscape. The most fundamental set that a landscape can be envisaged in, is as natural and anthropogenic. A natural area of the landscape is that part of a landscape that retains is original character, the anthropogenic is that part of a landscape that has been influenced or changed by human activity (Plate 1).

The nature, proportion and juxtaposition of these elements on any landscape will vary with respect to its geographical location and economic or ecological history. Management will involve designing the landscapes that will meet the needs of sustainable development. The science of manag-

Plate 1: A landscape with two primary units

ing these two units has a long history. It has emerged as conservation biology (Soulé and Wilcox, 1980) for the natural element and as forestry and agriculture (Odum, 1983) for the anthropogenic element.

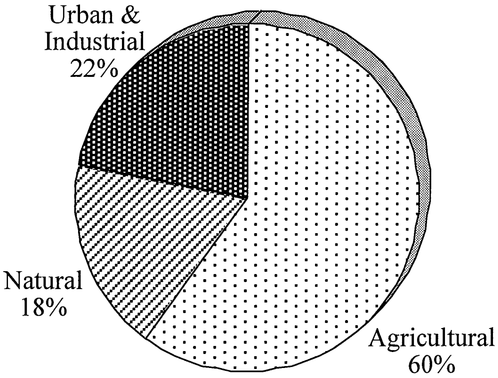


Figure 22: A hypothetical display of landscape components

The differences in these fundamental units of landscape evaluation have been summarised by the considerations for patches of natural ecosystems suggested by Soulé (1986) and for agricultural syst-ems by Odum (1983). A summation of Soule's studies (*op cit*) suggests that in patches representing an anthropogenic ecosystem:

> many of the species that constitute natural communities are the products of co-evolutionary processes,
> diversity is greatly reduced compared with natural ecosystems,
> dominant animals and plants are under artificial rather than natural selection and
> controls on the systems are largely external rather than internal via subsystem feedback.

In an agro-ecosystem, ecological processes found in other vegetation formations, such as nutrient cycling, predator/prey interactions, competition, commensalism and successional changes, are also found (Altieri, 1983), but, as Marten (1986) points out, human energy shapes the structure of the agro-ecosystem. This structure changes with the level of management and inputs. An agro-ecosystem can be defined and measured according to views of that system by different disciplines. This allows the generation of some common value, based upon the value scores of the various views or descriptors. Measurements of these same variables at later periods of time can indicate a change in state, which can be interpreted as 'better' or 'worse' (Senanayake, 1991a).

Agro-ecosystems have developed from traditional forms analogous to natural systems, to highly organised, centralised production systems. Today, the character of these ecosystems has undergone a massive change. Along with the rise in productivity ascribed to 'modern' or industrial agriculture, there is also a concomitant loss of diversity at both species and trophic levels as well as increases in the levels of external input required to maintain production (Odum, 1993).

Thus agriculture as much as silviculture can be seen to have representation along a continuum of land management systems such that one pole describes systems that function in a manner similar to natural systems and can be described as an analogue system. The other pole describes systems that function very differently from natural systems and are best described as industrial systems. The proportion of each in a landscape determines its stability. The other component of a landscape is urban or industrial land (Figure 22).

As the proportion of industrially used land increases, the stability of the landscape decreases. Thus the relative proportions of the various types of land use helps to determine its stability.

Perspectives

Another important consideration in terms of landscape management is the effect of scale. As we extend or reduce scale from a certain perspective, certain elements will change, in the same manner as the change of vision wrought by focussing a lens. Some elements will gain importance at the new settings while others lose importance. For instance when looking at a flatweed that is a crucial element providing habitat for a certain species of millipede, the plant is the most important consideration of the ecosystem. But if the scale of the ecosystem is increased the flatweed goes out of focus and becomes one with the grassland. At this scale it is the occurrence of patches of flatweed in time

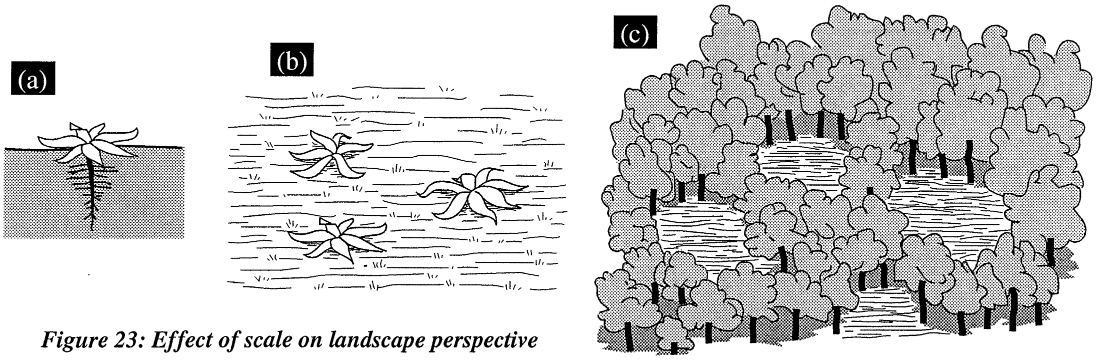


Figure 23: Effect of scale on landscape perspective

and space that is seen to be important to considerations of the millipede. On further expansion of scale the grassland is now seen as a patch in a forest, so the occurrence of the grassland in time and space becomes the important consideration (Figure 23). The landscape perspective has changed radically, so that retaining meaning relative to the object of concern requires the information to be retained by encoding or otherwise including the information into some element of design within the planning process. Thus, defining the species of tree to be used in a revegetation context ensures that the species chosen will be a food source for another group of organisms not addressed in the revegetation needs.

A similar recognition of the value of hierarchical tiering using abiotic, biotic and cultural sub-systems has provided a planning framework for urban planners and developers in the urban ecosystem.

The modern realisation that species are becoming extinct, that farmland is degrading, that forests are disappearing and that the climate of the planet itself is danger of perturbation, has brought about a response from individuals, groups and governments (Curtis, 1995). This realisation is manifest in tree planting, conservation works, farm planning, mining rehabilitation etc. These efforts can be rationalised in a system of management that answers to the needs of human society in terms of agriculture, urban and industrial development, as well as the needs of the ecosystem in terms of biodiversity, sustainability, genetic and habitat conservation. It has to operate at the largest scale practical for management. This scale, it is suggested is landscape. The word landscape connotes many meanings as its has been used in diverse contexts.A useful concept, is that of Foreman and Godron (1986, p.11) who define landscape as: 'a distinct, measurable unit defined by its recognisable and spatially repetitive cluster of interacting ecosystems, geomorphology and disturbance regimes'.

It is possible to define landscape boundaries using many different features, for example, cultural, hydrological, geological or ecological. For the purpose of management, however, a utilitarian boundary that incorporates as many features as possible has to be developed. Within the defined landscape individual dwellings, orchards, farms, mines, towns and forests become the elements to be managed. Landscape elements usually range from around 10 m to 1 km or more in width (Foreman and Godron, 1986).

A landscape exhibits the fundamental characteristics of structure, function, and process (change). Structure refers to the spatial relationships among the landscape elements; function refers to the interaction among the landscape elements in terms of energy, material or species flows; and process is the alteration in the structure and function of the landscape mosaic over time.

Landscape can also be seen as being constituted of two primary components, the biotic and abiotic. The abiotic is constituted of the non-living and non-organic constituents of the landscape such as rocks, earth, air and water. The biotic is consti-

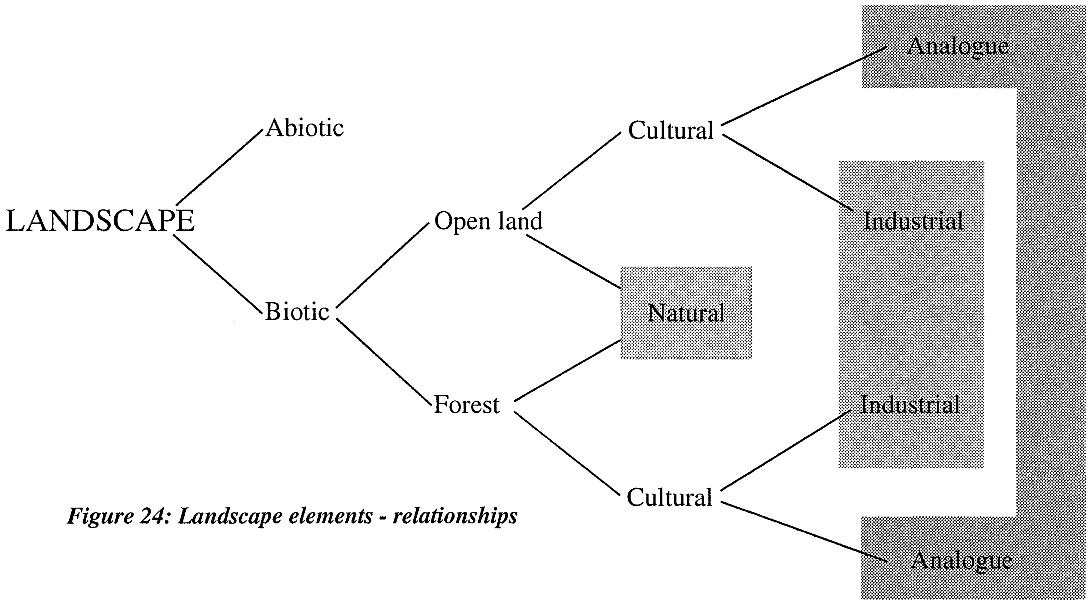


Figure 24: Landscape elements - relationships

tuted of the living and organic components of the landscape such as plants, animals, microbes and soil organic matter. The juxtaposition of these elements in time and space gives rise to all landscapes.

In analysing a landscape it is useful to consider the presence and distribution of its various elements (Figure 24). Here it will be seen that every biotic component has a potential natural and anthropogenic response. The anthropogenic response can be further subdivided depending on the intensity of use into systems that function in a manner similar to the natural systems (analogue) or systems that function in a manner different from the natural systems and require high maintenance inputs (industrial).

As natural landscapes evolved, ecosystems developed within them. Any area that contains living organisms can be described as an ecosystem. The boundaries that are delineated define the character of that ecosystem. A drop of water can be the ecosystem of certain bacteria, while a pond is an ecosystem for larger aquatic organisms and an ocean is an ecosystem for whales. Often the categories are not mutually exclusive; they vary in history or scale. Each ecosystem contributes to the organisation and stability of the larger ecosystem of which it is a part.

An agricultural system is also an ecosystem, although it may bear little resemblance to the natural ecosystem that existed on the same land prior to its conversion to agriculture. Species that comprised the original ecosystem may be greatly reduced or completely lost and replaced with other exotic organisms. For example, the wheat cropping systems of the mallee in Australia have no resemblance to the original mallee vegetation that they replaced and legume-based improved pasture contains very few species of the original grassland or forest that it replaced. However, it is also a fact that certain elements of the landscape regenerate effectively if the agents of change (animals, human activity) are withdrawn. The example of the re-establishment of oak-hickory woodland on farmland in the eastern United States (Oosting, 1942) occurred when the agent of change (agriculture) was abandoned. Similarly, the revegetation of Black Mountain in the ACT, Australia, changed the landscape from open grassland to dense woodland in 75 years. This occurred when the agents of change (large exotic herbivores) were excluded from the area (Muston, 1987). The ability to regenerate depends on the proximity of seed trees, suitable seedbed conditions and intensity and frequency of disturbance.

DESIGN AND MANAGEMENT

Landscape structure and function

Each ecosystem within a landscape can be identified as a patch, corridor or the background matrix that the latter categories occur in (Figure 25).

Determining the spatial distribution of these ecosystems will identify landscape structure. Evaluating and predicting the flows of biotic and abiotic objects among the landscape elements will identify landscape function.

Flows

Heterogeneity, or a difference between various landscape elements, is a fundamental cause of species movements and material flows. The distribution of species and the condition of landscape structure are linked in a feedback loop so that, the expansion and contraction of species among landscape elements has a major effect on, as well as being controlled by, landscape heterogeneity.

As spatial heterogeneity increases so does the potential for energy flow across ecosystem boundaries. As the number of individual ecosystems increases within a landscape, a greater proportion of edge animals and plants move between adjacent systems. Thus, as landscape heterogeneity increases so do the flows of heat energy, nutrients and biomass across the boundaries separating the various elements.

Mineral nutrients flow in and out of a landscape. Their residence time within an ecosystem is governed by the dynamics of wind, water and organisms. Most ecosystems have well-developed regulatory mechanisms to hold their requirement of nutrient within that system. However, disturbance, especially when severe, disrupts these mechanisms and facilitates transport to adjacent or other ecosystems. Therefore the rate of redistribution of mineral nutrients among landscape elements increases with the intensity of disturbance within them.

Diversity

Landscape heterogeneity decreases the abundance of climax community or rare interior species and increases the abundance of early successional communities or edge species. Landscape heterogeneity enhances the sustainability of the full spectrum of potential species.

The horizontal structure of a landscape tends towards increasing homogeneity if undisturbed, as

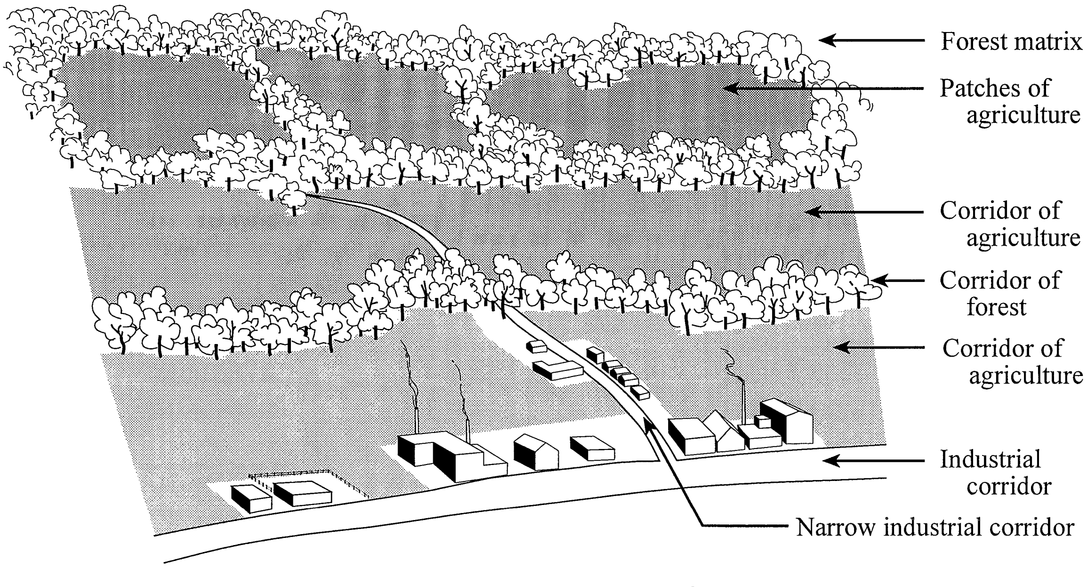


Figure 25: Landscape structure and function

all seral stages within can mature towards a climax. A moderate disturbance rapidly increases heterogeneity as different patches respond in relation to its local condition. Severe disturbances may increase or decrease heterogeneity as such events can eliminate or diminish the majority of biotic forms and expose a homogeneous abiotic component such as sand, rock or subsoil beneath.

Some Critical Elements

The stability of a landscape has to be perceived in three distinct ways. The first, through physical system stability, is characterised by an absence of biomass such as a sand dune, rock or highway. The second is an increase in stability achieved by the ability of biological organisms to recover rapidly from disturbances. In this latter case there is a low amount of biomass present and the system is characterised by ecosystems of early-seral stages as in the case of a cultivated field. The third is stability achieved by a high resistance to disturbance. Here there is a high amount of biomass present and the system is characterised by ecosystems of late-seral stages such as forests.

The juxtaposition of the various elements can be designed to function optimally in reference to these general principles to enhance or depress various elements of the native biota. The impact of landscape design on the biota can be illustrated by the behaviour of butterflies in relation to the environment. In a study of butterfly flight paths Wood and Samways (1991) found that the structure and orientation of the landscape elements modify the flight paths. Edge areas such as water or a forest stand are important, as is naturally regenerated vegetation. Exotic trees such as plane (*Platanus spp*) or mowed grass lawns have a negative effect.

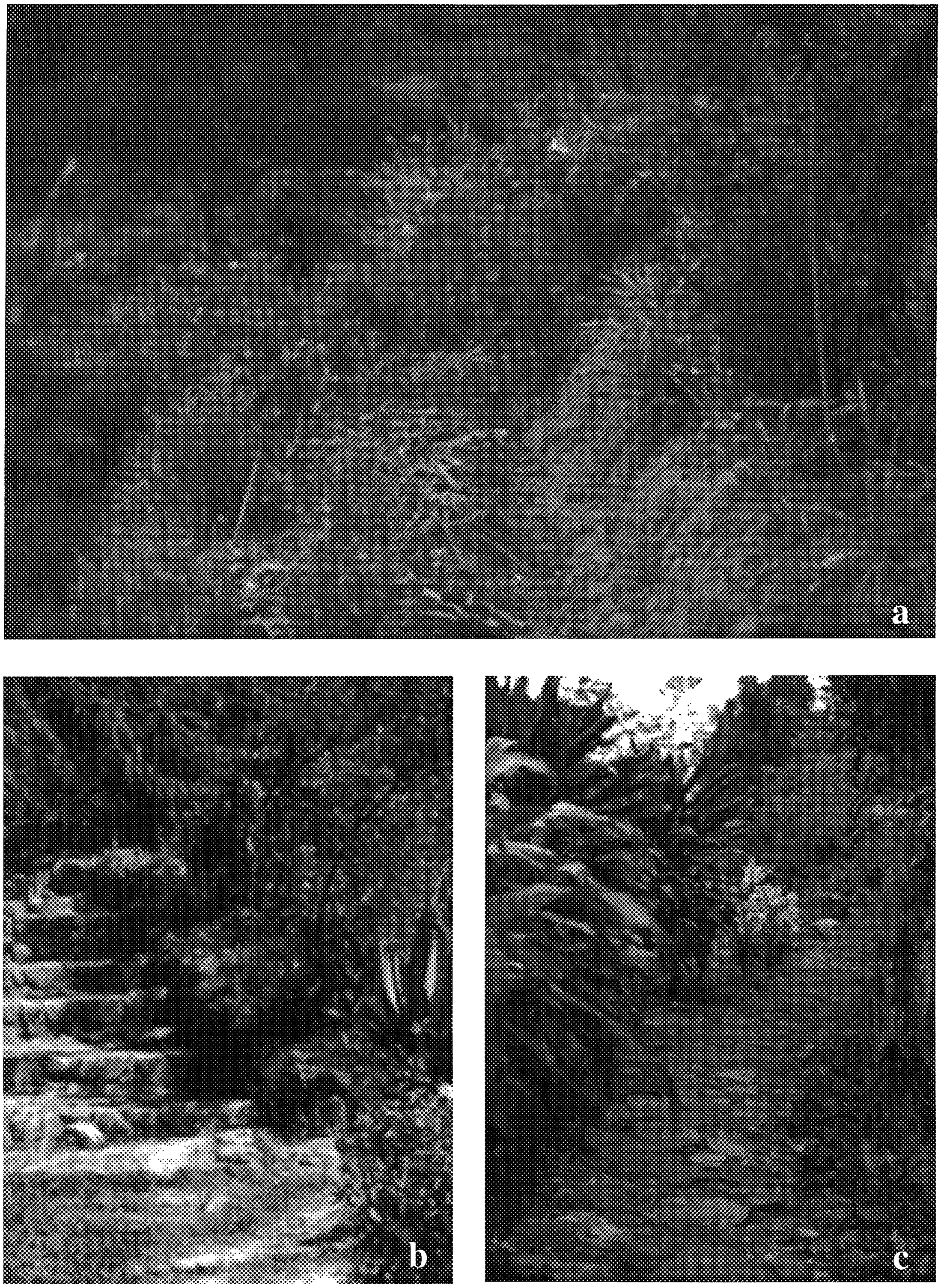
Forgetting that we are dealing with living things can lead to designing amenity in landscapes that insist on clumsily and expensively fighting the natural characteristics of vegetation instead of understanding and manipulating them. Consideration of the natural ecosystems can be incorporated into landscape design. An example is the water drainage design experiment in Sri Lanka. Here the tea estates have to construct efficient drains to remove rainwater as a part of the erosion control strategy. However the original design of the drains precluded the formation of habitat for two species of amphibian *Rana corrugata*, and *Rana (hylarana) temporalis* (Plate 2a). A redesign of the drains allowing pool formation resulted in creating silt traps as well as re-establishing populations of the two amphibians (Plates 2b and c).

While, there are some fundamental ecological needs of a landscape, human perception of the landscape is also an essential design feature. As Muston (1987, p.94) states: 'The landscape cannot be contained on a designer's drawing board. It is all-encompassing and it should be seen as a dynamic entity whose parts are both variable in time and space and are fundamentally interwoven'. People belong in that entity and their actions must be rationalised together with all of the contributing parts. However, human responses to land use can generate fashions in landscape and as landscapes depend on the growth of trees and other long lived plants, it can never catch up with a fashion before it changes. On the other hand societies that lived on and influenced a landscape over time produced anthropogenic landscapes with recognisable features. These have been termed cultural landscapes. In Australia the largest number of individual entries on the register of the National Estate reflect European or European related exploration and settlement (Frawley, 1989). This suggests that it is the dominant culture that influences the permanence of landscape elements of value.

The development of vegetation on a landscape is created not only by human design but by human default. Neglect is too often presented as an aspect of the 'bad old days' which will somehow not occur in the future, rather than as a neutral aspect of human nature whose effects should be understood, provided for and turned to an advantage. All these processes must be recognised and utilised in the development of a range of silvicultural techniques to meet with the needs of the different landscape elements.

In designing these 'fabricated landscapes'. The potential for exotic species to act as weed species

Plates 2a, b and c: Drains, before (a) and after (b and c) redesign to improve habitat for amphibians



must be carefully evaluated. Muston (1987) describes a revegetation program along a powerline clearing in a national park in Australia. The seed mixes used to re-establish vegetation were natives but from other parts of Australia not indigenous to the site. The result was that these native species, in the absence of their usual competitors on the site, invaded the surrounding un-degraded forest. The presence of exotics on a landscape must be carefully evaluated as they may provide a great deal of positive impact too. An example is the Australian tree *Acacia saligna*, considered a weed species and threatening the Cape flora of South Africa (Stirton, 1978). An eradication program has begun with the introduction of the rust fungus *Uromycladium tepperianum*. But this tree was the species that stabilised many of the drift-sands in Cape Town, provided large quantities of fodder for goats and sheep and is a source of cheap firewood (Armstrong, 1992). The removal of this tree is expected to impact local economies and the stability of many coastal landscapes.

CHAPTER NINE

ANALOGUE FORESTRY, POTENTIAL

DESIGN COMPONENTS

In creating an ecosystem that seeks to be analogous to the natural vegetation of an area, the original vegetation provides a good guide. Often it is handy to first determine the physiognomic character of the natural vegetation. The physiognomic character in terms of structure, is the three dimensional spatial pattern created by the architecture of the trees. Here the consideration of an individual tree in terms of its canopy position, growth habit, rooting habit and other physiognomic features is required. Similarly, the spatial pattern, in terms of closed forest, woodland, canopy with or without emergents, levels of canopy and depth of rooting and type of soil, must be addressed in a community context. For example the notation b; 8i, 7c, 5i; c, w, 4i: xc6; hlr indicates that the forest in question is a broadleaved evergreen forest with three layers of canopy. The uppermost layer is at a height of over 35 m with interrupted cover (50-75%), the second layer of canopy is at a height of 20-30 m with continuous cover (over 75%), the third layer is at 5-10 m with low, interrupted cover (50-75%). There are lianes and epiphytes at heights from 10-20 m. The ground has patches of forbs, lichens and mosses (6-25%). Thus the structure, a principal design component, is thereby defined. The other major factors determining design are process and function. These three factors have to be considered in an individual species context and a whole community context in order to achieve design that is analogous to the natural system.

Structure

The structure of the system will demonstrate a wide range of different architectural responses varying from trees to lianes. The provision of a suitable structure is addressed via the growth habit of the species being evaluated for use. While it is useful to appreciate that there may be differences between juvenile and adult forms, the primary design consideration will centre on the adult form. Thus species can be identified as having a terminal, decurrent or excurrent growth structure, with the crown occupying a dominant, co-dominant, intermediate or suppressed position. The nature of adult root system should be noted for each species, whether the root system consists of fibrous roots, tap roots or heart roots, and whether there are any modifications such as aerial roots or buttresses. Finally any physiognomic features of interest to management are noted.

For example coconut (*Cocos nucifera)* is a tall palm 20-25 m in height, of columnar, terminal growth habit, with the crown occupying a co-dominant position in the canopy and with a fibrous rooting habit and palmate evergreen leaves. It is an early- to mid-seral stage species that functions well as a pioneer tree, providing the canopy necessary to establish other, more shade-demanding species. As the leaves are connected to a large branch there is a contribution to coarse woody matter but no build up of a litter mulch. This feature allows the growth of grasses or other ground cover to the base of the trunk. This tree is favoured by reptiles such as geckos due to the complex range of microhabitats formed by the crown and in Asia it provides habitat for the flying snake (*Crysopelea ornata*), that feeds largely on geckos. The architecture of the tree also makes it a safe nesting habitat for many birds. It has been recorded as the most important of all palms, providing a wide variety of products including food, sugar, drink, medicine, palm wine and alcoholic spirit, fibre, timber, thatch, domestic utensils etc. (Macmillan, 1935).

Bunya pine (*Araucaria bidwillii*) is a tall tree attaining 45-60 m. It has an excurrent growth habit with the crowns occupying a dominant position in the canopy, the adult crown is dome-shaped and the taproot has large lateral roots. It is an early- to late-seral species that can be grown as a pioneer and allowed to mature into a dominant tree. It is a dense tree that can bear branches close to ground level. The leaves are small, and stiff and end in a sharp point. The shedding of small parts of leaf-bearing branches creates a continuous coarse mat of litter under the tree that precludes establishment of ground cover. The flaky bark on the trunk and branches offers prime hiding places for insects and spiders and food for birds. It is very fire-sensitive at all ages. It yields good timber. The seed of this tree is edible and in Queensland it was the most important large rainforest seed. Aboriginals from hundreds of kilometers away assembled to collect the seed at fruiting time (Low, 1968).

Process

Ecological Value

In a tree community context, the key to the total outcome of the planting is what provides ecological value. For instance, the design may require the growing of a community that has a closed canopy with emergent trees, many levels of vegetation and a clear ground area with litter but few grasses or forbs. This design is typical of wet tropical rainforests and can be accomplished by a planting of *Erythrina lithosperma* to provide a closed canopy, with jak (*Artocarpus integrifolia*) and champak (*Michelia champaca*) as emergents. The canopy is dense and will allow shade loving plants such as cardamom (*Elettaria cardamomum*) or cloves (*Eugenia caryophyllata*) to occupy the suppressed positions. These layers of canopy will effectively control erosion by rainfall and will present a floor that is free of light-demanding grasses and forbs, a situation analogous to the natural vegetation of a wet tropical forest.

Another possible design of tree communities is the growing of a community that has a more open canopy with the trees co-dominant. The open areas between the trees allow for light penetration and thus favour the growth of grasses, forbs, herbs or annuals. This design is typical of the temperate woodland ecosystems and could be accomplished by the planting of pines (*Pinus radiata, P. elliottii*) or by the planting of oaks (*Quercus spp*) or eucalypts (*Eucalyptus spp*). The planting pattern is usually a close even-aged plantation, which is thinned out as the community grows. Grazing animals are a component of this design and provide regulation of the open grassland that forms with increasing light penetration (Reid and Wilson, 1986). The grassland also provides a protective thatch to control soil erosion by rainfall.

Position

Evaluation of process is the evaluation of the position of an ecosystem on a seral or ecological continuum. This should be determined before a particular species or community is selected. Here the life strategy of a species and its position in the ecosystem process is considered. The process of ecosystem maturation is defined as the process of adding a new species capable of initiating change within that ecosystem. Processes such as the hydrologic cycle and carbon cycle are also variables that can be considered in design. Early successional forest will have more r-selected species as its components (see Chapter Five, Table 4). As the forest ecosystem matures an increase in the representation of K selected species indicates one measure of maturity. The outcomes of agricultural, horticultural or forestry activities are ecological analogues of different seral formations. The annual cropping systems are analogous to the grasslands or early-seral stages and short rotation forests are analogous to later-seral stages. If abandoned, each system will mature along the local gradient. Studies in forest succession in the eastern United States demonstrate such a process (Ricklefs, 1973).

Climate

Another variable that affects the process of succession or maturity is climate. In this case, an environment of low climatic amplitude, such as the wet tropics, will have a greater potential for diversity than a temperate system. Within each system the local conditions will determine what ecological responses can express or sustain themselves. The nature of the soil and other landscape variables will determine the final expression of a forest in terms of its successional processes. The zoning of redwood and oak woodland in California at the edge of the coastal climate zone; or messmate stringybark (*Eucalyptus obliqua*), and mountain ash (*E. regnans*) in Victoria, Australia (Ashton, 1981a), at the edge of its rainfall zone provide examples. As the landscape changes to a drier rainfall regime all species occupy ever decreasing patches of microclimate within ridges, illustrating the specific micro-environment requirements of many forest species. This aspect of forest life strategies is determined by history, climate and landscape and is often reflected in the home gardens of traditional societies. In many cases these societies have developed production systems that are similar to the vegetation types of the native ecosystem. Home gardens in the tropics demonstrate a large use of tree crops, perennial plants and vegetative cropping (Plate 3). Temperate home gardens are less shaded and consist of seed- and tuber-dominated cropping. Both systems have used the life strategies of the natural vegetation to design their cropping systems (Ninez, 1984).

Function

An assessment of function includes an assessment of both ecological function and anthropocentric function, which includes economic, social or cultural value provided by a single species or by the community as a whole. In this instance, wood products, non-wood products, religious, cultural and aesthetic needs will be important design criteria. Ecological function includes the provision of keystone species, food species and microhabitats, both as single species and as a community. The most obvious function of such species is to provide shade. Another function is supporting the complex, trophic web of that ecosystem by providing the energy input through photosynthesis. In the functioning of a forest, it is these trophic webs that give each forest its unique identity.

If the planting is being designed for ecological function, the ecological factors that contribute to the stability of that ecosystem must be identified. These include factors such as keystone species, microhabitat formation, maximising the edge or ecotones. Keystone species that affect the functioning of each seral stage will change as a consequence of forest maturity. The canopy-forming, keystone species of early-seral stages will not be effective in this role under a taller and denser canopy provided by later-seral stages. For instance, in tropical forests, pioneer trees of genera such as *Cecropia*, *Macaranga* and *Muntingia* provide food for a large range of organisms during early-seral stages, especially herbivores and nectar or fruit feeders. These organisms support predator communities at increasing trophic levels. Such trees are important sources of energy to the ecosystem and lend stability in the manner of a functional keystone. However, as the forest matures taller trees such as *Albizzia* and *Michelia* begin to shade the pioneer species and deprive them of light and nutrients. The pioneers die back and the ecosystem becomes supported by the photosynthetic activity and habitat provision of the taller species. The keystone species at this level will then be comprised of a different suite of species to those preceding.

Keystone species can be identified for every tree-dominated ecosystem. Keystone species provide food and microhabitats in both a single species and community context. In some situations the optimum settings for both functions may be difficult to reconcile, as seen in the need to produce wood biomass and protect biodiversity. The most effective method of producing wood biomass may involve monoculture plantations, which reduces biodiversity and will require ecological compromises. In other situations, the optimal setting for both may be extremely compatible, as in the need to declare a national park and protect biodiversity. In any area of land there is a series of responses possible between these two settings. The settings are on a scale that evaluates the quality of any variable or group of variables deemed to have a value. In the case discussed above, the variable is biodiversity. When translated to a landscape scale the question is whether the land use is ecologically compatible or incompatible with the conservation of biodiversity.

Anthropocentric function includes economic, social or cultural value provided by a single species or by the forest as a whole. Wood products, non-wood products, religious, cultural and aesthetic needs are important design criteria. In terms of social values and goals which reflect both the need to conserve the quality of the human environment and the productivity of the economic environment, there is a need to develop new techniques of evaluation and design that take cultural needs into account.

DESIGN CONSIDERATIONS

Seral Stages

In the development of a forest system maturity brings changes in the trophic web which are demonstrated by changes in species composition. This trend is illustrated by studies of the distribution of mammals in the forests of western Oregon by Harris *et al*, (1982). The forest was studied as a sequence of six successional stages; terrestrial vertebrate species were studied at each stage. These successional series all maintain about an equal level of species at each level, but the composition of the species represented changes with the change in vegetation.

The tree species that are characteristic of each stage confer stability to that particular stage. Thus, mid-seral successional stages are often better adopted as design criteria for woodlots, orchards, home gardens, tree farms or agroforests. Annual agriculture and pasture mimic early successional stages. Incorporation of ecological processes that contribute to further stability can thus lend a great deal to design. In the tropics, the use of mid-seral leguminous trees such as *Erythrina* and *Grevillea* as shade trees for tea, coffee and cocoa (Plate 4), is common. As the crop plants are shade-adapted, mid-seral plants do best in a microclimate created by light shade; the use of shade trees is important to achieve optimum production. In this design it is clear that the species of shade tree above the crop plant can change in composition but not in structure. That particular seral analogue is the best design that has been found for the production of perennial crops like tea, cocoa and coffee.

The structure of this system, means that crop trees up to 2 m in height are protected by shade trees at about 7-10 m. The crops are the same in each country but the species used as shade trees are often very different. For instance, *Erythrina* is used for shading coffee in India, while in central America *Inga* is the common shade tree for coffee. Also while growers in Papua New Guinea use *Casuarina, Leucaena* is the popular shade tree in the Philippines. Sometimes, this structure is developed into a more mature ecosystem by adding larger trees such as *Albizzia* or *Michelia* (Plate 5).

The early-seral stages, such as grasslands, herb-fields and meadow, have their particular seral analogues; these are the systems of annual cropping or pasture. The ecological characteristics of the early-seral stages are r selected life strategies, that is plants that are short lived, low root/shoot ratios and produce many seeds. While it is possible to enable many such ecosystems to develop into more mature states, the relative advantages of changing such land to forest type ecosystems have to be carefully considered.

In designing for structure, the seral stage that is best suited for the crops chosen provides the model. Thus, if the crops in question are annuals, such as cereal grain, beans and squashes, the pioneer stages provide the model. If the crops in question are perennials such as coffee and fruit, the later-seral stages provide the model. The pioneer stages in most ecosystems are diverse and incorporate a range of plant types capable of high productivity, a pattern often reflected in traditional agriculture. The early-seral stages of forest ecosystems, provide the next growth, or building up, phase (Brunig, 1983).

However, the need for yet higher levels of productivity has created a demand for intensive rates of production from all agro-ecosystems. The contemporary response has been to move towards monoculture cropping. The trends are similar in tree crops, orchard crops or annuals. Although this system of agriculture is dependent on high inputs of external energy (Meiring, 1977) and results in reduced biodiversity (Altieri and Merrick, 1988), it has enjoyed a tremendous growth at the expense of fossil fuel. This leads to the observation by Odum and Odum (1981) that potatoes are partly made of oil. As the economic system dictates that land be productive in marketable output, a cropping system that is as productive as the one being replaced, and also displays characteristics of ecological stability will be the desired design. In most cases this design will be more analogous to the natural pioneer vegetation and tend towards polyculture, with structural diversity. Studies of such systems demonstrate the increase in long-term viability in addition to a reduction in external input requirement and increase in biodiversity (Altieri, 1983). Thus,

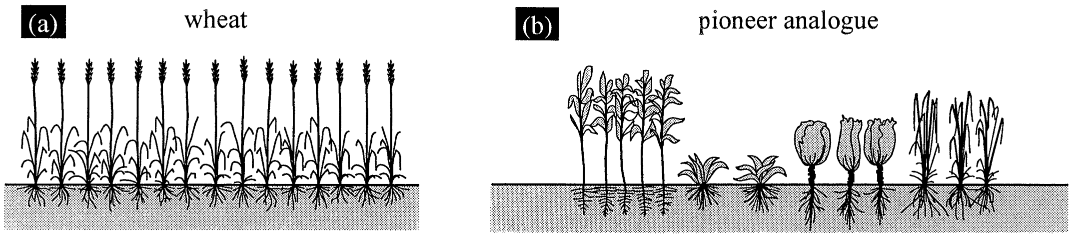


Figure 26: Monoculture, wheat (a), Polyculture, pioneer analogue (b)

the design of a pioneer analogue will have a heterogeneous design (Figure 26). The creation of a polyculture, as opposed to a monoculture, creates a structure that is analogous to the structure of the natural communities and therefore able to provide microhabitat for a range of species that could not exist in a monoculture. A diversity of flowers provide food for a variety of insects beneficial to the production system (Leuis, 1960). For instance, wild-flowers often nurture populations of parasitic wasps that control the populations of pest species (Leuis, 1967). This effect can be quite substantial as demonstrated in a Russian study that indicates the effect of Umbellifer plants when interplanted with a cabbage crop. At a ratio of one flowering plant to 400 crop plants these produced a parasitation rate of 94% in cabbage cutworms (Merrill, 1976). The structure also supports a large population of insect predators, such as spiders and mantids, that are absent from intensive monocultures.

If the crops are perennials or tree crops the relative seral stage best suited to the crops and to the environment must be provided. The structure of the planting provides an analogue of the seral stage that the crops are adapted to. Thus for a cropping system that uses early-seral plants, such as tea or coffee, the structure of an early-seral stage with a low canopy and light shade is of utility (Figure 27). Here the shade trees are not allowed to mature, the branches are lopped every few years so that a tall, dense, canopy cannot form. In a cropping system that uses plants adapted to a late-seral stage the same species of shade plants can be used, but they are allowed to grow into trees with a full canopy. The space so created can be further designed to be closer to the natural system. For instance, a common shade plant for tea in the mountains of Sri Lanka is the pioneer tree, *Gliricidia sepium*. This tree produces long, arching, feathery, leafy branches that provide good shade. The management regime requires the tree to be lopped every year or two so that the structure is one of a series of erect branches. Replacing *Gliricidia* with another leguminous shade tree, *Inga*, produces a change to the structure of the ecosystem. *Inga* produces spreading branches with large leaves. This tends to create a crown that affords more shade than *Gliricidia*. In trial plantings species of the forest-dwelling Lady Torrington's wood pigeon and the emerald-winged dove, were both recorded from the *Inga* which offers shelter among its leaves but would not use the smaller, lighter-leaved *Gliricidia*. While the structure of the canopy remained similar they differed in function, relative to the habitat re-

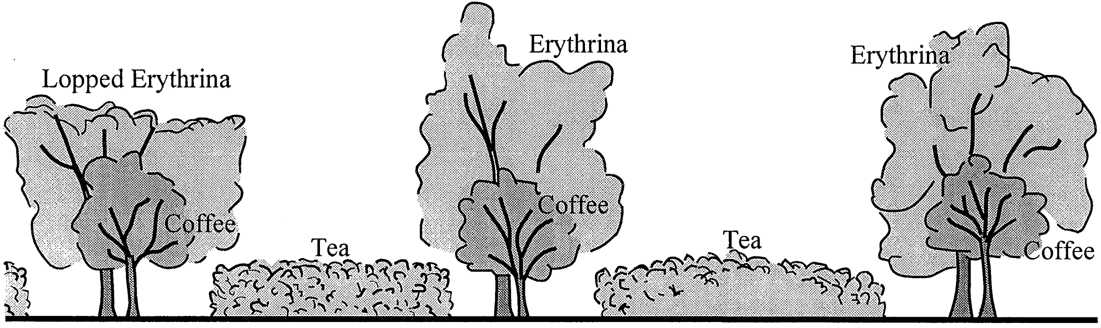


Figure 27: Profile of Erythrina *providing shade for coffee and tea*

Plate 3: Home garden in the tropics

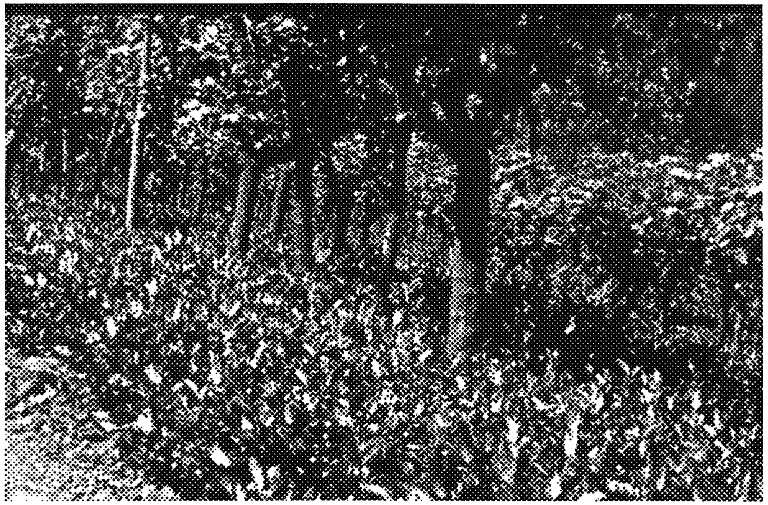


Plate 4: Mid-seral shade tree for tea

Plates 5a and b: Late-seral shade for tea, Upper view (a), Lower view (b) quirement of two bird species.

Hydrology

In terms of hydrology, old growth forests have been identified for the high quality of water that they yield; however if quantity of water is the goal, a watershed with short rotation patches may be better. In Victoria, grassland is capable of providing a greater water yield than growing forests (Bren *et al,* 1979). Some studies suggest that the total yield of water in streams from forested watersheds is lower than from other kinds of plant cover or even rural land use (Hamilton and King, 1983). This effect, if used in sequence with forests, can have great value in stabilising the hydraulic system of a watershed. Hamilton (1989) suggests that one eighth of a bio-fuel forest watershed maintained on an eight year rotation will yield more water than if there were no cutting. In more permanent types of forest a proportion of early-seral analogues can have a similar effect. Although short rotations will give an overall increase in the quantity of water yield, longer rotations will yield a better quality of water

Silviculture

Any of the silvicultural systems can be used to create a tree-dominated ecosystem as part of its design. Unfortunately the history of modern forestry has produced largely clearcutting and even-aged management systems (Robinson, 1988). This is a consequence of a very narrow set of selection criteria being assigned economic values. Such selectivity favours the industrial forestry approach and precludes consideration of other designs. It is also essential to maintain as many seral stages of a forest system as possible if biodiversity is to be conserved (Figure 28).

DESIGN TECHNIQUES

Establishment of Shade/Shelter

Shade and shelter are among the more traditional uses of trees. As discussed above, many crop plants are adapted to light shade conditions and require a canopy above. The plants selected for the shading function are usually legumes due to their ability to fix nitrogen. However non-leguminous timber species such as *Grevillea robusta* are also used as a multipurpose tree, where they function as a shade tree for about 43-50 years and then are felled for timber. Many species of trees used for shading also have the capacity for growing from large woody cuttings placed directly in the ground where they root, a feature that greatly reduces tree establishment time. Cuttings for field planting are taken at about 1.5 m in height and 2-3 cm in diameter and the leaves and side branches are removed. Next, the bark at the base of the cutting is scored and

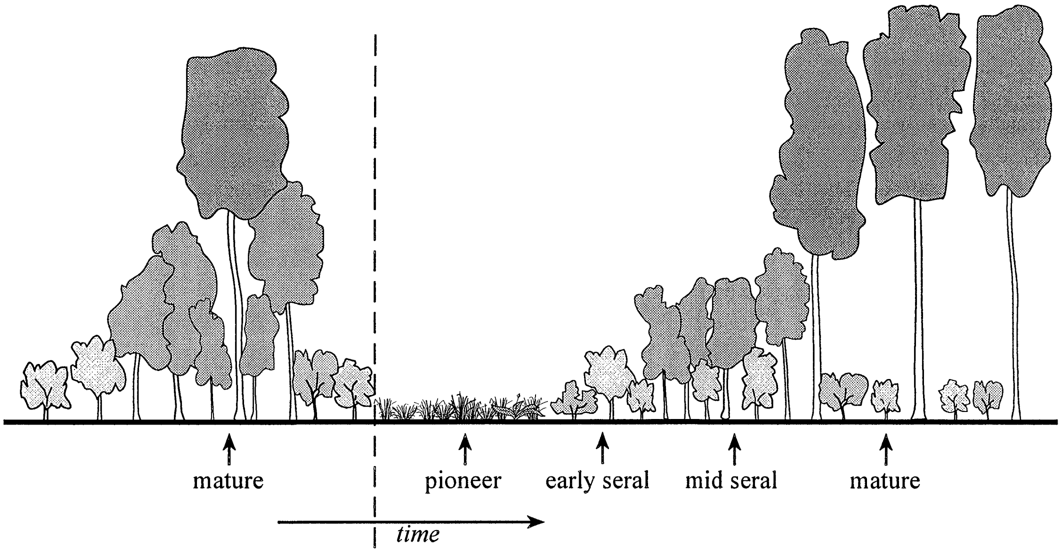


Figure 28: Analogue process as seen along a natural forest progression

rooting hormone applied if available. The cuttings are then planted out in the field with a piece of polythene or wax covering the upper cut so as to prevent infection and desiccation from affecting growth. Sometimes a weak solution of lime (calcium carbonate) is painted on the lower 2/3rds to dissuade sprouting at lower levels and protect against sunburn. Some of the trees that are suitable for planting in this manner are listed in (Table 14). During the wet season it is common practice to lop the branches of the shade trees. This has the effect of allowing more sunlight to reach the crop plants during times when the sunlight is reduced. The removal of shade and the consequent desiccating effect on the crop is useful in controlling fungal diseases that tend to proliferate in the wet weather. The loppings from the shade trees if left as a green mulch between the rows of the crop plants can provide nutrient to the crop; this effect is enhanced if the trees are nitrogen-fixing legumes (Halliday and Nakao, 1982). Shade trees can yield a considerable amount of biomass to the ecosystem if pruned regularly. In one measurement eight year old trees of *Erythrina poeppigiana* produced an annual output of 2-4 t/ha of fallen leaves and 12-18 t/ha of pruned biomass (Russo, 1983). One ton of *Erythrina lithosperma* loppings analysed for their nutrient status demonstrated a content of 54.91 kg/t nitrogen, 51.23 kg/t potassium as potash and 12.21 kg/t phosphorus as phosphoric acid.

In temperate zones, willow (*Salix spp*) and poplar (*Populus spp*) can be directly struck in the ground as cuttings of about 1 m in length. These trees grow fast and may compete with other crops for water, but they also provide good fodder for stock (Reid and Wilson, 1986).

In Australia the requirement for shelter is most commonly for livestock. Shelter is required as protection from cold, often exacerbated by rain and wind-chill on lands that have been cleared of much of the original tree vegetation and are open to high wind velocities. A prime cause of stock losses is due to wind-chill (Bird, 1981). In such situations the creation of effective wind barriers has been a strong design criteria. In addition, studies on the effect of wind velocity on crop yields also suggest benefits to be gained by shelterbelts that act as a wind baffle (Staple and Lehane, 1955). These needs produced designs that allowed permeability and utilised both tree and understorey species (Table 15) planted in four rows about 3 m apart (Campbell *et al*, 1989).

Contour Cropping

Working on the contour has been developed as a soil conservation technique in Asia (Watson, 1988) and a water conservation technique in Australia (Yeomans, 1968). Both techniques have been applied successfully. The contour cropping system begins by locating the contour lines across the land. Ideally the cropping spaces are at least 4-6 m wide. Once the contour lines are marked out they have to be ploughed or prepared for the planting of seeds. One or more rows of leguminous trees or perennials are planted along the contour, at a fairly close

Table 14: Some trees that can be established by planting large, woody cuttings

Species	Best Size of Cutting (cm)	Nitrogen Fixing	Fruit Fodder	Final Height (m)
Cassia spectabilis	100-150	Yes	No	20-25
Ceiba pentandra	100-125	No	Yes	15-20
Delonix regia	100-200	Yes	No	15-20
Erythrina lithosperma	30-100	Yes	Yes	15-20
Erythrina poeppigiana	30-100	Yes	Yes	25-30
Gliricidia sepium	30-100	Yes	Yes	15-20
Peltophorum ferrugineum	50-100	Yes	No	15-20
Pterocarpus indicus	100-150	Yes	No	25-30
Samanea saman	100-200	Yes	Yes	25-30
Spondias purpurea	50-150	No	Yes	10-15

Table 15: Species of trees used in creating shelterbelts in western Victoria

Overstory species	Understorey species
Eucalyptus camaldulensis	*Acacia pycnantha*
Eucalyptus viminalis	*Bursaria spinosa*
Eucalyptus ovata	*Leptospermum juniperinum*
Eucalyptus pauciflora	*Leptospermum laevigatum*
Allocasuarina verticilliata	*Leptospermum lanigerum*
Casuarina muelleriana	
Acacia melanoxylon	
Acacia mearnsii	
Melaleuca halmaturorum	

data from Campbell *et al,* 1989.

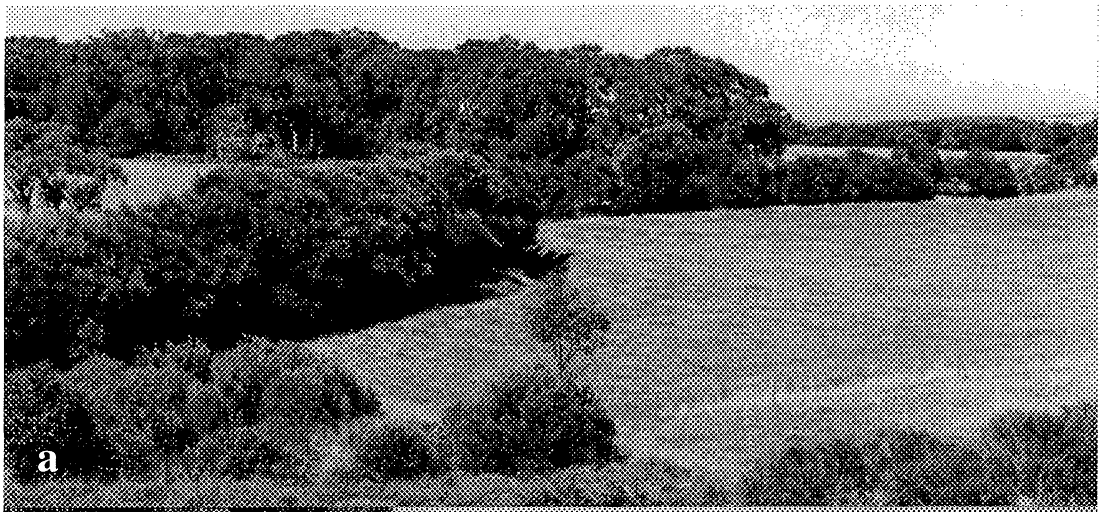
spacing of about 5-8 m apart. The plants used for this purpose have been *Leucaena leucocephala, Gliricidia sepium, Flemingia congesta, Desmodium spp.* The spaces between the nitrogen fixing trees are cropped with grass or annual crops. As the nitrogen-fixing trees are growing, the more permanent crops such as coffee, banana, citrus and papaw are planted along the contour. The system is then managed by lopping the nitrogen-fixing trees regularly. Loppings are used as mulch and the only trees allowed to gain height are the permanent crop plants. Finally the soil profile is extended by building green terraces (Plate 6). This technique, now known by such names as sloping area land technology (SALT), and biological erosion control (BEC), is used to stabilise erosion-prone hillsides through planting perennial crops along differentially-spaced contours (Watson, 1988). It can be used in conjunction with tree cropping systems to add environmental stability to an integrated production system. As the permanent crop plants are often tree crops, the inclusion of a range of ecological characteristics in the choice of tree species, can provide for a more robust application.

The use of land contours to obtain the optimum distribution of water is seen in many societies. A treatment that has been found very effective in Australia is the Keyline approach (Yeomans, 1968). Here water is collected in dams at the highest practical level and circulated around the land in channels with a very small fall. This radical development of the familiar farm dam also provides ideal opportunities for developing vegetation along the contour (Plate 7) and producing a more tree-influenced ecosystem.

Water

Water is one of the most important flow systems of the forest. Its influence is most easily seen in terms of landscape. Most of the gross features of the landscape have been wrought by wind or water; if poorly managed these can also create problems for production and stability. This can happen by erosion of soil, by flooding and by changing the groundwater equilibrium. The erosion of soil is an effect of raindrop impact and overland flow. Soils that are bare and unshaded, and soils that do not have intermediate vegetation or mulch protection, can be subject to rain drop displacement of soil particles. This often leads to erosion. Control of this type of erosion requires the establishment of some barrier between the falling drop and the surface of the soil so that the kinetic energy is absorbed by the barrier. In open, unshaded land the best protection is the establishment of a healthy ground cover of grasses or forbs. In shaded, or tree-dominated land, control is achieved by plants that provide one or more layers of canopy below the crown of the dominant trees and lower the erosive potential of the rain. These plants protect the soil/root zone from erosion by attenuating the kinetic energy of the falling water. The principal mechanism of control at the soil level is by building a deep cover of forest litter. This protects the soil from the erosive effect of raindrop splash. In addition, the litter layer:

Plate 6: Building a 'green' terrace on a steep slope using large cuttings



Plates 7a and b: Keyline with trees

Increases the resistance to the downhill flow of water and sediment
Intercepts a portion of the rainfall which reaches the forest floor; this will decrease the amount of water potentially available for infiltration and local runoff
Protects the openings of pores in the soil surface by acting as a filter to sediment flow
Increases the stability of the surface soil
(Ronan, 1986, p.20)

Different types of vegetation have different effects on the flow of water across a landscape. For instance, trees create more sub-surface flow than grasses. Different types of vegetation can be used for management needs. Trees with high evapotranspiration capacity are being identified for use in their function and position on that landscape to provide for better planned water conservation techniques. Some trees extend their root surface to become living mulch as seen in trees like fig (*Ficus elastica*) (Figure 29). Another strategy in high rainfall areas will be to use trees or plant communities with a high canopy interception value. As the interception rate increases there is a reduction in streamflow (Smith *et al*, 1974). Protection from surface flow erosion can be gained by using well-designed tree communities.

Trees often play an essential role in controlling hydrologic cycles. In Victoria, Australia the groundwater in many regions has high salt levels due to its geologic history (ACIL Australia Pty. Ltd., 1983). Vegetation growing on such lands needs to have a source of freshwater in order to survive. Also, the groundwater recharge must not be allowed to exceed runoff and evapotranspiration levels or water acquisition to the watertable will result in a rise in toxic groundwater levels. Tree communities on these lands were capable of using most of the rainfall and stopping it from reaching the water table. Some 100 years ago the advent of Western agriculture (Adamson and Fox, 1982), as well as a yearning for European cultural landscapes and their emulation of England's hedges, fruit trees and green and pleasant fields, led to the exclusion of almost everything Australian (Blainey, 1980). The native forests were cleared and replaced with farmland, analogous to early-seral stages of European ecosystems. These new ecosystems behave differently in ecological function and have different environmental effects from those of the replaced systems. In terms of the system's hydrology, recharge of groundwater has now increased greatly. The new ecosystems consist mostly of annual plants and cannot maintain the hydrologic balance maintained by the older tree-dominated ecosystems. The consequence has been a widespread increase in dryland salinity in many areas of Australia, a problem that affects over 45,000 ha of land in the State of Victoria. It has been accepted that control of the regional groundwater flow systems in terms of reducing the salty water table may take generations and in some cases be virtually unattainable (DWRV, 1986).

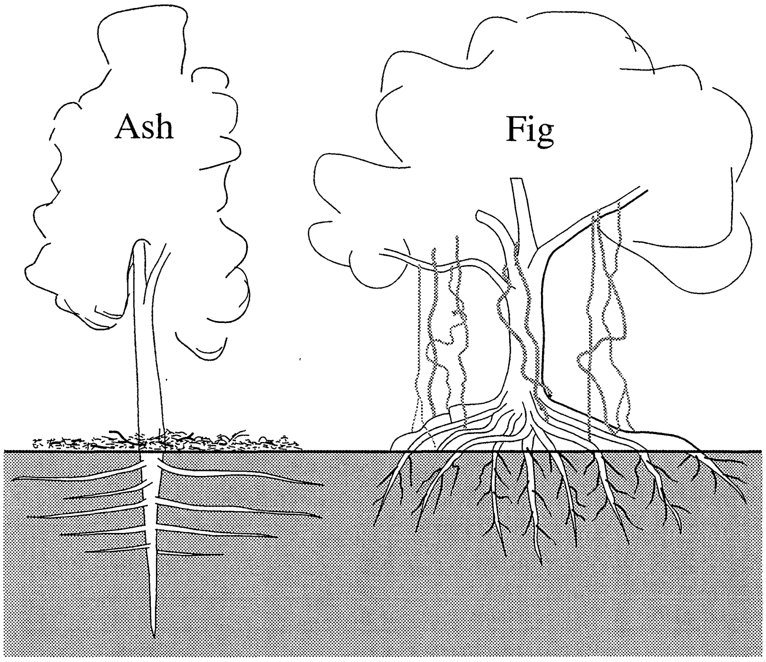


Figure 29: Living and dead mulch contributions

The response to this process of environmental degradation has been to plant trees in recharge areas, i.e. those parts of the landscape that contribute the greatest supplies to

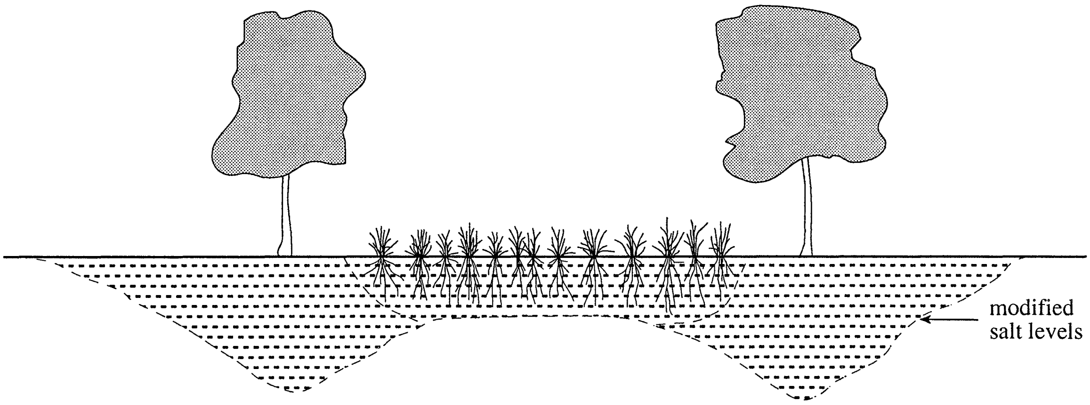


Figure 30: Use of salt tolerant Wheat Grass and River Red Gum to improve the quality of salt affected soils

ground water accession. Trees with a high transpiration capacity planted in recharge areas are being established to slow the rate of accession. In those regions that have already been affected by salt the response has been to grow back the land by using salt-tolerant species as early pioneers and build the soil as well as the effective rooting depth (Figure 30). Some experiments facilitated by the Potter Farmland Plan in the western district of Victoria, used grasses like tall wheat grass (*Agropyron elongatum*) and salt tolerant trees like the Lake Albacutya form of *Eucalyptus camaldulensis* have reversed the negative trend and illustrate the potential of designing effectively at a local scale.

In addition to the use of salt-tolerant species another useful landscape element may be the use of indicator tree species in unaffected areas. The best species for this function will be salt-sensitive species that have a deep rooting system. Another group of indicator species is the halophytes or salt plants. These begin to dominate in areas with rising salt and are good indicators of the presence of salt (Mathers and Brown, 1989). These are all shallow-rooted plants and respond to salt that is very near, or at the surface. In regions prone to dryland salting problems, the strategic planting of salt indicator tree species as a part of forest or landscape design, can enable future response to be better prioritised.

Flooding

Flooding, as a consequence of unusual rainfall events or disturbed hydrologic systems, such as the silting up of river channels, is a phenomenon that has an increasing degree of impact. The effect of flooding is exacerbated by rapidly expanding human populations living in close proximity to flood-prone regions. The situation of Bangladesh illustrates the problem succinctly. The country lies mostly in the delta formed by three rivers, the Ganges, Brahmaputra and Meghana. Only 7.5% of the total drainage area of these rivers lies within Bangladesh (Zaman, 1983). Deforestation and the resulting erosion in the upper watershed of these rivers, in countries beyond Bangladesh produces a sediment load of approximately 1.6 billion tons, that is deposited annually in the river channels and delta (Milliman and Meade, 1983). As a consequence of the silting of the river channels and coastal areas of the delta, storm surges created by cyclonic action can move water inland and cause flooding as far as 160 km from the sea (Bird and Schwartz, 1985). This study also indicates an average of 1.5 severe cyclonic storms affecting the area annually and reinforces the pattern of annual flooding. The death rate accompanying these events varies from 5,000-250,000 people, many deaths being caused by drowning and hunger. A contributory cause for deaths by drowning has been the inability to identify the areas with strong flow currents that represent the channels within the relatively homogenous surface of the flooded landscape.

The natural vegetation of these highly agricultural and flood-prone lands was originally fresh water mangroves. A tree-planting proposal that seeks to re-establish the natural character of the channels by planting species of timber, bamboo or palms along channel edges, will create a landscape that will identify areas of dangerous flow (Figure 31). Once the area is flooded such trees will mark the channel for navigational or other purposes (Lohani, 1989). The use of flood-resistant trees such as *Barringtonia insignis* that produce tree vegetable and *Sonneratia acida* that produces fruit will also be of utility in this design as these crops will be available even if the annual crops are destroyed by flood. This design is analogous to the riparian vegetation that existed at earlier times, but can provide a wider array of services.

Building soil

The condition of the soil ecosystem does have a bearing on the productivity and stability of the land. The diversity of species and trophic levels makes soil as complex an ecosystem as a forest. An effect at one trophic level will have consequences at other levels. Work on pathogenic organisms of forest trees demonstrates that application of a particular chemical can suppress beneficial bacteria that control plant pathogens and create increases of plant infections in the treated area. The application of another chemical can encourage the growth of beneficial bacteria which suppress pathogenic organisms and promote better plant growth in the treated area (Cerra *et al*, 1987). Further, the application of herbicides can have either an inhibitory or stimulatory effect on many soil organisms (Anderson, 1978) by changing the nature of the ecological relationships of these organisms. The critical nature of these inter-relationships has been shown by work done in Russia demonstrating that the feeding patterns and growth of soil-inhabiting saprophagous invertebrates depends on the activity of soil-micro-organisms, which in turn are stimulated by the activity of the soil-inhabiting saprophagous invertebrates (Ghilarov, 1963). These observations suggest that the soil ecosystem can be managed to produce greater volumes of organic matter over a relatively short period of time. Studies on pasture management in Australia and New Zealand suggest a high potential rate of growth. Jackman (1960) reported an increase in soil carbon from 4.6-20% in 22 years following pasture in Taupo (New Zealand) pumice soils. This represents a carbon accumulation rate of approximately 1100 kg/ha/y. In a similar study Barrow (1969) reported a gain of 440 kg/ha/y during a period of 30-40 years in Western Australia. Building up organic matter levels in land that was once forest is important because the loss of organic matter after breaking up a forest soil is usually high. When trees of a temperate, evergreen forest are cleared and the soil cultivated the organic matter decreases by about half during the first fifteen years (Attiwill and Leeper, 1987). This suggests that the development of tree crops may provide a doubling of the soil organic matter on land that was once forest. The growing of soil organic matter, is a relatively fast process under certain circumstances. Soil organic matter is mostly made up of bacterial biomass. In the tropical rainforest soils of Hainan Island, China, bacteria accounted for 75% of total biomass and bacterial biomass was closely co-related to total organic matter (Yang and Insam, 1991).

Multi-canopy cropping

Multi-canopy cropping has been a common characteristic in many traditional systems of forestry. It requires an intimate knowledge of the crop plants and their ecological requirements. An example of such a system is the home gardens of the Chagga people of Tanzania (von Clemm, 1963). The Chagga settled on the once forested foothills of Mount Kilimanjaro and began a process of transforming the native forest. They retained the original species that provided fodder, fuel or fruit and the less useful species were eliminated and replaced with new tree and crop species (Boonkird *et al*, 1984). This study found the spatial arrangement of components irregular and haphazard but the vertical components demonstrated several distinct zones. In terms of canopy depth the lowest zone (0-1 m) consisted of food crops like taro, beans and fodder herbs. The next zone (1-2.5 m) was comprised of coffee with medicinal plants; next up was the banana zone (5-20 m) which had banana and fuelwood and fodder species. Finally the upper canopy (15-30 m) contained timber and fuelwood species such as *Albizzia schimperiana* and *Olea welwitschii.* Similar patterns of planting have been recorded from Asia and South America.

An additional canopy can also be added to an existing system. The species chosen to contribute the next layer of vegetation can be assessed in terms

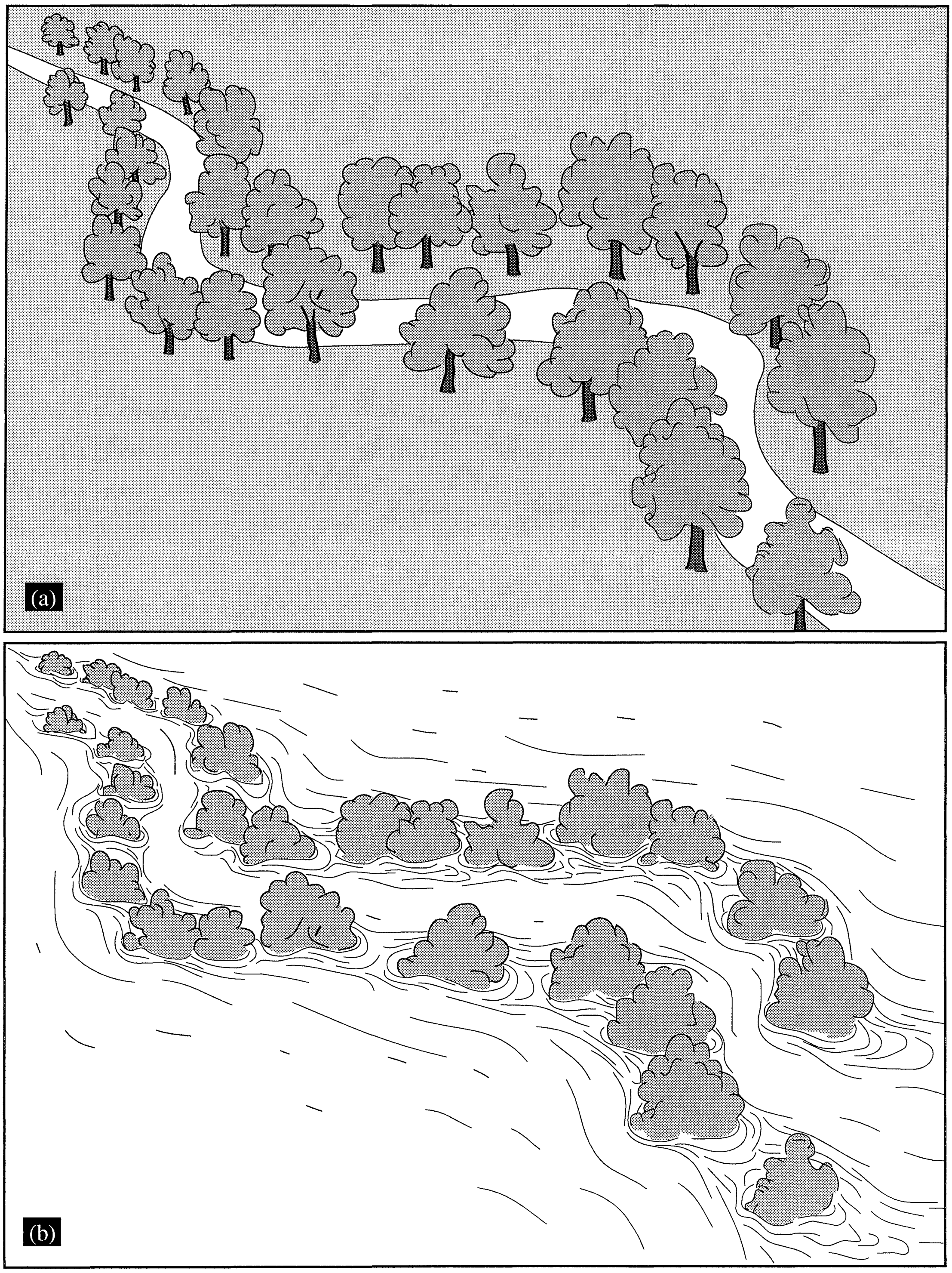


Figure 31: Plantings define channel boundaries in dry (a), in flood (b)

of its ability to provide for design goals. For example, the sisal plantations of Tanzania use the plant *Agave sisalana* for fibre extraction. The crop is grown in a winter rainfall/summer drought climate, but is grown as a monoculture. Nitrogen-fixing trees, that provide food or fodder interspersed throughout have been suggested by Sholto Douglas (1985). Trees such as carob (*Ceratonia siliqua*) or algaroba (*Prosopis spp*) will be capable of supporting dairy cattle and thus begin to add value and canopy depth to the production system.

Lianes and vines

In growing vines and lianes the adult morphology becomes an important feature to consider. A feature of many tropical forests is a profusion of vines and lianes. Some species are short-lived, the early-pioneer types living as an annuals, while others like the woody *Anodendron spp* live for over a hundred years. The vines of early seral stages like the winged-bean (*Psophocarpus tetragonolobus*) grow as rambling perennials and are easily trained onto fences or function as ground cover vines at the forest edge. Vines that need more shade, like passion fruit or yams, are longer-lived and can be cropped in early-seral stages. The shade-loving vines like *Vanilla spp* or *Coscinium fenestratum* are planted individually by the tree that it uses as support. Heavy woody lianes like *Salacia reticulata*, which bear edible fruit have to be planted together with the tree that it will be used as primary support to grow to best form. Woody climbers of the rattan group *Calamus spp*, on the other hand, can be planted at any stage of forest growth as they are effective climbers and reach stem lengths of 100-200 m. The vines that grow onto the trunk with the aid of roots are best planted after some growth of the trees has been achieved. Crops that grow in this manner include pepper (*Piper nigrum*) and monstera (*Monstera deliciosa*).

Epiphytes as crop

Epiphytes or plants that grow on the trunk and branches of trees are generally neglected as a group of plants for cropping and conservation potential. Many epiphytes are gathered from the wild for medicinal, cultural or ornamental purposes. Some, like the orchid genus *Cattelya* have been turned into monoculture crops in highly-controlled agricultural systems. Others, like epiphytic ferns of the genus *Nephrolepis*, are collected from oil palm (*Elaeis guineensis*) plantations in conditions analogous to the secondary forests and the early-seral stages that they occur in naturally. Both of these products enter the international florist market. In creating ecosystems that have a forest structure, large areas of trunk and branch substrate are available for the growing of epiphytes.

Some epiphytes with potential for cropping in this situation are orchids such as *Vanda spp, Cattleya spp, Phalaenopsis spp, Miltonia spp* and *Dendrobium spp*; many species within these genera provide flowers with a high demand on the international market. Ferns such as *Nephrolepis, Asplenium, Polypodium* or *Davallia* provide cut foliage for the international florists market. Cacti such as *Rhipsalis* are valued for medicine in traditional medical systems of Asia; this latter epiphyte is presently collected from the wild.

The establishment of epiphytes on tree trunks and branches creates a series of microhabitats around their growing roots, which then support colonies of lichens, mosses and bryophytes that would not establish on a tree without such formations. Epiphytes tend to mature these ecosystems and add to the species diversity.

Epiphytes can also function as indicator species. The differences between the communities of lichens and bryophytes on managed second-growth and unmanaged old-growth grand-fir forests in Montana, suggest that these epiphytes may be effective indicator species of forest history. Both lichen and bryophyte communities differ between the two stages of forest (Lesica *et al*, 1991, p.1745). The authors conclude 'our results suggest that many species of lichens and bryophytes find optimum habitat in old-growth forests and that these species will become less common as silvicultural practices continue to convert old growth to younger-aged forests'.

Simulation of old growth

Designing to simulate old-growth will involve long maturing species such as ebony (*Diospyros ebenum*) or walnut (*Juglans spp*) as the primary crop species and the inclusion of faster-growing species that create canopy and coarse woody debris. Another useful design element is to use a percentage of known epiphyte host plants among the faster growing species. For instance, in a planting of ebony, jak (*Artocarpus integrifolia*), and neem (*Azadirachta indica*) can function as co-dominants. Jak is a good epiphyte host, matures fast and is long lived. Neem is not a good epiphyte host, but produces a crop, has valuable timber, is long lived and grows well in the same zone as the other species. Here, the short-term crop species are jak producing fruit and vegetable output on an annual basis and neem producing an annual output of commodity seed. Both species of trees are productive for 40-50 years. Trees of this age begin to produce coarse woody debris and begin to support old growth epiphytes. In this planting ebony can attain a size that represents a valuable investment. The value increment in the ebony will also be enhanced by the annual crops of fruit, leaves and seed of the other two species.

General

In the development of a tree crop model that seeks to be analogous to the natural system as many as possible of the ecological features of the natural ecosystems of the local region should be utilised. Using indigenous species is of value, but native species may not provide economic crops, necessitating replacement with more valuable crop yielding exotic species. In addition environmental changes may have altered exposure levels unsuitable for the original vegetation and more hardy species may be needed temporarily to help return the environment to a condition closer to the original state. Responding to other ecological features may include the activity of more than one group of organisms. The pioneer organisms that first colonised coastal sand dunes in Queensland were found to be fungi. Many of the pioneer fungi were endomycorrhizal with the roots of the pioneer vegetation. These fungi appear important in plant colonisation of these dunes (Jehne and Thompson, 1981). This feature may be of importance in establishing vegetation on hostile environments. Thus, the inclusion of as many ecological variables as can be addressed is important to good design.

Applying the concepts of good design requires a good local database and a good delivery infrastructure for implementation. A 'farm forestry register' (Anon 1991b) was produced by the former department of Conservation Forests and Lands in Victoria, Australia for the 'small forest grower'. The register lists the names and addresses of the department personnel, plantation establishment contractors, plantation utilisation contractors, pulp mills, softwood sawmills, veneer mills, wood preservation plants, hardwood sawmills, seed collectors, nurseries specialising in local plants, public groups specialising in local plants, public groups specialising in conservation projects and farm tree groups, for every region within the state (see also Plant Databases Chapter Ten.)

Another important extension tool is the arboretum. A local arboretum, if well-designed becomes not only a seed source for local tree-planting work, but also a reference collection, an experimental station, a teaching tool and can provide the focus for a local park or recreational area.

CHAPTER TEN

DESIGN NEEDS FOR CONSERVATION

Forests of the future, among other objectives, need to be designed in terms of their conservation function. It is suggested that conservation goals can be pursued effectively and efficiently in many forest situations where a need is expressed and not only in specific conservation reserves. The present concern over the loss of global biodiversity translates to a loss of critical ecosystems in reality. Current forestry practices have generally ignored the need to consider the range of ecosystems that are negatively affected by their activity. Freshwater habitat is one such set of ecosystems (Maitland*et al*, 1990), old-growth forest is another (Franklin, 1988). However, good design can modify some of the negative ecological effects of monocultures. For instance, the creation of ponds in the forestry programs in Scotland demonstrates the conservation potential in increasing habitat diversity within a plantation forest (Jeffries, 1991). This design can be made more robust by extending the habitat diversity within the forest. In the development of a pond ecosystem the most important factor in influencing the population size of amphibians in ponds was not the age of the pond but its proximity to treecover (Laan and Verboom, 1990). Species of both age groups (larvae and adults) were positively correlated with the proximity of a wood.

In addition, the species of trees designed to provide conservation needs must be evaluated in terms of their effect on the seral or trophic structures. Studies in South Africa suggest that different tree species can provide very different habitat potential for smaller organisms. The grasshoppers (*Orthoptera*) are good indicator species for general grassland communities. Studies of grasshopper populations under two exotic genera, *Cupressus arizonica,* and *Pinus elliottii* and *Pinus roxburghii,* demonstrated that *Cupressus* increases species richness under its crown, but *Pinus* harbour only a very sparse population under their crowns (Samways and Moore, 1991). The grasshopper populations were affected by the presence of their favoured food plants, *Bidens pilosa* and *Tagetes minuta,* which grow well under *Cypress* but do not grow under *Pinus.* The ecological effects of trees functioning as a forest often extend far from the individual tree; studies on populations of the golden-ringed dragonfly, *Cordulegaster bolton,* demonstrate that it breeds in streams that flow in forested areas. However, while this species was abundant in deciduous woodland streams it was not encountered in streams draining conifer plantations (Ormerod*et al*, 1990).

The ecological processes of a forest include all the seral stages from pioneer to climax; therefore management under conservation forestry must address the conservation of all the species that represent a forest in that unit or large patch. Most management systems suggest a dynamic mosaic to conserve all the species of forest succession, either as random patches across a landscape, or as patches with a design component (Figure 32). The patch design is practical in terms of conservation as long as the patches are in a matrix of old-growth forest. However, if the entire area is subject to rotational felling, old-growth will become increasingly younger in age.

In an environment where the occurrence of old-growth has reached critically small dimensions the pie design would seem to be especially impor-

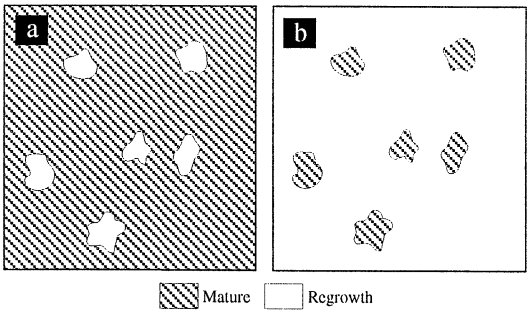


Figure 32: Conservation of all species of a forest succession may be achieved by a patch design in case (a), but a pie design is likely to be more effective in case (b)

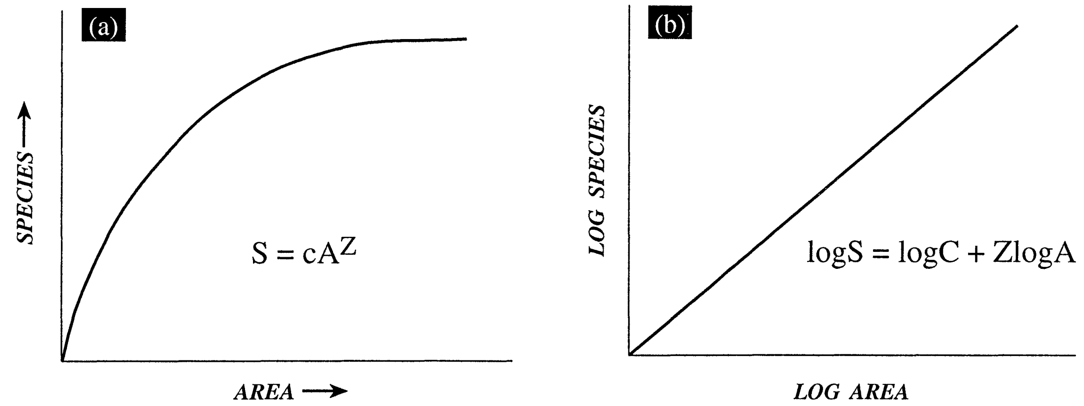


Figure 33: Increase in number of species occurring on progressively larger-sized sample plots or islands, graphed arithmetically (a) and logarithmetically (b)

tant as it extends the range of all the species. It also creates a larger patch, or island, and will tend to lose less species than the smaller, random patch. This consideration arises from the fact that every species requires a minimum size of habitat to maintain sustainable populations. This minimum size may be as a composite area or a connected series of patches or islands. Further, the number of viable species in a patch is also related to the size of that patch. The first study to draw attention to this originated from the study of the number of species on isolated mountain peaks (Grinell and Swarth, 1913, p.394). They observed 'that the more restricted as to association a form is in its distribution, the more liable it is to manifest the phenomenon of geographic variation'. This observation has been developed into the island biogeographic theory (McArthur and Wilson, 1967) which states that as the area of an island gets smaller so does the number of species it can support. The relationship is stated as:

$$S = cA^Z$$

Where S is the number of species, c a constant describing the number of species in a unit area of the island, A the area in question and z the slope that describes the population patterns of the area in question. For instance, in any homogenous community of plants and animals the average number of species sampled from a quadrat will increase as the quadrat size is increased. If the data are graphed arithmetically a curve describing the relationship of species to area results (Figure 33a). However, if graphed on a double logarithmic scale, the relationship is essentially linear (Figure 33b); this provides the value z. The value of z is important in designing for conservation because when variables appear as exponents, their values have dramatically powerful effects on the dependent variable (Harris, 1984). If, for instance, z takes the value 0.5, a four-fold increase in area is required to double the number of species. However, if z takes the value 0.14, the size of the area must be increased 140-fold to double the number of species (Figure 34). When using these considerations to determine areas it is important to determine if the population is a true, unconnected 'island', or part of a generally contiguous area. The size, shape and interconnectedness of forest patches are important considerations in species conservation.

While there is undoubtedly a relationship between area and species numbers subsequent research suggests that it is not as straightforward as the formula $S = cA^Z$ would indicate and each situation must be assessed with considerable care if errors are to be minimised (Zimmerman and Bierregard, 1986; Gilbert, 1980). Shaffer (1981) and Soulé (1986; 1993) have usefully drawn attention to the potential of such factors as demographic, environmental and genetic stochasticity and natural catastrophes to influence the viability of a species.

Any determination of the minimum viable population for a given situation must therefore in-

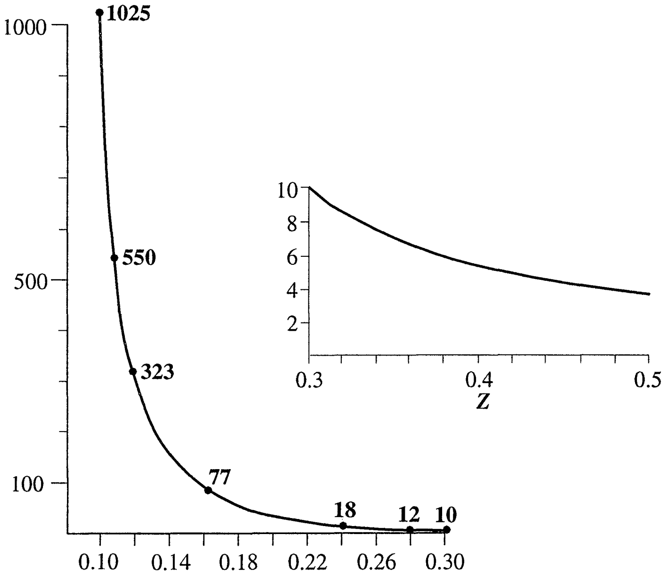


Figure 34: Relation between the value of exponent z in the species-area equation $S = cA^{z}$ and the increase in the area that would be necessary to double the number of species present

clude the external factors as well as the inherent/ internal factors, such as fire, flood and disease versus species genetic variability and population characteristics. Changes in any such factors can alter each of the others. Soulé and Kohm (1989) suggest that the interaction of environmental factors on a population's vital rates can be critical to that population's survival.

An important aspect of a patch in respect to conservation goals will be its size. As seen from the perspective of island biogeography theory, it is evident that the number of species that can occupy a patch is determined by its size. But this size may be gained by linking patches with corridors, islands and peninsulas (Figure 35). Ecologically, patches are distinct ecosystems within a relatively homogenous matrix or in terms of the physical landscape it is 'a non-linear surface area differing in appearance from its surroundings' (Foreman and Godron, 1986).

Silviculture creates such patches or islands in harvested areas. The original harvesting decision may have been based on size, age or the particular species of tree. The outcome of the decision, particularly in respect of the size and shape of the patches in the total matrix will greatly influence the conservation potential of the original decision. For instance the resultant patch may vary in size or shape; for shape generally an outcome closer to that of a circle is best. This arises from the fact that the interior-to-edge ratio is higher for a circle than for a square. The interior of the patch can maintain itself for greater decreases in area than a square (Figure 36). Interior species are not able to use patches below a certain minimum size or shape.

The connection of these habitat patches with corridors will reduce the populations' vulnerability to extinction. Small, isolated populations are particularly threatened with extinction due to ongoing deterministic factors and greater influence of stochastic processes (Shaffer, 1981). Indeed it is the stochasticity inherent in small populations (e.g. the chance that all offspring born in one season are male) that will ultimately lead to its extinction. Corridors can increase the effective size of the habitat patch and lessen the chance of local extinction (Soulé and Wilcox, 1980). The more analogous to the original, the more effective the corridor will be. Another possibility is to increase patch size by creating an outwardly-expanding zone of vegetation analogous to the original ecosystem.

A common response to the loss of treed landscape is the establishment of windbreaks and wildlife corridors. While such actions can make valuable additions to the total biota it could, by increasing the number of linear patches, increase the dominance of edge biota and thus threaten the stability of the larger system.

The structure of existing vegetation can be developed by enrichment plantings of species that provide more stability. It is useful in building a mature structure to incorporate tree species that have a long rotation time. Such species also provide for the needs of long-term carbon sequestering and high-value timber. Some long rotation species can also

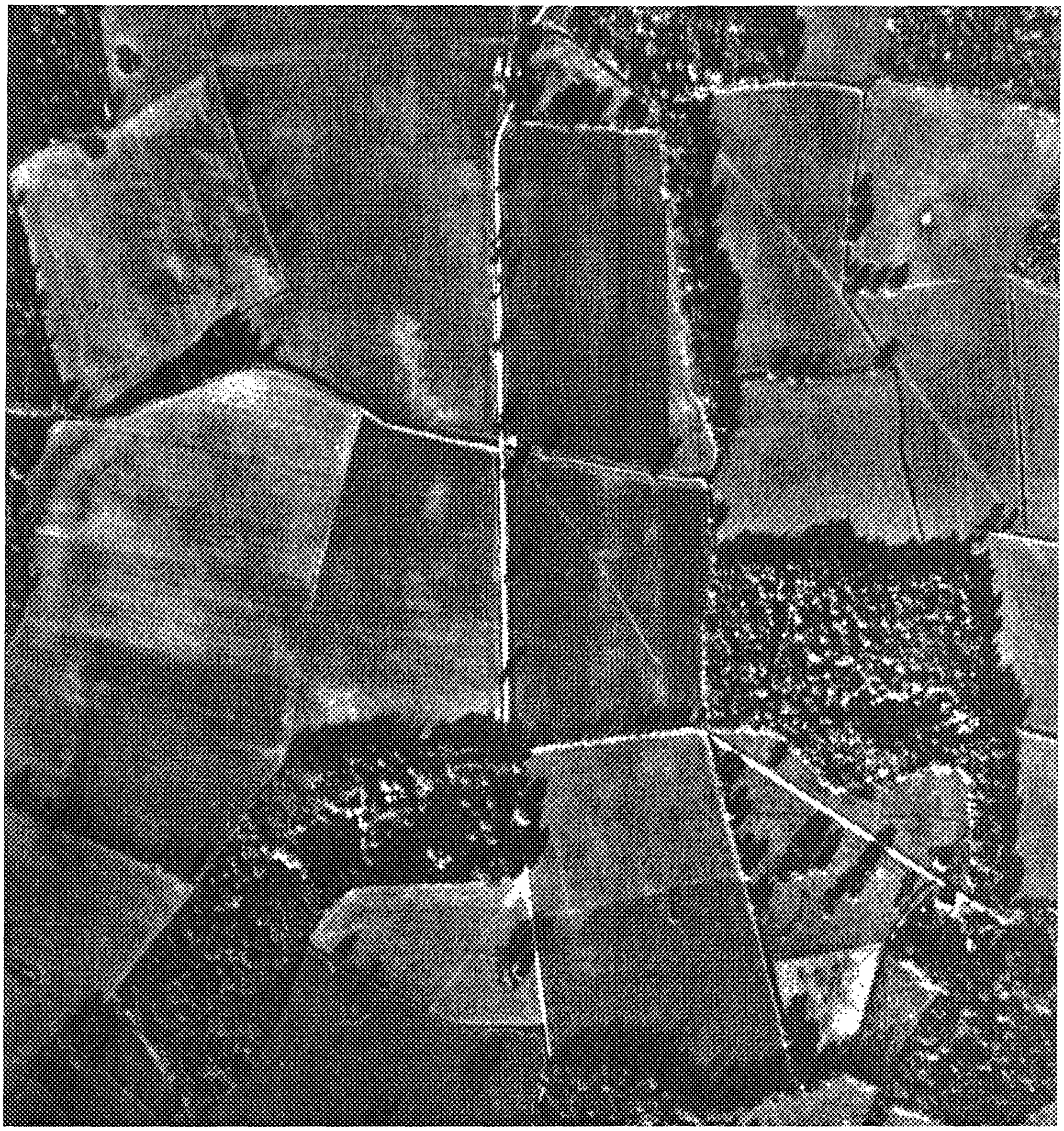


Figure 35: Patches, islands, peninsulas and corridors

help in the conservation of biodiversity by acting as keystone species. In terms of a species responding to these needs, satinwood provides an example. Satinwood (*Chloroxylon swietenia*), of the Indian sub-continent, is a sub-dominant, mature-seral stage tree species of the dry deciduous forests of southern India and Sri Lanka. It was felled in large quantities for its beautifully marked, high quality wood (Macmillan, 1962) and exported to Europe during the last three centuries. Because it requires a growing time of over 100 years to produce wood of good quality, no plantations have been established and it is still gathered from forests.

Long term rotations (>100 years) will bring into focus many 'new' species that can provide a wide range of forest services. In the case of the satinwood example, the integration into anthropogenic landscapes will be advantageous, as it will provide very valuable timber, sequester carbon into pools

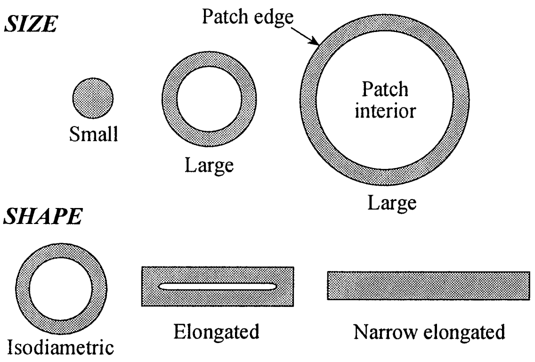


Figure 36: Interior and edge areas are affected by patch size and shape (after Forman and Godron, 1986)

with long residence times and extend the range of many species of animals for whom the tree is an essential keystone. Satinwood is the food plant for the juvenile stage of the butterfly *Papilio crino.* With the loss of the native forests and of satinwood the range of this beautiful butterfly is continuing to diminish. The incorporation of satinwood into forest design can effectively extend the range of this butterfly. Similar examination of species and community ecology can demonstrate many other ecological relationships.

Another area for examination is the value of traditional knowledge and management systems in providing design criteria for conservation and development. The planting of mee (*Madhuca longifolia*) was a part of the traditional management procedure in many Sri Lankan rice fields (Goldsmith, 1982). These trees were planted at a density of approximately 8/ha. The tree has a good timber that can be used as sawlog. It provides fleshy, edible, sweet flowers that can be dried like raisins. The seeds yield an oil that is edible. The oil is used for cooking and for medicine and the oil cake is a valuable source of plant nutrient. It is also a very important food tree for fruit bats (*Pteropus spp*) whose visitations to the trees means addition of nitrogenous fertiliser to the farmer's fields (Ulliuwishewa, 1991). This design (Figure 37) is similar to the many levels of function provided by other features of this landscape.

The buffalo wallow (Plate 8) functions as the drought refugia for the aquatic species that use the rice field ecosystem (Senanayake, 1983). In such ecosystems, where there has been a long history of co-evolution, the traditional practices will tend to reinforce ecosystem stability as local ecological information is embodied into cultural practices.

The emerging processes of restoration ecology (Lopez, 1991) also provide good models and

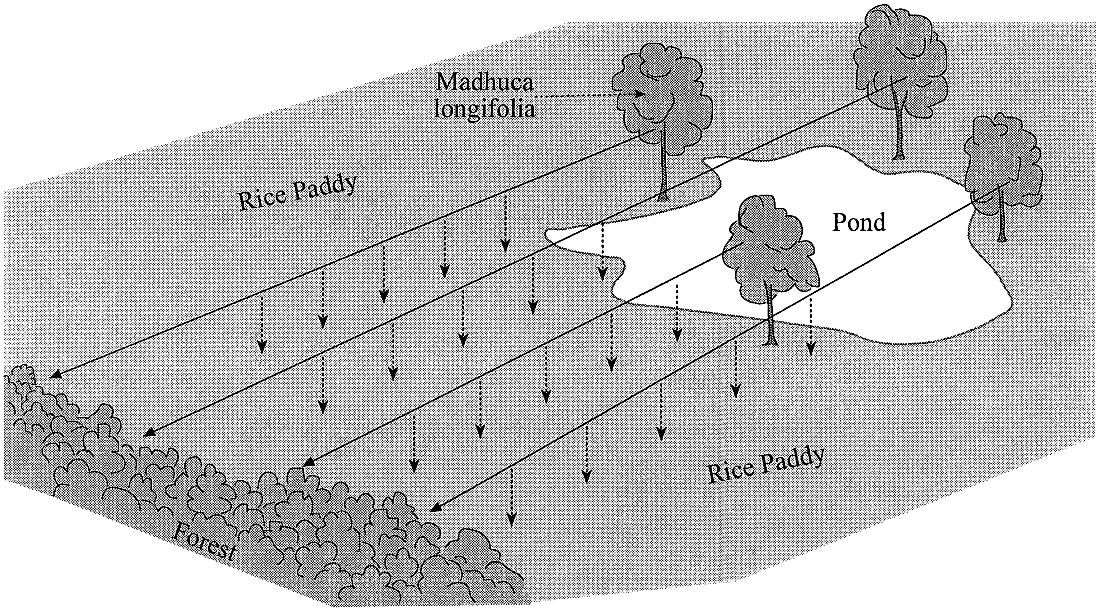


Figure 37: Traditional plantings of* Madhuca longifolia *at approximately 8/ha of rice paddy attract bats that add nitrogen to the paddy

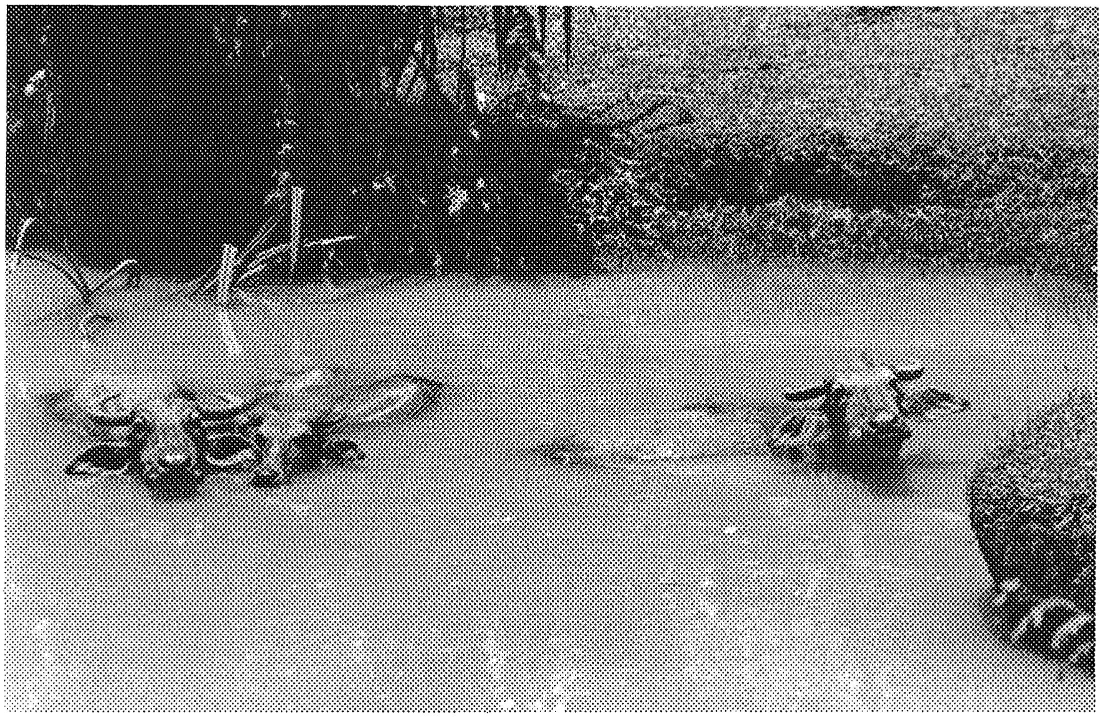


Plate 8: Buffalo wallow functions as drought refugia

design techniques. Current experience with restoring nature, suggests that many species can be sustained or even rescued from extinction by applied management and revegetation. The example of a very successful revegetation program to create habitat for the cahow or Bermuda petrel, a bird brought back from the brink of extinction, employed exotic pioneer vegetation to mature the ecosystem for the re-establishment of essential native forest plants (Wingate, 1991). Another restoration project on an old limestone quarry in Kenya used the pioneer tree species, *Conocarpus spp* with a legume *Prosopis spp,* to establish shade and provide biomass. This has created habitat for a wide array of native wildlife (Myers, 1991). Restoration ecology will soon provide many techniques of microhabitat reconstruction, techniques that can be used in the designing of a multi-purpose forest. Manuals for local areas like *Landscaping for Wildlife* (Henderson, 1981) are beginning to provide local databases and models. Such databases are invaluable to good design as they allow the comparative analysis of a range of species. The Environmental Management Unit at Monash University is developing a database of global relevance.

CHAPTER ELEVEN

ANALOGUE FORESTRY, APPLICATION

GOALS

The forest, as designed, must produce goods and services that are needed locally and then beyond. The final economic output of the forest will involve the use of a large part of the vegetation to provide products for the present market as well as providing products for future markets. To a large degree the single-species product and whole-forest product differentiate these markets. The single-species product may be timber, leaf, flower or seed, while a whole forest product is water yield, carbon sequestering potential, biodiversity conservation and the like. Some of these products, like water, have a currently realised value. Others like carbon sequestering potentially await evaluation.

To understand the design required for goods and services needed locally a good knowledge of the local species associations and cultural uses has to be gained. This information identifies the currently available local species in terms of crop and performance. The crop values of these species are ranked with other species that are analogous to, but new, or exotic, to that area.

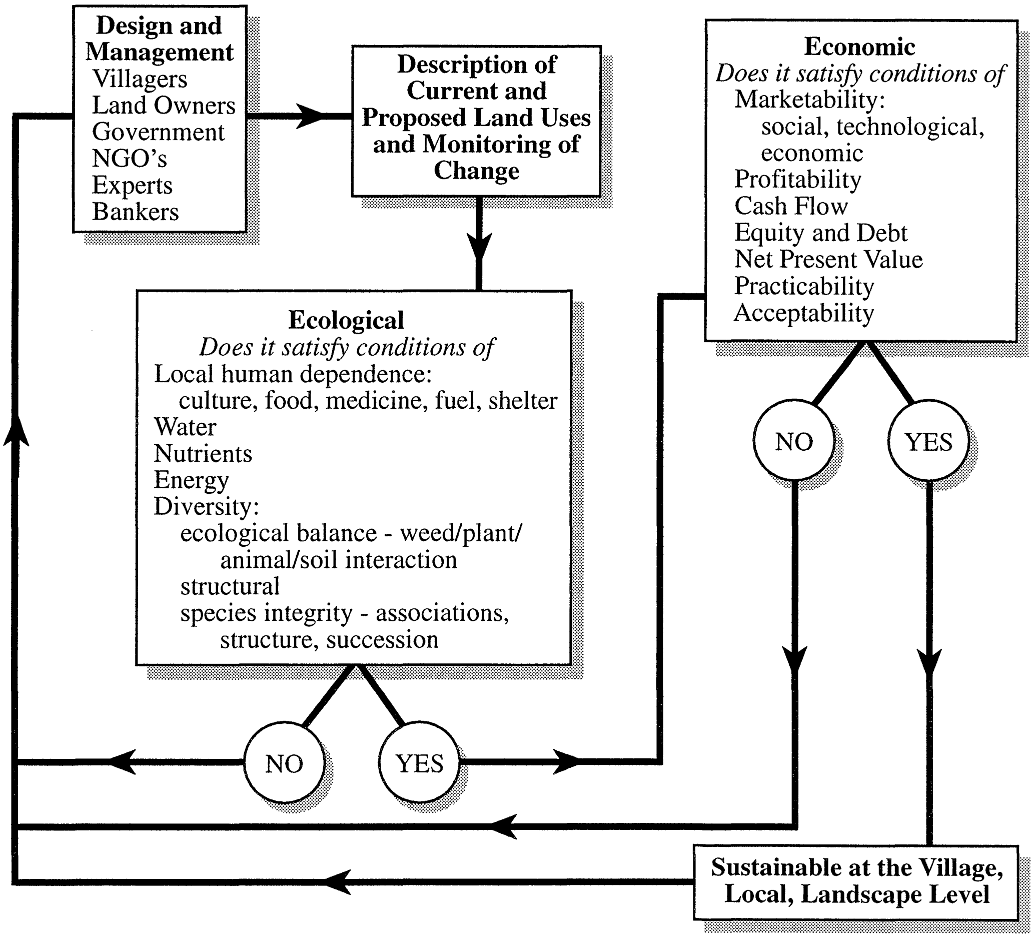


Figure 38: A holistic decision model (after Lefroy and Hobbs, 1992)

Those involved in establishing, managing, harvesting and financing the proposed analogue forest unit(s) need to be involved in consultation on the goals, design and operation. One suitable process of consultation for setting goals and selecting the system and species is illustrated in Figure 38.

DESIGN CONSIDERATIONS

Land

If the land that is being developed is degraded and treeless, the first question is: what is, or was, the natural vegetation of the site? This question may be answered by observing a forest or remnant patch of native vegetation. It may often be the case that there are no examples of native vegetation to provide a model. In such cases an idea of the natural vegetation has to be gleaned from other sources such as early occupiers, books, paintings, and pollen records.

Once the type of mature ecosystem has been identified, planting to achieve this end is designed. If the land is in an open, treeless state the first address is landform. Are the contours of the land conducive to erosive forces? If so, that becomes a primary need to be tackled through the use of any of the various contour management technologies. The other fundamental question is: what is the condition of the soil? What kind of soil ecosystem can be identified? If the soil is rich and deep the establishment of a mature forest system can be proceeded to quickly with the first plantings of mid-sere species for shade. If the soil is thin and poor, a planting of pioneer species that will build an active soil as well as establishing a canopy needs to be instituted.

Former Vegetation and Management

Human-managed ecosystems attain stability through age. One of the oldest plant communities to be facilitated by the use of fire as a management tool is seen in the sclerophyll woodland of Australia. The process has evolved over 40,000 years to produce distinctive ecosystems. The incidence of greatest fire activity and consequently the assertion of sclerophyll woodland is seen to be contemporaneous with the arrival of humans and has been attributed to human actions (Singh *et al*, 1980, Kershaw, 1986). Although climate remained the major determinant of vegetation distribution or change (Clark, 1983), Aboriginal land use particularly burning, affected the rate of change by reinforcing or opposing the climatically determined direction of change (McPhail, 1980). Thus, human activity has been identified as an agent in determining the vegetation complex for many thousands of years so that many landscapes encountered by the first Europeans were already 'cultural' landscapes (Clark, 1990).

Another stable ecosystem is the pasture land of England, a cultural feature of the European landscape. The plants that comprise these pastures are found as naturally-occurring plants in the forests. The development of grazing land favoured these species. The pressure of management selected for certain suites of species. Different species respond to different levels of management more than to natural features such as the soil or weather (Davis, 1945). Other human-modified ecosystems of antiquity demonstrate similar features of ecological stability (Senanayake, 1983). Such traditional responses demonstrate ecosystems with complex trophic webs and a large percentage of utility species in the vegetation.

The mature ecosystems of an area may not be dominated by tall trees. The banksia scrub of Western Australia or the mallee of South Australia are examples; both form the upper canopy at about 2-8 m high (Parsons, 1981). In such situations the development of a forest similar in form is more appropriate to the local ecosystem than the development of a tall forest. The development of a tall tree-dominated structure must be critically examined in environments of low rainfall. Studies conducted in South Africa (Malherbe, 1968), Kenya (Pereira and Horsegood, 1962) and India (Samraj *et al*, 1977) confirmed the loss of water yield arising from the introduction of tall-tree vegetation. This has led to restrictions on tree planting programs in South Africa and Swaziland (Evans, 1984). However, as the South African study demonstrates, it is the native Fynbos shrubland that is most stable and yields a higher volume of water, suggesting that plantings analogous to this structure may be better suited to the region than exotic plantations of tall trees.

In situations where the natural vegetation previously consisted of tall trees, rapid re-establishment processes for an analogous system will depend greatly on the number and types of trees that still exist in the area. If the vegetation has been degraded planting can proceed in a series of enrichment plantings by planting early-seral stage species and adding late- seral stage species as the ecosystem matures. On the other hand, if the land in question already has a good representation of trees and soil, mid- and late-seral species can be used. This approach has a large application in rural areas of many developing countries. In many of these situations, the tree cover is sparse and diminishing, but does still exist. These trends can be reversed by the application of analogue forestry as a technique for building back the structure and percentage of tree cover. Such moves can greatly improve the quality and stability of the rural environment.

Meeting the Goals

The forest as designed can have characteristics of the mature forest in regard to its provision of water, biodiversity etc, independent of other economic products. The characteristics of a mature forest and the value of its economic products are often co-related, as seen in the increase in the value of quality timber or quality water with forest age, but such value is frequently extended only to a few such products. The process of forest succession has been discussed. Indicator states such as early-seral or late-seral provide well-identified characteristics. In addition, indicator species that are confined to the late-seral stages can act as indicators of system maturity.

A consideration when choosing a suite of species is their ecological compatibility with one another and the environment. Different species of vegetation have different effects on the performance of other species in their proximity. The effects may be beneficial or detrimental to the other species. For instance, an aggressive vine may choke a slow-growing tree with rough permanent bark, but cannot grow on trees with smooth trunks. Such considerations require the placement of the species chosen in a pattern that optimises the interactive responses of various species of plants.

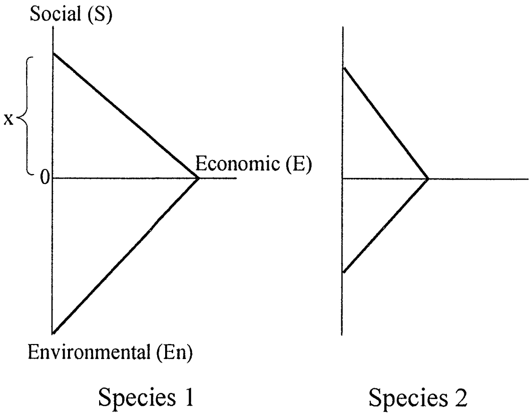


Figure 39: An area plot of SEEn values; compare species 1 and 2

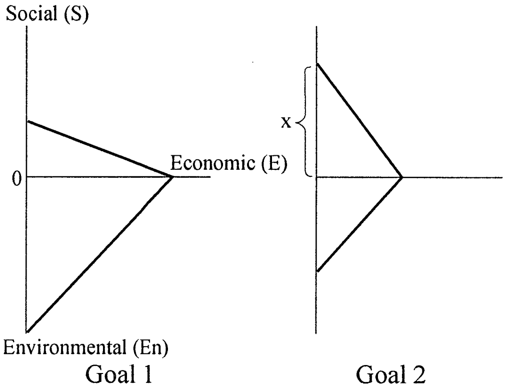


Figure 40: An area plot of SEEn values; compare goals 1 and 2

To facilitate the selection of species a SEEn plot can be generated. This plot is a field representing three variables, social value (S), economic value (E) and environmental value (En). Each variable is given a relative ranking from 1-10 (Figure 39), and plotted on three axes. The evaluation of the potential species can be performed rapidly by superimposing a frame depicting project goals (Figure 40). The frame will be a volume within the SEEn plot. All the species occurring within the frame will be species with high potential for use in Analogue Forestry. We see that for Goal 2 of Figure 40 both the species selected in Figure 38 will not only produce economic goods but will also have social and ecological value. This approach will also allow the

Table 16: SEEn values for a range of species

	Values			Sum
Species	**Social**	**Economic**	**Ecological**	
Acacia leucocephala	4	4	4	12
Acacia nilotica	6	6	5	17
Acacia planifrons	5	4	4	13
Albizzia lebbek	3	6	5	14
Artocarpus heterophylla	5	6	4	15
Azadirachta indica	7	6	5	18
Bassia latifolia	7	7	6	20
Borassus flaballifer	9	9	5	23
Ceiba pentadara	5	6	4	15
Delonix elata	5	4	4	13
Ficus benghalensis	9	3	7	19
Mangifera indica	8	8	6	22
Prosopis juliflora	6	5	6	17
Santalum album	7	7	6	20
Sesbania grandiflora	5	5	5	15
Tamarindus indica	7	8	6	21

identification of species best suited to respond to local needs. The analysis of trees in the farm landscape in Tamil Nadu State in south India (Jambulingam and Fernandes, 1986) suggests about 30 species have dominant representation within the village environment. Fifteen of these species were evaluated for their SEEn value to provide an example of the evaluation process (Table 16). When these values are plotted out the relative differences become clearer.

As the advantage or disadvantage of each species in regard to maintaining some forest stage becomes manifest it must be responded to in terms of management. For instance, the tree *Inga edulis* is a new species of tree to Sri Lanka. When it was used the criterion of choice was its ability to shade, fix nitrogen and provide fruit. At flowering, the tree was found to be an efficient ecological keystone species for a large bird community. On maturity it provides habitat for a rare bird. All these factors were previously unknown but can now be used when evaluating the potential of tree species for future design. Observation of all aspects of tree species is essential to the successful design and implementation of an analogue forest.

CASE HISTORIES

The following case histories identify a range of considerations undertaken at each of the two chosen locations. They are not intended to be comprehensive either in respect of ecological or economic issues. Such studies will be detailed in other publications.

Sri Lanka

The montane forests of Sri Lanka had an undisturbed cover of natural vegetation until the advent of British colonial expansion around 1700-1800 when forests were felled for timber. Before 1800 the export plantation industry was in its infancy with small monocultures of cinnamon being grown for the East India trade. The large-scale felling of forests began after 1820 when all land without title was deemed ‘crown land’ and sold to commercial interests. The ‘coffee boom’ of 1835 brought a rush for land that was only equalled by the rush for land during the gold discoveries in North America (Tennent, 1856). The intensity of this activity in Sri Lanka is reflected in the government land sale figures which show that over 117,360 ha of montane forest were sold for coffee-growing in less than 10 years.

The early colonial landscapes saw the creation of new ecosystems, 'agro-ecosystems', that usually had exotic organisms as the dominant species. They contained large areas of monoculture, first coffee, then tea, rubber and coconut. These ecosystems replaced the more diverse indigenous forms. Coffee and tea replaced montane forests, rubber replaced lowland rainforest and coconut replaced lowland rainforest and evergreen forest. A further problem with these crops was the fact that large quantities of firewood were required in processing for export. The source of firewood was from the forest ecosystems.

This period saw a reduction of indigenous landscapes not only as a consequence of forest clearing, but also as a consequence of timber and firewood extraction. Much of the agricultural endeavour at this time did not pay any heed to good management practices. Thus large areas began to lose topsoil, became impoverished and were abandoned to become grasslands maintained by burning. Indigenous landscapes were transformed, the new landscape contained far less natural forest with a high representation of grasslands (Senanayake, in press). Revegetation programs have concentrated on the establishment of *Eucalyptus* monocultures. These forests have been designed as industrial forests with no attention to non-timber cropping or biodiversity. The comparative biodiversity as measured by the avifauna and soil invertebrate fauna suggest that these plantations have low biodiversity value (Senanayake, 1987b). These studies have also confirmed that the traditional pattern of tree planting, as seen in the village provided the greatest amount of biodiversity when the three major anthropogenic land uses were compared. As a consequence of this study an experiment was instituted to develop a silvicultural response based on the village model, but answering to a greater range of economic and ecological needs.

An experiment was designed and termed 'Analog Forestry' (Senanayake, 1987b) and presented to the Department of Forestry in Sri Lanka in 1980. Unfortunately this period was marked by international funding for even-aged monoculture plantations and no official support was obtained. Thus, a privately-funded experiment was instituted by the Neo Synthesis Research Centre (NSRC) to examine the process of establishing an analogue forest. The analogue forest created was analogous in structure and function to the forests that were once prevalent in the Uva valley of Sri Lanka.

The Uva valley is situated in the central mountains and contains a large percentage of old tea and coffee land now degraded into grassland dominated by *Imperata*. The control of *Imperata* is difficult due to its extensive network of underground rhizomes. However, observation of the village gardens in the vicinity indicated that this grass was absent from well-shaded properties. Further inquiry in the area confirmed that *Imperata*, which is a pioneer species loses viability and cannot maintain itself under shade. Thus the first consideration in controlling the grass was to develop a canopy that would allow control of *Imperata*. The development of small trees within the grasslands, a feature of the natural seral process was arrested due to the propensity of the grassland to be burnt annually or bi-annually. Control of fire and the quick establishment of shade became primary considerations.

As the first planting required species that could grow quickly, the village areas surrounding the experimental plot were examined to determine which of the locally-used species performed well in this function. Four possible species were identified (Table 17). These plants were then analysed as to the performance ability of eleven variables that recorded growth characteristics and ecological function. The species chosen as a result of this analysis was *Erythrina lithosperma.*

Once the shade tree species was established the potential crops that could be grown under this species were considered. The only perennial crop that was widely grown in this area was tea (*Camellia sinensis*). Thus the first plants set out were seedling tea at 1 m and 1.5 m stakes of *Erythrina lithosperma.* In 1980 the *Erythrina* were planted out at a distance of about 12 x 12 m (±2 m) and tea planted out at a spacing of 2.5 m on the cleared *Imperata* grassland. In two years the *Erythrina* had established medium shade over the tea. In the normal maintenance of tea plantations the branches of the shade trees are lopped each year to maintain a

Table 17: Analysis of potential performance according to growth characteristics and ecological function

Characteristic	***Erythrina lithosperma***	***Gliricidia sepium***	***Grevillea robusta***	***Cassia spectabilis***
Fast canopy establishment	yes	yes	no	yes
Dense canopy potential	yes	no	no	yes
Biological nitrogen fixation	yes	yes	no	yes
Litterfall mulches and builds soil	yes	yes	yes	yes
Flowers nectar source	yes	yes	yes	no
Fruits/seeds eaten by native spp	yes	yes	no	no
Leaves good fodder	yes	yes	no	no
Trunk suitable for climbers	yes	yes	yes	no
Potential for large lateral roots	yes	yes	yes	yes
Fuelwood potential	yes	yes	yes	yes
Establishment from cuttings	yes	yes	no	yes

light shade. However, in this experiment the *Erythrina* were not maintained as pruned shade trees but allowed to grow into large shade trees. This tree was found to be ideal to establish the first canopy. It was fast-growing, could grow in poor soils, had nitrogen-fixing ability, foliage that was good as fodder, and a flowering and fruiting habit that provided food to the native biota and acted as a keystone species. Within five years the *Erythrina* had established canopy at 8 m that provided microhabitat for species specialised for life in a closed canopy forest.

Thus, in 1986 *Elettaria cardamomum* was planted at a spacing of 2 m and *Coffea arabica* was planted at a spacing of 2.5 m along the contours and *Monstera deliciosa* was planted at the base of the *Erythrina* trees. It is also useful to note that this planting was the first commercial crop of cardamom grown in the area, as the region had been considered too hostile for the crop before. This early stage consisted of two layers of vegetation (Figure 41).

Subsequent plantings followed in 1987 and 1990. In addition to the original species new plants were added to enhance the final canopy structure: durian (*Durio zibethinus*) as an emergent, jak (*Artocarpus integrifolia*), champak (*Michelia champaca*), candle nut (*Aleurites moluccana*) as co-dominants forming the canopy and fish tail palm (*Caryota urens*) and clove (*Eugenia caryo-phyllata*) as sub-dominants. The environment so created will allow plants such as *Elettaria cardamomum*), vanilla (*Vanilla planifolia*) and pepper (*Piper nigrum*) to be grown as intensively managed crops. The trees used in this design can provide most of the basic essentials needed for human nutrition in addition to energy and economic potential (Table 18).

The plants have established well and have created soil and microhabitat conditions that promote

Table 18 Anthropocentric utility function

Species	**Crop**	**Use**	**Economic potential**
Aleurites	seed	food/energy	domestic
*Artocarpus**	fruit/leaves/seed	food/medicine	market/domestic
Caryota	sap/sugar	food	market/domestic
*Michelia**	flowers	perfume	market
*Durio**	fruit	food	market/domestic
Eugenia	flower buds	spice	market

* good quality timber

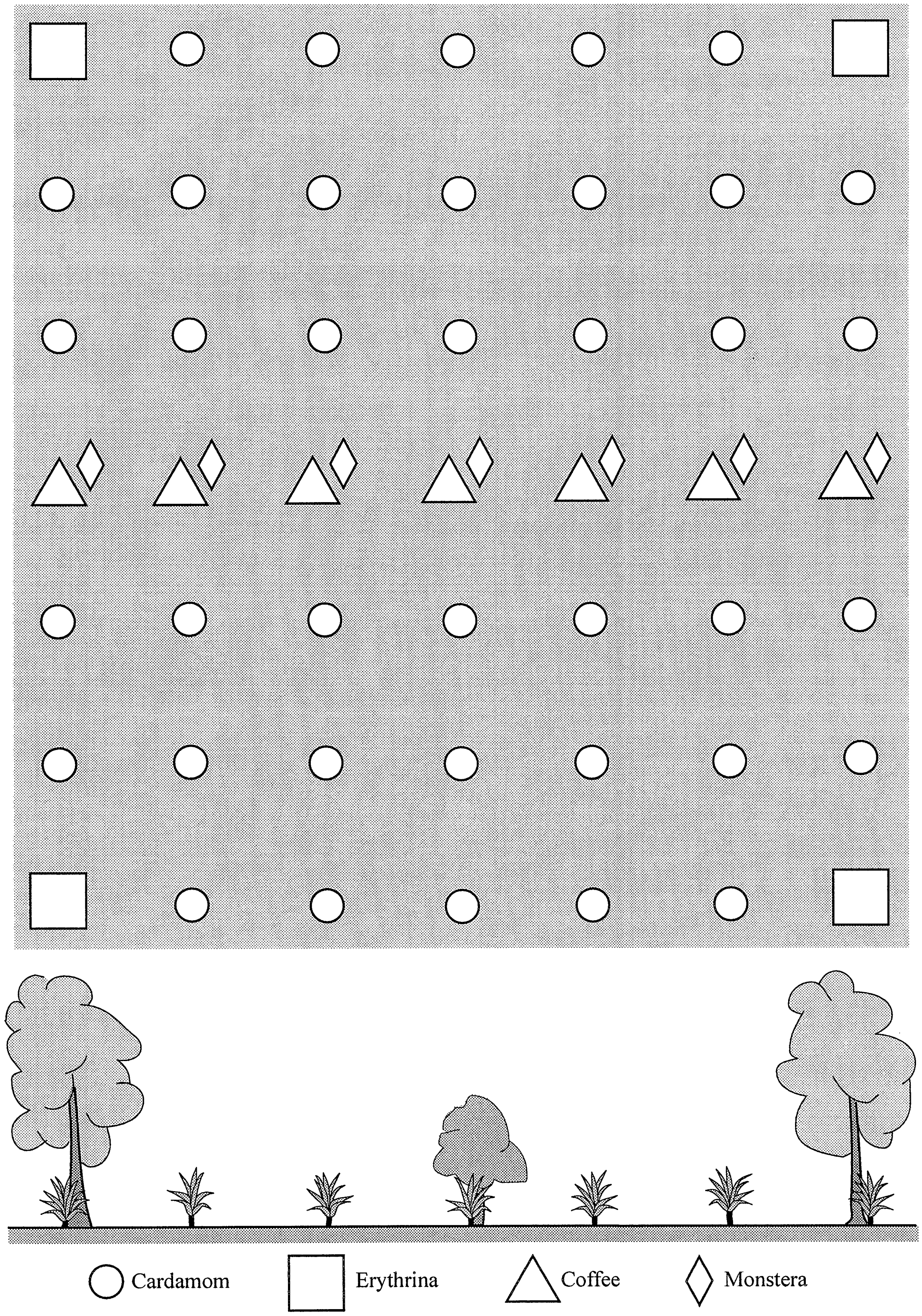


Figure 41: Layout arrangements for **Erythrina** *and associated species with coffee*

Table 19: Species of volunteer tree species recorded in 1991 at the Belipola experiment (Source NSRC)

Species
Allophyllum cobbe
Caryota urens
Ligustrum walkeri
Litsea ovalifolia
Mallotus philippensis
Michelia champaca
Neolitsea involucrata
Phyllanthus spp

the establishment of 'volunteer' early-seral trees of the local forests (Table 19). The soil has acquired a layer of organic matter and is under a constant mulch of *Erythrina* leaves. Many organisms not found in the surrounding grassland or agricultural environments have now been recorded from this forest.

An ecosystem was sought that was analogous to the native system. Such a system should support a population of forest species and could be made more diverse by adding analogues of microhabitat that were absent in the newly planted forest.

In examining examples of local forest a significant physiognomic feature that was missing was the vines. *Raphidophora spp* grows as a climbing vine in the local forest. It does not have any recognised economic use, so it was substituted for by *Monstera deliciosa,* very close in form and growth habit but capable of producing marketable fruit.

The other physiognomic feature that was lacking in the new planting was epiphytes. The local forests support a diverse growth of epiphytic lichens, orchids and ferns. Trials on three species, suggest that jak fruit (*Artocarpus integrifolia*) and avocado (*Persea americana*) were the best host plants for the species of orchids tried; while *Erythrina lithosperma* as the mid-seral selection was a poor host plant. The orchids were chosen on the basis of commerce (*Cattelya aurantiaca*) and on the basis of conservation *(Dendrobium macarthiae*). The trials also demonstrated that orchid roots created microhabitat on the bark that allowed other epiphytes to colonise (Plate 9).

Many aspects of the forest ecosystem can be reproduced within the anthropogenic ecosystem. For instance rot holes have been demonstrated to be a common phenomenon in most forests of the world. In many instances these formations were seen to harbour a biota that had evolved to occupy this niche. An experiment performed at the NSRC in Sri Lanka looked at the potential of using epiphytic bromeliads as analogues of tree rot-holes. Most fast-growing tree species that are used to establish shade are smooth-barked and have not aged sufficiently to have surfaces in which rot holes can form. Forests established with these species display a singular lack of epiphytes and rot holes. As the trees at the *Erythrina* experimental site were still in a growing phase creating holes in live wood was not seen as a viable option. The best analogues were epiphytic bromeliads that possessed a 'tank' structure capable of retaining a small pool of water within it.

Two species of bromeliads and one species of orchid were mounted on five tree species in December 1987. Observations made in December 1991 suggest that all species displayed a prefer-

Table 20: Survival of bromeliads and an orchid on five tree species

Bromeliad, Orchid	**neo spectrabilis**		**neo concentrica**		**Dendrobium**	
Tree species	**p**	**e**	**p**	**e**	**p**	**e**
Erythrina lithosperma	19	17	10	0	10	0
Diyakirilla spp	12	11	8	6	8	0
Psidium guayava	12	0	8	0	8	6
Trema spp	9	3	6	1	6	0
Macaranga spp	9	4	6	2	2	0

p = planted e = established

Plate 9: Epiphytes and tree microhabitats, four views

ence to certain species of trees, establishing well on some species and not on others (Table 20).

The bromeliads formed suitable habitat for tree frogs of the *Rhacophorous microtympannum* complex, with a resident population establishing in two years after mounting the bromeliads, thus demonstrating that the bromeliads could function as rot hole analogues.

In creating an analogue forest the potential for some of the early trees to act as keystone species for the ecosystems being designed needs to be addressed as this will develop a more robust design of the forest ecosystem. The identification of keystone species can be done by comparing the various ecological attributes required by the ecosystem. Table 17 demonstrated some criteria. In that case *Erythrina* demonstrated the ability to meet with all the criteria set. Other criteria can be set depending on site need and circumstance. For instance the restatement of item 6 to read 'Fruits/seeds as commercial crop' will yield a whole different range of species.

The patch of *Erythrina lithospermsa*-dominated forest that was grown over ten years provided bird counts of 44 species (NSRC 1991). Many of the species recorded were either nectar feeders or insectivores which fed on the insects attracted to the flowers or foliage. The system has now matured into a relatively complex ecosystem with *Erythrina* acting as the keystone species. The potential for large lateral roots was part of the design criteria because the treatment area was steep with no land platforms. In 10 years the *Erythrina* roots were assisting to build up platforms as well as trap large amounts of organic matter.

The experiment has generated interest in the village around the experiment. Over 100 farmers are now upgrading the ecological status of their existing vegetation. The product of the tree species from these gardens is certified by the NSRC as Forest Garden Products (see box) and has begun to enter the export market.

Forest Garden Products

Rainforest Environment Rehabilitation
The destruction of tropical rain forest not only beggars traditional people but also beggars the world. This destruction must be stopped, but so much has been lost in the past few decades that if we are to make any difference to the world of the future these trends must be reversed. With this goal in mind the Neo Synthesis Research Centre in Sri Lanka began a series of experiments in analogue forestry. Here, forests analogous to the rainforest in structure and ecological function but containing trees that yield valuable products, were established. This work also demonstrated that if all crops in the new forests were grown organically, many species of animals and birds that were once confined to the rainforest could move in and establish populations.

Today, many villages (40 in 1995) in Sri Lanka participate in creating these analogue forests, aware that their growing of organic produce protects both their children and the environment from poisonous chemicals, and aware that the planting of tree crops in this manner has helped replace some of the lost rainforest.

Forest Garden Products are collected exclusively from these forests. The consumer of these products not only purchase the finest, cleanest and freshest herbs and spices on the market, but also contribute to a change in the lifestyles of tropical subsistence farmers and help reverse the trends in tropical rainforest habitat destruction.

Forest Garden Products,
NSRC, Mirahawatte, Sri Lanka.

Australia: Streatham, Victoria.

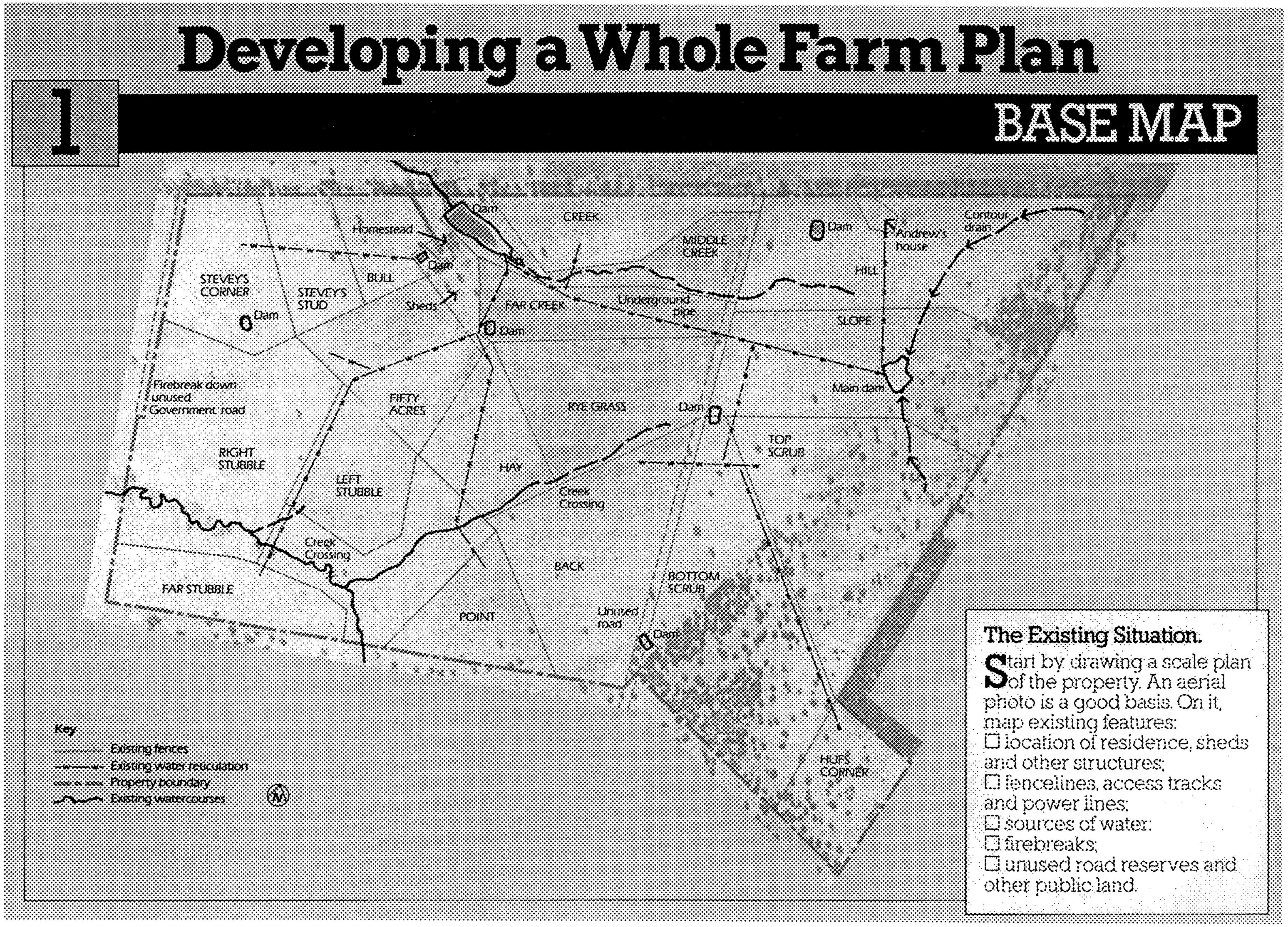
Contemporary Australia has a history of about 200 years. In this relatively short time the landscape has changed in a dramatic manner. The transposition of European civilisation with its attendant patterns of land use, has been described as 'so vast' that it is not yet possible to measure the impact on Australian ecosystems (Adamson and Fox, 1982, p.144). Modern ecological science is beginning to appreciate the degree of the calamity, as stated by Lowenthal (1976, p.358). 'Nowhere else, it was implied, had technological man lately occupied so fragile an ecosystem, nowhere else had settlers so utterly failed to identify with their new landscapes; nowhere else was man's environmental impact so patently reprehensible'.

Alien plants, animals and agro-ecosystems were rapidly introduced. The spread of the new species was so vigorous that Hooker, (1860) observed that native species of plants were replaced by exotic species when land was disturbed or modified. The rapid growth in agriculture and industry has resulted in a corresponding loss or modification of native ecosystems. The cost of poor ecological land management became evident in a relatively short period of time. The national cost of droughts, dust storms and massive erosion events is significant in modern Australian history (Beckermann and Coventry, 1987).

These events have produced attitude shifts in the protection of land and the recognition of native traditions through modern Australian society (Hobbs and Hopkins, 1990). They are exemplified by calls for the involvement of Aboriginal information in nature conservation and land management (Kean *et al*, 1988), or the use of 'Sustainable Wisdom', in farming, or the response to revegetation programs on an individual, group, community and state level (Bourke and Youl, 1990), and the 'Decade of Landcare Plan' at a national level (Anon, 1991). This latter plan outlines two ecosystems as needing attention, the natural ecosystems of Australia and the agricultural ecosystems. The juxtapositioning of these is of critical importance to sustainability in a biodiversity context as well as in an agricultural context. This is especially pertinent in the Australian landscape as maturity follows inimically different pathways in both. For instance, the soil ecosystem and its characteristics are very different in the natural and agricultural ecosystems (Senanayake, 1991a). The initial response to land care has been a massive tree-planting program. Surveys of 260 South Australian rural landowners who have been active in tree-planting demonstrate an increasing recognition of the utility value of revegetation. The main purpose of establishing trees was seen to be utilitarian, that is to assist in providing shade and shelter, wind control, soil erosion and salinity control (Howett and Lothian, 1988). There is a continuing process of testing various land management models that use trees as a significant component of land design. In Victoria an experiment termed the Potter Whole Farm Plan (WFP) involved using trees as an integral part of the farm. A farmland plan was seen as a dynamic between the farm elements, such as laneways or ponds and the whole farm (Campbell *et al*, 1989). Some of these relationships appear in the plans of a hypothetical farm seen in Figures 41 and 42).

In 1989 a group of six farmers in the Streatham area of the Western District decided to explore the possibilities of adapting analogue forestry ideas to their farms.

Their farms were being managed in general for the production of wool and lambs, with varying proportions of each being devoted to crops of oats, wheat and canola. The Environmental Management Unit (EMU) of Monash University worked with the group to evolve an experimental treatment. All the farms that participated were developing Whole Farm Plans and agreed to add the analogue design to some existing or planned landscape elements. The shelterbelt was the landscape element chosen to be developed into an analogous series. Shelterbelts are important to the agricultural landscape of this area as the wind-chill factor contributes to large stock losses, especially in new born lambs and off-shears sheep (Nixon-Smith, 1983). Many treatments have been proposed to increase its efficiency in terms of modifying wind velocity and other factors (Figures 44 and 45), most are related to porosity factors (Brown and Hall, 1968) but some also use site geometry (Foreman and Godron, 1986). The cropping potential in planting these windbreaks with timber species has been examined by Reid and



1 Developing a Whole Farm Plan

BASE MAP

The Existing Situation.

Start by drawing a scale plan of the property. An aerial photo is a good basis. On it, map existing features:

☐ location of residence, sheds and other structures;

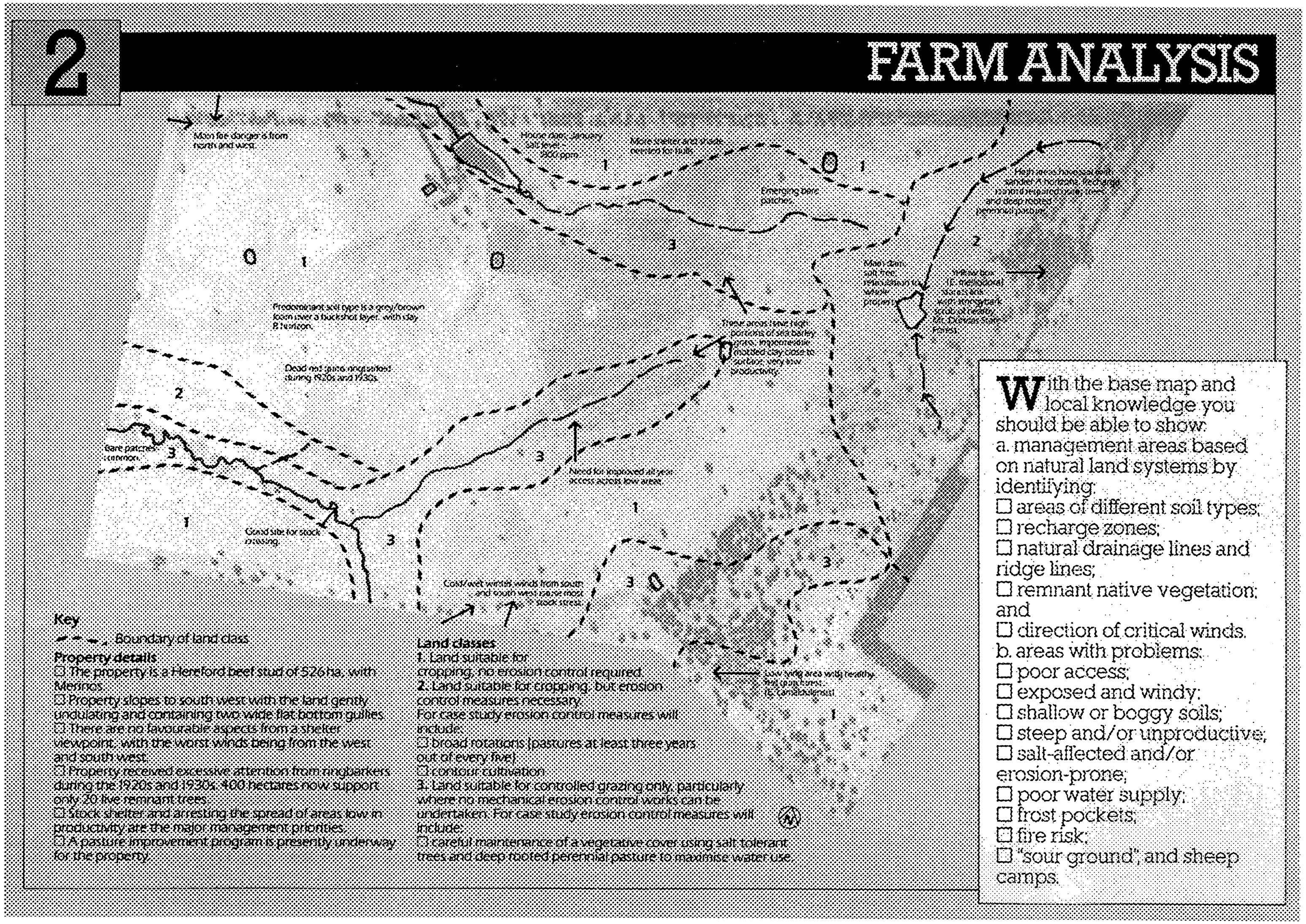
☐ fencelines, access tracks and power lines;

☐ sources of water;

☐ firebreaks;

☐ unused road reserves and other public land.

Figure 42: Current condition of a hypothetical farm (from Campbell et al, *1989)*



Key

Boundary of land class

Property details

☐ The property is a Hereford beef stud of 526 ha, with Merinos.

☐ Property slopes to south west with the land gently undulating and containing two wide flat bottom gullies.

☐ There are no favourable aspects from a shelter viewpoint, with the worst winds being from the west and south west.

☐ Property received excessive attention from ringbarkers during the 1920s and 1930s. 400 hectares now support only 20 live remnant trees.

☐ Stock shelter and arresting the spread of areas low in productivity are the major management priorities.

☐ A pasture improvement program is presently underway for the property.

Land classes

1. Land suitable for cropping, no erosion control required.

2. Land suitable for cropping, but erosion control measures necessary.
For case study erosion control measures will include:

☐ broad rotations (pastures at least three years out of every five)

☐ contour cultivation

3. Land suitable for controlled grazing only, particularly where no mechanical erosion control works can be undertaken. For case study erosion control measures will include:

☐ careful maintenance of a vegetative cover using salt tolerant trees and deep rooted perennial pasture to maximise water use.

With the base map and local knowledge you should be able to show:

a. management areas based on natural land systems by identifying:

☐ areas of different soil types;

☐ recharge zones;

☐ natural drainage lines and ridge lines;

☐ remnant native vegetation; and

☐ direction of critical winds.

b. areas with problems:

☐ poor access;

☐ exposed and windy;

☐ shallow or boggy soils;

☐ steep and/or unproductive;

☐ salt-affected and/or erosion-prone;

☐ poor water supply;

☐ frost pockets;

☐ fire risk;

☐ "sour ground", and sheep camps.

Figure 43: Analysis of current condition of a hypothetical farm (from Campbell et al, 1989)

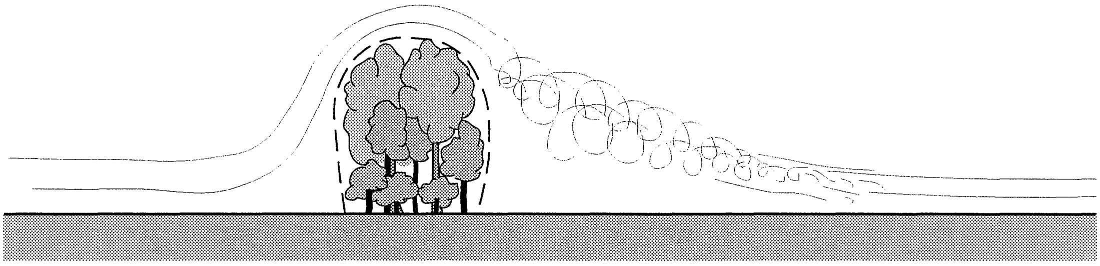


Figure 44: Wind attenuation effect of non-porous windbreak

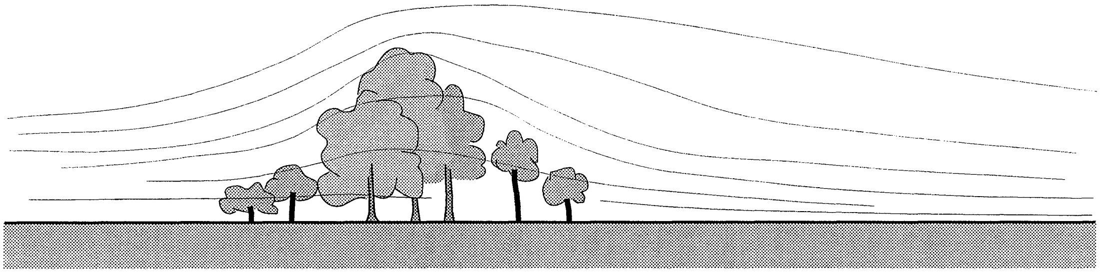


Figure 45: Wind attenuation effect of porous windbreak

Wilson (1986). The Streatham project looked at ways of developing the economic and ecological potential further using analogue forestry approaches.

The width of windbreak that was commonly utilised in the region was 10-15 m and was represented by four rows of trees. The older windbreaks in the district are even-aged monocultures dominated by species like sugar gum (*Eucalyptus cladocalyx*), cypress (*Cupressus spp*) and pines (*Pinus spp*). The younger windbreaks, though, are often highly diverse containing many different families of trees. These latter also incorporate more modern, wind-control features like relative porosity and varied cross-sectional profile.

The farms were largely devoid of native vegetation, though most were situated on former savanna-woodland and open sclerophyllous forest. The gently rolling country generally had well-drained soils with slightly alkaline stony soils on the higher parts and slightly acid clay loams and more productive soils in the lower parts. The analogous species were selected to meet the ecological requirements of such systems.

The range of genera in Table 21, together with local inspections, provided a good basis for selecting appropriate analogues of ecological and economic potential. The farmers in group discussion had identified early cash-flow to offset current depressed wool and grain prices as one of the economic goals of the experiment.

The soils of the region were somewhat degraded from their native condition and would have benefited from a period of rehabilitation using early- and mid-seral pioneers. However, because local plantings of the selected, mature, seral tree-species

Table 21:* Eucalyptus *woodland and* Themeda *tussock grassland of south-eastern Australia (Keast, 1981)

TREES (> 10 m)	
Myrtaceae	*Eucalyptus*
LOW TREES (< 10 m)	
Casuarinaceae	*Casuarina*
Cupressaceae	*Callitris*
Pittosporaceae	*Pittosporum*
TALL SHRUBS (>2 m)	
Mimosaceae	*Acacia*
Myrtaceae	*Melaleuca*

Table 21 continued

Pittosporaceae	*Bursaria*
Proteaceae	*Banksia*
Santalaceae	*Exocarpos, Santalum*
Sapindaceae	*Dodonaea*
LOW SHRUBS (<2 m)	
Asteraceae	*Olearia*
Chenopodiaceae	*Atriplex, Chenopodium, Rhagodia*
Fabaceae	*Eutaxia*
Lamiaceae	*Westringia*
Solanaceae	*Solanum*
GROUND-LAYER PLANTS	
Amaranthaceae	*Ptilotus*
Amaryllidaceae	*Calostemma*
Apiaceae	*Daucus, Eryngium, Hydrocotyle*
Asteraceae	*Angianthus, Brachyscome, Calocephalus, Calotis, Centipede, Cotula, Craspedia, Cymbonotus,*
Eclipta, Flaveria, Gnaphatium,	*Helichrysum, Helipterum, Isoetopsis, Leptorhynchos, Microsemis, Minuria, Myriocephalus, Podolepis, Rutidosis, Senecio, Vittadinia*
Brassicaceae	*Lepidium, Rorippa*
Brunoniaceae	*Brunonia*
Campanulaceae	*Lobelia, Pratia, Wahlenbergia*
Caryophyllaceae	*Sagina, Spergularia*
Centrolepidaceae	*Aphelia, Centrolepis*
Crassulaceae	*Crassula*
Cyperaceae	*Carex, Chorizandra, Cyperus, Eleocharis, Lepidosperma, Schoenus, Scirpus*
Droseraceae	*Drosera*
Euphorbiaceae	*Euphorbia, Poranthera*
Fabaceae	*Indigofera, Psoralea, Swainsona*
Gentianaceae	*Centaurium, Sebaea*
Geraniaceae	*Erodium, Geranium, Pelargonium*
Goodeniaceae	*Goodenia, Scaevola, Velleia*
Haloragaceae	*Haloragis*
Hypericaceae	*Hypericum*
Hypoxidaceae	*Hypoxis*
Juncaceae	*Juncus, Luzula*
Lamiaceae	*Ajuga, Mentha, Teucrium,*
Liliaceae	*Anguillaria, Arthropodium, Bulbinopsis, Burchardia, Caesia, Chamaescilla, Dianella, Dichopogon, Laxmannia, Thysanotus, Tricoryne*
Linaceae	*Linum*
Lythraceae	*Lythrum*
Onagraceae	*Epilobium*
Orchidaceae	*Diuris, Prasophylum*
Oxalidaceae	*Oxalis*
Plantaginaceae	*Plantago*
Poaceae	*Agropyrum, Agrostis, Amphibromus, Chloris, Danthonia, Deyeuxia, Dichelachne, Eragrostis, Neurachne, Panicum, Poa, Sporobolus, Stipa, Themeda*
Polygalaceae	*Comesperma*
Polygonaceae	*Rumex*
Portulacaceae	*Portulaca*
Ranunculaceae	*Ranunculus*
Rubiaceae	*Asperula, Gallium, Opercularia*
Scrophulariaceae	*Gratiola, Veronica*
Stackhousiaceae	*Stackhousia*
Thymelaeaceae	*Pimelea*
Urticaceae	*Parietaria*
Violaceace	*Viola*
Xanthorrhoeaceae	*Lomandra*
TRAILING AND TWINING PLANTS - INTRODUCED	
Convolvulaceae	*Convolvulus*
Fabaceae	*Glycine, Hardenbergia, Kennedia, Lotus*
Ranunculaceae	*Clematis*
FERNS	
Dennstaedtiaceae	*Pteridium*
Marsileaceae	*Marsilea*
Sinopteridaceae	*Cheilanthes*
EPIPHYTES - PARASITIC	
Cassythaceae	*Cassytha*
Loranthaceae	*Amyema, Lysiana*
TALL SHRUBS (>2 m) - INTRODUCED	
Oleaceae	*Olea*
LOW SHRUBS (,<2 m) INTRODUCED	
Asclepiadaceae	*Asclepias*
Asteraceae	*Chrysanthemoides*
Fabaceae	*Teline, Ulex*
Lamiaceae	*Lavandula, Marrubium*
Rosaceae	*Crataegus, Rosa*
Solanaceae	Lycium, Solanum
GROUND-LAYER PLANTS - INTRODUCED	
Amaranthaceae	*Amaranthus*
Apiaceae	*Foeniculum*

Table 21 continued

Asteraceae	*Arctotheca, Calendula, Carduus, Carthamus,Centaurea, Cichorium, Cirsium, Conyza, Cynara, Hedypnois, Hypochoeris, Inula, Onopordum, Picris, Silybum, Sonchus, Taraxacum, Tragopogon, Xanthium*
Boraginaceae	*Amsinckia, Echium, Heliotropium, Lithospermum, Myosotis, Neatostema*
Brassicaceae	*Coronopus, Diplotaxis, Lepidium, Brassica, Cardamine, Conringia, Sisymbrium, Raphanus*
Caryophyllaceae	*Spergularia, Stellaria, Vaccaria Cerastium, Sagina, Silene,*
Cyperaceae	*Cyperus*
Dipsacaceae	*Scabiosa*
Euphorbiaceae	*Euphorbia*
Fabaceae	*Medicago, Melilotus, Trifolium, Vicia*
Fumariaceae	*Fumaria*
Gentianaceae	*Centaurium*
Geraniaceae	*Erodium, Geranium*
Hypericaceae	*Hypericum*
Iridaceae	*Homeria, Romulea, Sparaxis*
Juncaceae	*Juncus*
Lamiaceae	*Salvia, Stachys*
Liliaceae	*Asphodelus*
Linaceae	*Linum*
Malvaceae	*Malva*
Onagraceae	*Oenothera*
Oxalidaceae	*Oxalis*
Papaveraceae	*Papaver*
Plantaginaceae	*Plantago*
Poaceae	*Aira, Alopecurus, Anthoxanthum, Avena, Brachypodium, Briza, Catapodium, Cynodon, Dactylis, Eragrostis, Holcus, Hordeum, Bromus, Molineria, Monerma, Oryzopsis, Koeleria, Lagurus, Lolium, Phalaris, Phleum, Poa, Schismus, Vulpia*
Polygonaceae	*Rumex*
Primulaceae	*Anagallis*
Rubiaceae	*Galium, Sherardia*
Scrophulariaceae	*Kickxia, Parentucellia, Verbascum*
Urticaceae	*Urtica*
TRAILING OR 'TWINING' PLANTS - INTRODUCED	
Convolvulaceae	*Convolvulus*
Cucurbitaceae	*Citrullus*
Polygonaceae	*Polygonum*

were known to have performed successfully it was decided, in the interests of speedy development and economy, to include all seral stages in the initial plantings.

A range of indigenous, local plantings and new species were discussed with the project farmers and ranked according to the characteristics in Table 22. No formal weightings were given between, or within, characteristics. Species chosen by this process are shown in Table 23.

Table 22: Selection characteristics used for initial plantings, Streatham

- fit the family and genus of the indigenous vegetation
- wind firmness
- deep rooting potential in heavy soils
- rapid canopy development
- frost-resistance
- good nectar producer
- early cash-flow
- good timber
- good firewood
- suitable to moderate heavy soils
- performed well locally
- readily propagated from seed or cutting

Table 23: Initial species selection, Streatham

Trees
- *Acacia melanoxylon*
- *Eucalyptus cinerea*
- *E. gunnii*
- *E. leucoxylon rosea*
- *E. maculata*
- *E. macrorhyncha*
- *Laurus nobilis*
- *Olea europea*
- *Peumus boldus*
- *Prumnopitys andina*

Shrubs
- *Acacia kempeana*
- *Artemisia absinthia*
- *Bursaria spinosa*
- *Leucadendron spp*
- *Protea spp*

Herbs
- *Achillea millifolium*
- *Lavendula spp*
- *Rosmarinus officinalis*

Table 24: Final species selection- Streatham

Scientific Name	Status	Soil	Exposure	Frost	Propagation
Achillea millefolium	herb	red buckshot		hardy	seed direct
Anthemis nobilis	herb	red buckshot		hardy	seed direct
Peucedanum graveolens	herb	clay loam			seed for above plants
Cynara scolymus	herb	clay loam		hardy	seed to tubes
Rosmarinus graveolens	herb	red buckshot		hardy	seed to tubes
Iris florentina	root	swampy	south	hardy	root
Acacia suaveolens	shrub	red buckshot	south	hardy	seed to tubes
Amelanchier canadensis	shrub	c/l-rb	south	hardy	seed to tubes
Arctostaphylos uva ursi	shrub	stony	south	hardy	seed to tubes
Artemisia dracunulunus	shrub	stony	north	hardy	seed to tubes
Banksia ashbyi	shrub	deep sand	north east	hardy	seed to tubes
Banksia baxteri	shrub	deep sand	north east	hardy	seed to tubes
Banksia burdettii	shrub	deep sand	north east	hardy	seed to tubes
Banksia prionotes	shrub	deep sand	north east	hardy	seed to tubes
Leptospermum hybrids	shrub	clay loam	north	hardy	cutting
Leucadendron xanthoconus	shrub	c/l-rb	north	hardy	cutting
L. platyspermum	shrub	c/l-rb	north	hardy	cutting
L. daphnoides	shrub	c/l-rb	north east	hardy	cutting
L. galpinii	shrub	c/l-rb	north	hardy	cuttings
L. orientale	shrub	c/l-rb	north	hardy	cutting
L. salignum	shrub	c/l-rb	north	hardy	cutting
Leucospermum caroline	shrub	red buckshot	north east	hardy	cutting
Protea repens	shrub	c/l-rb	north east	hardy	cutting
Protea hybrid	shrub	c/l-rb	north east	hardy	cutting
Acacia kempeana	tree small	clay loam	north	hardy	seed to tubes
Acacia melanoxylon	tree	red buckshot	south	hardy	seed to tubes
Eucalyptus cinerea	tree	clay loam	north	hardy	seed to tubes
E. kruseana	tree	clay loam	north	hardy	seed to tubes
E. gunnii	tree	swampy	south	hardy	seed to tubes
E. leucoxylon rosea	tree	clay loam	north	hardy	seed to tubes
E. maculata	tree	clay loam	north	hardy	seed to tubes
E. polybractea	tree med.	red buckshot	north	hardy	seed to tubes
Lauris nobilis	tree small	red buckshot	south	hardy	cuttings
Olea europa	tree small	red buckshot		hardy	cuttings

Planting out commenced in 1992 followed by further plantings in 1993.

The final list of selections for the project is shown in Table 24, together with some of their selection attributes.

Note: Table 24 above, and Figure 46 following, refer to *E. maculata* (since discarded after it failed to meet leaf-marketing standards). *E. maculata* was replaced by *E. macrorhyncha*; the latter chosen for its reliable local performance and exceptionally high rutin-yielding capacity.

The new design chosen was 22 m wide consisting of 10 rows of plants (Figure 46).

Ecological

All the eucalypts selected have potential as structural and functional keystones for the climax system. With the exception of *E. gunnii* all have performed satisfactorily in the region. The majority of species are deep-rooted and thus will be most

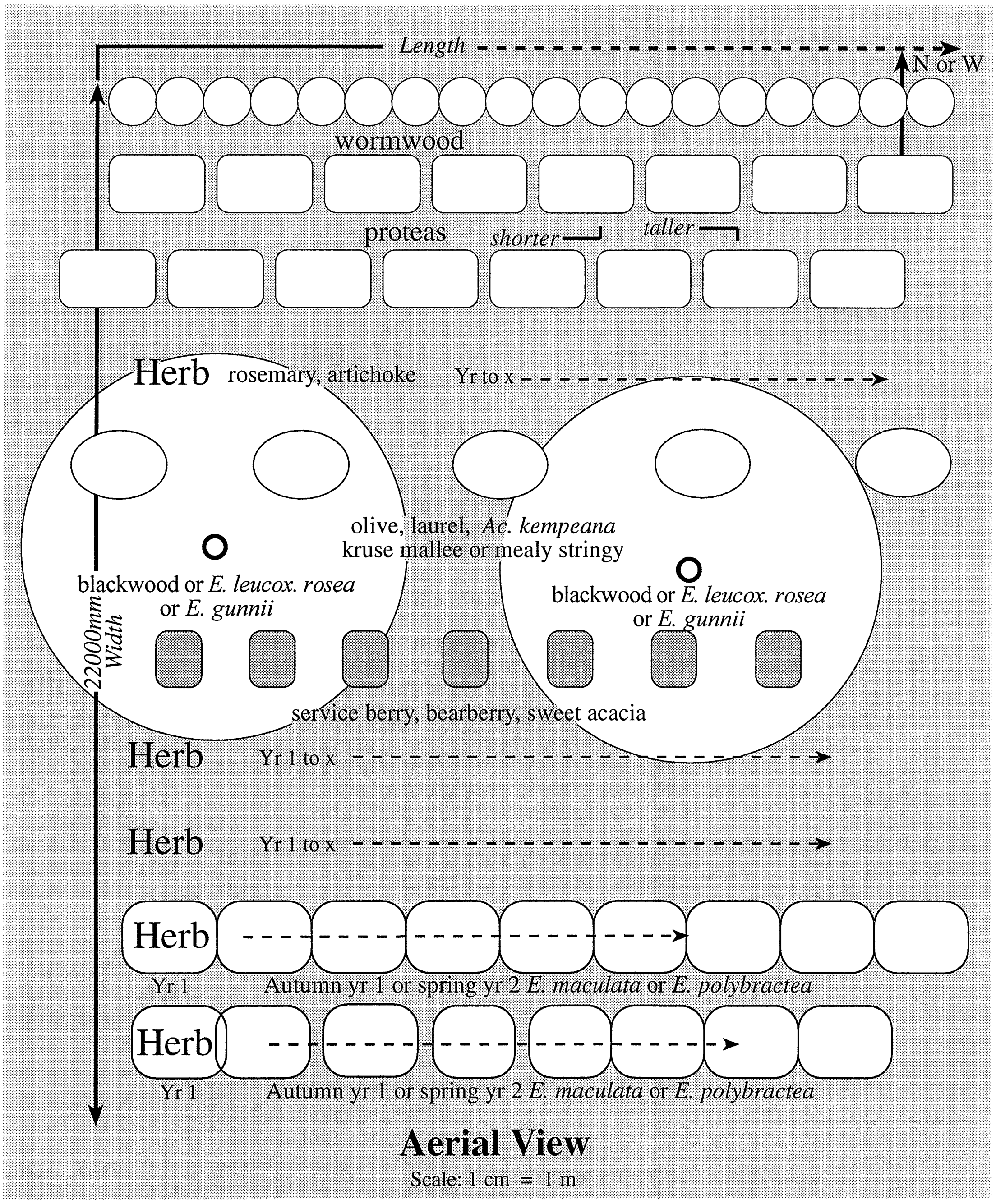


Figure 46: Analogue forestry layout for shelterbelt, Streatham

valuable in deepening the eroded and compacted soils. *E. cinerea* is relatively shallow-rooted and can usefully complement the deeper-rooted species in the moister locations. All species provide a useful source of nectar and pollen for insect, birds and arborous mammals. *E. polybractea,* while not normally shallow-rooted, will by virtue of its management for coppice leaves, provide a weed-free fire protective zone on the edge of the shelterbelt. The eucalypts include a mix of smooth and rough barked species that support both trunk and foliage feeding birds. Smooth bark species generally favour ant populations at an early age and so encourage insects and fungi that aerate the soil. The rough bark species are favoured by local sittellas and the ground-feeding eastern yellow robin uses the rough-barked trunks as vantage points to spot grubs and beetles in the ground litter. The chosen species include both coarse and fine litter producers that can be located so as to optimise for habitat provision. The selection includes a mix of angular and horizontal branching types that support the local range of tree nesting birds. For example the black shouldered kite builds or occupies stick nests high in dense foliaged trees with angular branches, while the peregrine falcon generally builds stick nests at the fork of a low-angled or horizontal branch. The grey-breasted silvereye favours dense branched low canopied species and *E. kruseana and E. cinerea* offer such environments. Blackwood has a valuable sub-dominant status. It can handle full sun in the early stages and low light as it matures. It thus contributes to the overall depth and porosity of the shelterbelt. It adds nitrogen and fine litter and improves soil depth and structure. It is long lived and its rooting and litter characteristics contribute valuable erosion control. Its nectar, bark micro-flora and fauna, foliage and litter are attractive to a range of local birds. The root systems of olives are both surface and deep. The former provide useful barriers to surface run-off and the latter are valuable because of their contribution to plant survival and soil deepening even on the stoniest of sites.

The chosen shrubs provide a variety of densely branched structures from ground level to 2 metres and thus valuable protection for small birds such as pardalotes and robins. They are also a useful element in the depth of canopy and porosity of the shelterbelt. The shrubs are dominated by the Proteaceae. The Proteaceae generally are early pioneers. They thrive in full sun and are capable of handling blustery conditions and low phosphate soils. Their rapid, early canopy, growth provides a shelter for the more sensitive herbs. The species selected include those that can handle slightly alkaline soils as well as those that can handle slightly acid soils. Their vigorous rooting behaviour is a useful aid in breaking up the agriculturally compacted soils providing the site is ripped before planting to improve general drainage. While banksias are indigenous to the locality, the local species were not chosen because their non-terminal flowers are unsuited for sale, whereas the chosen species are in high demand. Sweet acacia contributes nitrogen to the soil. Its flowers are a valuable source of pollen and its seeds a source of protein for birds and insects.

The herbs have been selected to cope with the variety of climatic conditions common to the site. It is not intended to irrigate any of the plants (including the herbs) except for possible initial watering. Timing of cultivation and seeding will therefore be critical to development. The intensive surface occupancy of the herbs is also expected to assist in the control of agricultural weeds. The selected herbs provide a pioneering function by way of an extended ground cover, protection and modification of the surface soil and utilising the surplus soil moisture in Spring and early Summer conditions. Orris and artichoke, in particular, extend these effects throughout the year and over a period of years. This particularly enhances the near sub- and above-surface microclimates and favours more diverse microflora and fauna. In general, the selected herbs are designed to contribute for up to 5 years in any one stretch of the shelterbelt. After 5 years it is expected that shading and root competition for nutrients and moisture by adjoining shrubs will considerably diminish the ecological and economic contributions of the herbs at that location. Orris might be expected to contribute for a longer period because of its moister site locations. Yarrow is a valuable compost activator and will be used together with pasture grasses and agricultural weeds as mulch to retain moisture adjacent to new plantings and to return nutrients and rebuild the structure of the agriculturally damaged soils.

Economic

E. cinerea, leucoxylon rosea, macrorhyncha and maculata have domestic fuelwood potential. Except for *E. cinerea*, all have potential for farm construction timbers and their potential for furniture timber is currently under examination. Production of fuelwood is possible from age 10 and construction and furniture timbers from age 25 years.

E. leucoxylon rosea flowers and buds find a ready domestic market. Production commences around 5-7 years and continues every 1-3 years to 100 years plus.

E. kruseana and cinerea foliage is valued in the domestic and export floral markets, though unreliable supply and quality control have hampered development of the latter market. Production of foliage is possible from coppice from age 5 and then every 1-2 years to age 25 years.

E. polybractea is a high and consistent producer of eucalypt oil for which there is an increasing domestic and export demand. Production of foliage is possible from coppice from age 5 and then every 1-2 years to age 35 years.

E. macrorhyncha foliage is particularly high in rutin (used in vessel-dilatent drugs for the treatment of heart conditions). It has an excellent potential for domestic and export markets, particularly as existing overseas sources are under threat of extinction. Production of foliage is possible from coppice from age 5 and then every 1-2 years to age 25 years.

E. gunnii has potential for the production of a unique Australian "syrup" to compare with maple syrup. The commercial possibilities are there to be explored. Production of syrup is possible from age 10 and seasonally thereafter for an indefinite period (trees in excess of 100 years of age continue to yield strong flows of syrup).

Blackwood is a most valuable source of furniture timber for domestic and export markets. Production is possible from 25 years of age with present technology.

There is a well-established and rapidly-growing domestic and export market for the flower and foliage of the selected Proteaceae and the Leptospermum hybrids. This is subject to careful attention to control of quality and consistency of supply. Production of the above products starts at 3 years and averages 10 years. On some sites progressive replacement with new varieties may be possible beyond 13 years. There is a developing domestic market for sweet acacia foliage. Bearberry provides a source of natural craft dyes and medicinal foliage (dried) and is in demand by herb marketers. Wormwood contributes to in situ control of moths and flies. It is grown as a hedge to service the above purpose and the periodically harvested foliage (fresh and dried) commands a ready market for insecticidal and medicinal purposes.

As indicated in the above ecological discussion the establishment and development of the herbs will be seasonally dependent and even though a hardy selection has been made a high level of risk exists. Notwithstanding there is ready market for those chosen.

Subject to suitable climatic conditions production is expected in the first year for all except artichoke, rosemary and orris which will take 2-3 years to come into useful production.The plants and their products are yarrow (whole plant for compost activator; flowers and leaves for medicinal, culinary and cosmetic uses), chamomile (flowers for cosmetic, aromatic and medicinal uses), dill (seed and foliage dry and fresh for culinary use), artichoke (flower head for vegetable), rosemary (flowers and leaves for culinary and cosmetic; leaves for medicinal use) and orris (tuber for cosmetic use).

Outcome and Analysis

A group propagation unit was established and all members participated in varying degrees in the propagating processes:

(i) Initial plantings were made by all and follow-up plantings by several of the group. None persisted beyond the third year.

(ii) All of the species selected performed satisfactorily with the exception of*Leucospermum caroline* which was too frost-sensitive. Nearly all plantings suffered from inadequate weed control.Weed density varied considerably from farm to farm.

(iii) EMU consultants visited the project monthly in the peak propagation and planting periods of the first and second year. Advice was provided by phone at other times.

(iv) The project failed because of several factors (largely non-technical). A return to better markets for the traditional farm products demanded more

of the time and attention of the group members particularly at the critical propagation and planting times of the new products. At the same time the group lost cohesion and leadership and the EMU consultants' visits were inadequate to sustain the group impetus.
(v) It is clear that time commitment and dedication of local operators is essential for success, particularly when dealing with unfamiliar plants and activities. These deficiencies cannot be overcome by good technical advice.

Contrast the Streatham result with that in Sri Lanka where the villagers were familiar with many of the plants. They were experienced gardeners and they could not expect improved incomes unless the project works were successful.

CHAPTER TWELVE

THE FUTURE

While it is already clear to many developing countries that they cannot continue working their land as in the past, that position is not yet clear to many of the developed countries, *vide* the farmers in Sri Lanka and Streatham, as outlined in the previous chapter. If developed country land managers are not to wait until they reach the economic position of those in developing countries some serious dialogue and decisions will be required. Some action is already apparent. Australian scientists and others are to seriously examine the 'Reinventing (of Australian Plant Production Systems' (Collie, 1997). Perhaps we may see analogous agriculture!

In previous chapters we have seen how Analogue Forestry can contribute to a wide variety of economic, ecological and social goals in a sustainable and developing way. In this final chapter we will examine what is required to translate the potential of Analogue Forestry into realisable benefits for people and the environment.

The identified issues appear in many ways to be unconnected (definition of terms, strategy, product guarantees). Yet if we consider that sustainable development can only be achieved if there is substantial understanding and recognition at global and individual operator level then we can see something of the way these issues link in to the technology we have been examining in this text.

SIGNIFICANCE OF TERMINOLOGY

The recognition of the role of scientific evaluation in the setting of global policy is clearly illustrated in the development and adoption of international instruments such as the Convention on Biological Diversity (1992) and the Montreal Protocol on Ozone Depleting Substances. While the role of forests are often critical to such international concerns, the management of forests to meet these international goals has yet to be acknowledged and developed. As discussed, the definition of the terms used to define the management tools are critical in terms of cost-benefit. For discussions on the forestry sector, a summary of the concepts discussed is listed in Table 25. Imprecise definition, especially in the use of the words, forest, forestation, reforestation, afforestation and tree-planting make the effective functioning of any policy very weak. For instance Spears (1984) suggests that the planting of a single tree is forestation and introduces categories such as farm forests and plantation forests as different categories.

Table 25: Glossary for the forestry sector

Forest = Tree dominated ecosystem

1. Natural

Natural forests are tree dominated native ecosystems, uninfluenced by humans, containing multiple age classes in its tree components and function as long term carbon sinks

2. Anthropogenic

Anthropogenic forests are tree dominated ecosystems, managed or influenced by humans over a varying degree of use. The ecosystems created usually contain a high proportion of exotic species

Tree Plantation = Formal systems of silviculture

Tree plantations are tree dominated anthropogenic ecosystems containing native or exotic species, usually of a single age class, managed according to scientific principles and function as short term carbon sinks.

1. Polyculture

The use of many species and techniques in planting and management design

2. Monoculture

The use of one species or cultural practice in planting and management design

Forest Plantation = Informal systems of silviculture

1. Traditional

The use and management of tree species to create a tree dominated ecosystem according

Table 25 continued

to traditional knowledge systems

2. Analogue

The use and management of tree species to create a forest analogue using scientific knowledge systems

Forestry = The art and science of managing forests

The art of producing and tending a forest by manipulating its establishment, composition and growth to best fulfil the objectives of the manager.

1. Traditional

The use and management of tree species to create a tree dominated ecosystem according to traditional knowledge systems

2. Modern

After the school of Hartig, etc. The application of science to this approach

Home Garden = Area of land around a house used for crop growing

1. Home Garden

An area that has under 40% tree shade

2. Forest Garden

An area that has over 60% tree shade

Biodiversity = The measure of diversity of species or genes at any spatio-temporal point.

1. Natural

Uninfluenced by humans

2. Anthropogenic

Influenced by humans

Non Timber Forest Products (NTFP)

1. Species products

Products that originate from a single species

2. Ecosystem products

Products that are created by ecosystem function, all species in a given ecosystem contribute to these functions

Reforestation = Restoration of native forests.

Enrichment of degraded lands with native species and encouragement of natural seral processes.

Sustainability = Sustainability is the ability to recover from perturbation and stress and has to be defined by both ecological and socio-economic criteria.

Future management for economic development will have to consider sustainability of the landscape, as being central to policy planning. Thus the ratio of natural to anthropogenic, or of forest to open land, will become important variables. Considerations such as the 'degree of permeability' or 'mesh size' of the anthropogenic features will become important design elements. The concept of landscape ecology was developed after World War II and has only recently expanded into an international science (Naveh, 1991). Management design, has to consider the focus of this discipline which Risser (1987), states as being 'the synthetic intersection of many related disciplines which focus on spatial and temporal patterns of a landscape'.

The description of Zonneveld (1990) of the three dimensions of landscape ecology study provides a basis for setting parameters. It will be seen that the chorologic and topologic are very useful in the application of analogue forestry design. The development of landscape ecology into all aspects of human activity (Dale *et al*, 1989) and eco-sphere functions (Naveh and Lieberman, 1984) suggests an active requirement of Analogue Forestry approaches to address many management questions.

STRATEGY

An Analogue Forestry strategy might examine the following:

1. The present and expected social, cultural (including political commitment), ecological and economic trends for individuals, groups and institutions; with particular consideration of potential intervention areas (e.g. youth and migrants). Also, the economic, cultural and regulatory constraints and opportunities.

2. What resources, persons and/or cultures need to be encouraged to enhance the wider application of Analogue Forestry and similar biodiversity enhancing systems?

3. Social and economic; given the role and nature outlined in 2 above, identify current social, economic and infrastructural influences (opportu-

nities and constraints relevant) to Analogue Forestry and similar biodiversity enhancing systems.

4. Regional; recognise the special cultural, economic and biological strengths and weaknesses and opportunities they provide (e.g. chronic food shortages in some developing countries).

5. The intervention strategies and feed-back mechanisms required to get from where we are to fully landscaped, biologically diverse, stable environments, including the productive and economic use of the land.

Pre-requisites for successful Analogue Forestry

1. land custodianship and tenure of a high quality;
2. knowledge of, or access to, knowledge of existing indigenous ecosystems;
3. practical ecological skills relating to selection, propagation, field design, field management;
4. ability to plan and manage the new time commitments associated with the analogue forestry operations;
5. participants must be good sharers of information e.g. feedback of performance of particular plants, response to weeding, pruning, shade, product handling, market information and the like;
6. access to international plant material and micro-organisms;
7. ability to meet local needs for products and services;
8. local operator access to skilled training in propagation and micro-ecological awareness in particular, plus ability to translate this into practical action;
9. multi-product production management skills;
10. new harvesting, post-harvest handling, processing and presentation skills;
11. diverse marketing skills;
12. finance raising, financial management and budgetary and accounting skills (if operating as a group, will require full and regular accounting statements to watch-dog(s)).

While each of the above pre-requisites may well deserve elaboration recent developments in the area of product certification have wide implications for most of the above. The long-term success of Analogue Forest projects will frequently depend on the quality of the output. While many Analogue Forest projects will survive successfully by local consumption of their output, they are unlikely to develop their full product potential unless they can compete in the outside marketplace.This implies a recognition of quality and consistency of their products and of the name of the marketing organisation. Given the nature of the organisation of world trade much of this recognition will revolve around statutory conformance.

Forest Stewardship Council, ISO 14001, and Earth Market Place (EMP) are three certification standards that apply to the growing and marketing of forest produce. Much of the debate at present concerns the first two and is being pursued largely by the large forestry companies and conservation organisations. By and large the aim of the standards is to ensure a sustainable production of the output and the maintenance of the quality of the land, water and biological resources involved, while at the same time meeting world standards in respect of health, safety and employment (La Fontaine, 1995). EMP is a relatively new concept and aims to provide an electronic market place where growers of certified 'forest garden' products can advertise their wares together with high visibility of the audit chain of the certification process. EMP is particularly set up to facilitate the marketing of small batches of production that would otherwise be difficult to market at the international level (Moles, 1995).

The final shape of the forest produce certification standards will be of great concern to future producers and it is vital that wide debate be undertaken in the setting of these standards.

CONCLUSION

In this introductory volume we have attempted to outline the main principles on which a new approach to productive enhancement of biodiversity is based.

1. The umbrella symbolises the tree and a collection of umbrellas the forest and thus a major modification of the environment and all within it.

2. A forest, however, is more than a collection of trees; it has structures, patterns and divisions above and below ground that provide a diversity of spaces and environments that encourage a diversity of organisms. Also as a corollary a collection of trees of the one species provides a lesser diversity of spaces and environments and thus a lesser variety of other organisms.

3. Dynamic activity and change is a natural outcome of biological action. Processes such as Analogue Forestry that recognise this can marshal that energy and minimise reliance on oil-based energy inputs. Again, contrast this with monocultures that attempt to constrain change and require large, and frequent, oil-based energy inputs.

Facilitating diversity can take advantage of available natural inputs and strengthen stability and ability to provide outputs of value for a range of conditions.

4. A wide range of biota have traditionally supplied the needs of man for food, shelter, culture and trade. Most needs can be supplied locally to the advantage and resilience of local communities. Where biota are unrecognised they are not appreciated. Contrast the foregoing with the current trend for food and other human needs to be supplied by international business to the detriment of local producers and traders.

5. Local cultural and economic imperatives play a vital role in any developmental change, including passivity in the face of the detrimental effects of some international businesses on local communities. These imperatives are also of vital concern to a locally-invoked process such asAnalogue Forestry. Any Analogue Forestry design can only proceed to implementation and successful outcome if it is based on local commitment and meets local needs.

6. Landscape management, including that of Analogue Forestry units within the total landscape, requires recognition of all of the above and in addition that structure, shape, position and balance of the elements within the total landscape are all critical to its resilience. Further, just as biota unrecognised are biota unappreciated, so the resilience of the landscape depends on their cultural recognition.

LISTING OF PLANTS REFERRED TO IN THE TEXT

Scientific Name	**Authority**	**Common Name**
Abies grandis	Lindl.	grand-fir
Acacia	(Tourn.) Linn.	wattle
Acacia albida	Delile	white wattle
Acacia decurrens	Willd.	early black wattle
Acacia kempeana	F.Muell.	witchetty-grub acacia
Acacia leucocephala	Link.	
Acacia mearnsii	De Wild	black wattle
Acacia melanoxylon	R. Br.	blackwood
Acacia nilotica	Delile	
Acacia planifrons	Wight & Arn.	
Acacia pycnantha	Benth.	golden wattle
Acacia saligna	Labill.	golden wreath wattle
Acacia suaveolens	Willd	sweet acacia
Acer macrophyllum	Pursh	maple
Acer saccharum	Marshall	sugar maple
Achillea millefolium	Ledeb.	yarrow
Acontias	Schott	
Aerides cylindricum	Hook.	
Agave sisalana	Perrine	sisal hemp
Agropyrum	J. Gaertn	
Agropyron elongatum	Linn.	tall wheat grass
Agrostis	Linn.	bent grass
Aira	Linn.	oat
Ajuga	Linn.	labiate
Albizzia	Durazz.	
Albizzia lebbek	Benth.	
Albizzia schimperiana		
Aleurites	Forst.	platylobe
Aleurites fordii	Helmsl.	candle nut/tung
Aleurites moluccana	Willd.	candle nut
Allocasuarina verticilliata	(Lam.) L.A.S. Johnson	
Allophyllum cobbe	(A. Brand) A. & V. Grant	
Alnus	Tourn.	alder
Alopecurus	Linn.	grass
Alsophila glauca	R. Br.	
Alsophila insulana	(Holtt.) R. Tyron.	
Altingia excelsa	[G. Don]	
Amaranthus	Linn.	tumbleweed
Amelanchier canadensis	Medic.	service berry
Amphibromus	Nees	grass
Amsinckia	Lehm.	heliotrope
Amyema	Van Tiegh.	mistletoe
Anacardium occidentale	Linn.	cashew
Anagallis	Tourn.	primrose
Ananas comosus	Merrill	pineapple
Angianthus	Wendl.	composite
Anguillaria	R. Br.	lily
Anodendron	A. DC.	
Anona muricata	Linn.	custard apple
Anthemis nobilis	Linn.	chamomile
Anthoxanthum	Linn.	grass
Antidesma bunius	Burm. ex Linn.	spurge
Aphelia	R. B r.	sedge-like herbs
Arachis hypogaea	Linn.	ground nut
Araucaria bidwilli	Hook.	bunya pine
Archaeopteris		
Arctostaphylos uva ursi	Spreng.	
Arctotheca	Wendl.	composite
Areca catechu	Linn.	area nut
Artemisia absinthium	Linn.	wormwood
Artemisia dracuculunus	Linn.	wormwood
Arthropodium	R. Br.	lily
Artocarpus	Forst.	jak fruit
Artocarpus altilis	(Parkinson) Fosberg	bread-fruit
Artocarpus heterophylla	Lam.	jak
Artocarpus intergrifolia	Linn. f.	jak
Asclepias	Linn.	asclepid
Asperula	Humb.	madder
Asphodelus	Tourn.	lily
Asplenium	Linn.	
Asteroxylon		fossil
Astralagus	Tourn. ex Linn.	milk vetch
Atriplex	Tourn.	salt bush
Avena	Linn.	oat
Azadirachta indica	A. Juss	neem
Bambusa	Schreb	bamboo
Bambusa beecheyana	Munro	bamboo
Bambusa vulgaris	Meres	bamboo
Banisteriopsis	C.B. Robinson	
Banksia	Domb. ex DC	
Banksia ashbyii	E.G. Baker	
Banksia baxteri	R. Br.	
Banksia burdetii	Domb. ex DC	
Banksia prionotes	Lindl.	
Barringtonia insignis	Hu	
Bassia latifolia	Roxb.	copper burr
Betula alba	Wahlenb.	silver birch
Bertholletia excelsa	H. et B.	brazil nut
Bidens pilosa	Linn.	composite
Bixa orellana	Linn.	annatto
Boehmeria nivea	Gaudich.	ramie
Bombax malabricum	DC.	silk cotton tree
Borassus flabellifer	Linn.	borassus palm/ palmyra
Bouea macrophylla	Griff.	
Brachypodium	Beauv.	brome grass
Brachycome	Cass.	composite
Brassica	(Tourn.) Linn.	crucifer
Briza	Linn.	grass
Brosimum utile	Fittier	
Brunonia	Sm.	milk tree
Bulbinopsis	Borzi.	lily
Burchardia	R. Br.	lily
Bursaria	Cav.	bursaria
Bursaria spinosa	Cav.	sweet bursaria

Cactus	Linn.	cactus
Caesia	R. Br.	lily
Calamus	Linn.	rattan palm
Calendula	Linn.	composite
Calethea lutea	Muell. Arg.	
Callitris	Vent.	pine
Callixylon		fossil
Calophyllum	Linn.	
Calocephalus	R. Br.	composite
Calochilus	R. Br.	orchid
Calostemma	R. Br.	alstromeric
Calotis	R. Br.	composite
Camellia	Linn.	camellia
Camellia sinensis (Thea)	Linn.	tea
Canna edulis	Ker-Gawl.	arrowroot
Cannabis sativa	Linn.	hemp
Carduus	(Tourn.) Linn.	composite
Carex	(Dill.) Linn.	sedge
Carica papaya	Linn.	papaya/paw paw
Carthamus	(Tourn.) Linn.	composite
Carya	Nutt.	hickory
Caryocar	Linn.	caryocar
Caryota	Linn.	carytoid palm
Caryota urens	Jacq.	fishtail palm/kitul
Cassia nodosa	Buch.-Ham. ex Roxb.	pink shower tree
Cassia spectrabilis	DC.	cassia
Cassytha	Linn.	cassytha
Castanea dentata	Sudworth	chestnut
Casuarina	Linn.	she oak
Casuarina muellerana	Miq.	she oak
Catalpa	Scop.	french oak
Catapodium	Link.	grass
Cattleya	Lindl.	
Cattleya aurantiacum	Lindl.	
Ceiba pentandra	Gaertn.	kapok
Cecropia	Linn.	
Centaurea	Linn.	composite
Centaurium	Gilib	gentian
Centrolepis	Labill.	centrolepid
Cerastium	(Dill.) Linn.	chickweed
Ceratonia siliqua	Linn.	carob
Chamaescilla	F. Muell.	lily
Cheilanthes	Sw.	polypod
Chenopodium	(Tourn.) Linn.	fat hen
Chloris	Sw.	grass
Chloroxylon swietenia	DC.	mahogany/satinwood
Chorizandra	Labill.	sedge
Chrysanthemoides	Tourn. ex Medickus	composite
Cichorium	(Tourn.) Linn.	composite
Cinchona ledgeriana	Moens	quinine
Cinnamomum zeylanicum	Nees	cinnamon
Cirrhopetalum grandiflora	Lindl.	
Cirsium	(Tourn.) Adans.	composite
Citrullus	Forsk.	cucurbit
Citrus	Linn.	lemon/lime
Clematis	Dill. ex Linn.	climber

Cnidoscolus chayamansa	Mc Vaugh	Chaya/tree-spinach
Cocos nucifera	Linn.	coconut
Coffea	Linn.	coffee
Coffea arabica	Linn.	arabian coffee
Cola nitida	Schott et Endl.	cola
Colocasia antiquorum	Schott.	taro
Comesperma	Labill.	milkwort
Conocarpus	Linn.	
Conringia	Heist. ex Linn.	crucifer
Convolvulus	(Tourn.) Linn.	convolvulus
Conyza	Linn.	composite
Cooksia [Cookia]	Sonner.	fossil
Copaifera	Linn.	copaiba balsam
Copernicia cerifera	Mart.	carna-uba (wax)
Cordaites [Cordia]	Linn.	
Corchorus capsularis	Linn.	jute
Coronopus	Miller	plantago
Corylus avellana	Linn.	hazel nut
Coscinium fenestratum	Colebr.	trop. liane
Cotula	(Tourn.) Linn.	composite
Couma rigida	Aulb.	
Couma macrocarpa	Barb. Rodr.	
Craspedia	Forst.	composite
Crassula	Dill. ex Linn.	stonecrop
Crataegus	Tourn. ex Linn.	hawthorn
Cucurbita pepo	Linn.	squash
Cupressus	Tourn. ex Linn.	cypress
Cyamopsis tetrogonoloba	DC.	guar
Cynodon	Rich.	grass
Cycas rumphii	Thunb.	sago palm
Cymbonotus	Cass.	composite
Cynara	Vaill. ex Linn.	composite
Cynara scolymus	Linn.	artichoke
Cyperus	Linn.	rush
Dactylis	Linn.	cocksfoot
Danthonia	DC.	grass
Daucus	(Tourn.) Linn.	umbel
Davallia	Sm.	polypod
Dendrobium	Sw.	orchid
Dendrobium heterocarpum	Wall. ex Lindl.	orchid
Dendrobium macarthiae	[Thw.]	orchid
Dendrocalamus asperatum	Backer ex K. Heyene	bamboo
Dendrocalamus hamiltonii	in Linnaea	bamboo
Dendrocalamus latiflorus	Munro	bamboo
Derris elliptica	Benth.	derris
Desmodium	Desv.	tropical legumes
Deyeuxia	Clar.	grass
Dianella	Lam.	lily
Dichelachne	Endl.	grass
Dichopogon	Kunth.	lily
Diospyros ebenum	Keen	ebony
Diospyros kaki	Thunb.	persimmon
Diospyros virginiana	Linn.	persimmon

Dipertocarpus	Gaertn.	dipterocarp
Diplotaxis	DC.	crucifer
Dipodium	R. Br.	orchid
Discorea	Plum. ex Linn.	yam
Diuris	Sm.	orchid
Dodonaea	Linn.	dodder
Doona	Thw.	dipterocarp
Drosera	Linn.	sundew
Durio	Adans.	durian
Durio zibethinus	Murr.	durian
Echinodium	Poit. ex Cass.	
Echium	Tourn. ex Linn.	heliotrope
Eclipta	Linn.	composite
Elaeis guineensis	Jacq.	oil palm
Elateriosperma tapos	Blume	
Eleocharis	R. Br.	rush
Elettaria cardamomum	Manton.	cardamomum
Eperua grandiflora	Benth. & Hook.	
Epilobium	Dill. ex Linn.	willow-herb
Eragrostis	Host.	grass
Eria bicolor	Lindl.	orchid
Erodium	L'Herit.	geranium
Eryngium	(Tourn.) Linn.	umbel
Erythrina	Linn.	coral tree
Erythrina lithosperma	Blume ex Miq.	coral tree
Erythrina poeppigiana	(Wlapers) O.F. Cook	coral tree
Eucalyptus	L'Herit.	eucalypt
Eucalyptus aromaphloia	Pryor & Willis	apple box
Eucalyptus camaldulensis	Dehnh.	river red gum
Eucalyptus cinerea	F. Muell. ex Benth.	mealy stringybark
Eucalyptus cladocalyx	F. Muell.	sugar gum
Eucalyptus diversicolor	F. Muell.	karri
Eucalyptus eremophila	(Diels) Maiden	
Eucalyptus falcata	Turcz.	white mallet
Eucalyptus gunnii	Hook. f.	cider gum
Eucalyptus kruseana	F. Muell.	kruse mallee
Eucalyptus leucoxylon rosea	F. Muell.	yellow gum, pink flower
Eucalyptus leucoxylon	F. Muell.	yellow gum
Eucalyptus macrorhyncha	F. Muell.	red stringybark
Eucalyptus maculata	Hook.	spotted gum
Eucalyptus marginata	Donn ex Sm.	jarrah
Eucalyptus obliqua	L'Herit.	messmate stringybark
Eucalyptus ovata	Labill.	swamp gum
Eucalyptus pauciflora	Siber & Spreng.	snow gum
Eucalyptus pileata	Blakley	
Eucalyptus polybractea	Blakley	
Eucalyptus regnans	F. Muell.	mountain ash
Eucalyptus viminalis	Labill.	manna gum
Eucarya spicata	Mitch.	quandong
Eugenia	Mitch. ex Linn.	eugenia
Eugenia caryophyllata	Thumb.	clove
Euphorbia	Linn.	euphorb
Euphorbia antisyphilitica	Zucc.	euphorb
Eutaxia	R. Br.	merbelid
Exocarpus	Labill.	exocarp
Fagus	(Tourn.) Linn.	beech
Ficus benghalensis	Linn.	bengal fig
Ficus elastica	Roxb.	fig
Fistulina hepatica [Fistularia]	Linn.	
Flaveria	Juss.	composite
Flemingia congesta	Roxb. ex Ait.	phaseolid
Foeniculum	Tourn. ex Linn.	umbel
Fumaria	Tourn. ex Linn.	fumatory
Furcraea gigantica	Vent.	mauritius hemp
Fragaria virginiana	Duchesne	strawberry
Gallium	Linn.	madder
Garcinia mangostana	Linn.	mangosteen
Geranium	(Tourn) Linn.	geranium
Gigantochloa levis	Merrill	
Gliricidia	H. B. & K.	
Gliricidia sepium	H. B. & K.	gliricidia
Glycine	Linn.	soya bean
Gnaphalium	Linn.	composite
Gnetum Gnemon	Linn.	
Gomphichis glutinosus	Lindl.	
Goodenia	Sm.	goodenia
Gossypium	Linn.	cotton
Gratiola	(Rupp.) Linn.	gratiolid
Grevillea	R. Br.	grevillea
Grevillea robusta	A. Cunn.	silky oak
Gymnoschoenus sphaerocephalus	Nees	rush
Gynandriris	Parl.	iris
Haematoxylon campechianum	Linn.	logwood
Haloragis	Forst.	halogarid
Hardenbergia	Benth.	phaseolid
Hedypnois	(Tourn.) Scop.	composite
Helichrysum	Vaill. ex Linn.	everlasting
Heliotropium	(Tourn.) Linn.	heliotrope
Helipterum	DC.	everlasting
Hemitelia latebrosa	Br.	tree-fern
Hevea brasiliensis	Muell. Arg.	rubber tree
Hibiscus subdariffa	Linn.	rosella hemp
Holcus	Linn.	fog-grass
Homeria	Vent.	iris
Hordeum	(Tourn.) Linn.	barley grass
Hydrocotyle	(Tourn.) Linn.	umbel
Hypericum	Tourn. ex Linn.	gutterifer
Hypochoeris	Linn.	composite
Hypoxis	Linn.	yellowstar
Ilex	(Tourn.) Linn.	holly
Imperata	Cyrilli.	lalang
Indigofera	Linn.	indigo
Inga	Scop.	inga
Inga edulis	Scop.	inga
Inula	Linn.	composite
Iris florentina	Linn.	orris
Isoetopsis	Turcz.	composite
Josephia latifolia	Wight.	orchid
Juncus	(Tourn.) Linn.	rush

Juniperus	Tourn. ex Linn.	juniper
Juglans	Linn.	walnut
Kennedia	Vent.	kennedia
Kickxia	Blume.	figwort
Kigelia africana	Benth.	sausage tree
Koeleria	Pers.	grass
Lagurus	Linn.	grass
Lannea grandis	Engl.	
Laurus nobilis	Cav.	laurel
Lavandula	Tourn. ex Linn.	lavender
Lavandula vera	DC.	lavender
Laxmannia	R. Br.	lily
Lepidium	Linn.	crucifer
Lepidosperma	Labill.	sedge
Leptorhynchus	Less.	composite
Leptospermum hybrids	Forst.	hybrid ti-tree
Leptospermum juniperinum	Sm.	ti-tree
Leptospermum laevigatum	F. Muell.	ti-tree
Leptospermum lanigerum	Sm.	ti-tree
Leucadendron platyspermum	Berg.	
Leucadendron	Forst.	
Leucadendron daphnoides	Meissn.	
Leucadendron galpinii	Phillips & Hutchinson	galpin conebush
Leucadendron orientale	I.J.M. Williams	
Leucadendron salignum	Berg.	
Leucadendron xanthoconus	Berg.	
Leucaena	Benth.	leucaena
Leucaena leucocephala	(Lam.) de Wit	legume
Leucospermum Caroline	R. Br.	caroline coneflower
Ligustrum walkeri	[Tourn.] Linn.	privet
Linum	Tourn. ex Linn.	flax
Linum usitatissimum	Griseb.	flax
Liparis viridifolia	Rich.	orchid
Lithospermum	(Tourn.) Linn.	
Litsea ovalifolia	Trimen	laurel/avocado
Lobaria oregana	Haw.	
Lobelia	Plum. ex Linn.	lobelia
Lolium	Linn.	rye-grass
Lomandra	Labill.	lily
Lonchocarpus nicou	DC.	rotenone
Lotus	(Tourn.) Linn.	trefoil
Luzula	DC.	wood rush
Lycium	Linn.	thorn
Lysiana	Van Tiegh.	
Lythrum	Linn.	loosestrife
Macranga	Thou.	euphorb
Madhuca longifolia	Macbride	mee
Mallotus philippinensis	Karst.	mallotus
Malus	Tourn. ex Linn.	apple
Malva	(Tourn.) Linn.	mallow
Mangifera caesia	Jack	mango

Mangifera indica	Wall	mango
Maranta arundinacea	Linn.	arrowroot
Marrubium	Tourn. ex Linn.	horehound
Marsilea	Linn.	marsilea
Medicago	Tourn. ex Linn.	medic
Melaleuca	Linn.	paper-bark
Melaleuca halmaturorum	F. Muell. ex Miq.	paper-bark
Melilotus	Tourn, ex Hall.	melilot
Mentha	(Tourn.) Linn.	mint
Mesua	Linn.	mangosteen
Metroxylon sagu	Mart.	sago palm
Michelia	Linn.	magnolia
Michelia champaca	Th. Dur.	champak
Microseris	D. Don.	composite
Miltonia	Lindl.	orchid
Minuria	DC.	composite
Molineria	Parl.	grass
Monerma	Beauv.	grass
Monstera deliciosa	Leibm.	monstera
Moringa pterygosperma	Gaertn.	moringa
Morus nigra	Linn.	mulberry
Muntingia	Plum. ex Linn.	elaeocarp
Musa	G.C.G. Argent.	hemp/plantain
Musa textilis	Nee	manila hemp
Myroxylon balsamum	Harms	balsam of peru
Myosotis	Linn.	forget-me-not
Myriocephalus	Benth.	composite
Myristica fragrans	Houtt.	nutmeg
Neatostema	I.M. Johnston	
Neolitsea involucrata	Alston	avocado
Nephelium lappaceum	Linn.	rambutan
Nephrolepis	Schott.	epiphyte
Nessia	Steud.	
Neurachne	R. Br.	grass
Nipa	Thunb.	
Nothofagus cunninghamii	Oerst.	myrtle beech
Nothopanax pinnatum	Miq.	ivy
Octarrhena parvula	Thw.	orchid
Oenothera	Linn.	fuschia
Olea	(Tourn.) Linn.	olive
Olea europa	Jacq.	olive
Olea welwitschii	(Tourn.) Linn.	olive
Olearia	Moench.	composite
Onopordum	Linn.	thistle
Opercularia	Gaertn.	opercularia
Oroxylon indicum	Vent.	
Oryzopsis	Michx.	grass
Oryza sativa	Linn.	rice
Oxalis	Linn.	oxalis
Pangium edule	Reinw.	flacourtiad
Panicum	Linn.	millet
Papaver	Tourn. ex Linn.	poppy
Parentucellia	Viv.	
Parietaria	(Tourn.) Linn.	nettle
Parkia javanica	Merril	
Passiflora edulis	Sims	passion-fruit

Peltaphorum ferrugineum	Walp.	legume
Peumus boldus	Molina	
Persea americana	Plum. ex Linn.	avocado
Pelargonium	L'Herit.	pelargonium
Peucedanum graveolens	S. Wats.	dill
Phalaenopsis	Blume	orchid
Phalaris	Linn.	grass
Phoenix sylvestris	Linn.	indian date palm
Phleum	Linn.	grass
Phyllanthus	Linn.	euphorb
Phyllostachys bambusoides	Sieb. & Zucc.	cane
Phyllostachys pubescens	Torr.	cane
Phyllostachys vivax	Mc Clure	cane
Picea	Link.	spruce
Picris	Linn.	composite
Pimelea	Banks et Soland.	rice-flower
Pinus	[Tourn.] Linn.	pine
Pinus elliotti	Engelm.	slash pine
Pinus pinaster	Ait.	maritime
Pinus radiata	D. Don	monterey pine
Pinus roxburghii	Sarg.	chir pine
Pinus strobus	Linn.	white pine
Piper nigrum	Linn.	black pepper
Pittosporum	Banks	pittosporum
Planchonia valida	Blume	pear
Plantago	(Tourn.) Linn.	plantain
Platanus	[Tourn.] Linn.	plane
Plumeria	Tourn. ex Linn.	plumeria
Poa	Linn.	meadow-grass
Podolepis	Labill.	composite
Polygonum	(Tourn.) Linn.	buckwheat
Polypodium	Linn.	
Populus	Linn.	poplar
Poranthera	Rudge	euphorb
Portulaca	Linn.	purslane
Prasophyllum	R. Br.	orchid
Pratia	Gaudich.	campanula
Prosopis	Griseb.	algaroba
Prosopis juliflora	DC.	
Protea	Linn.	protea
Protea repens	Thunb.	protea
Prumnopitys andina	D.J. deLaubenfels	
Prunus amygdalus	Stokes	almond
Pseudo tsuga taxifolia	Britton	Douglas-fir
Psidium	Linn.	guava
Psidium guyava	Linn.	guava
Psophocarpus tetragonolobus	DC.	goa bean
Psoralea	Linn.	legume
Psychotria	Linn.	madder
Pteridium	Gled.	bracken
Pterocarpus indicus	Linn.	legume/sandalwood
Ptilotus	R. Br.	amaranth
Pyrus malus	Linn.	apple
Quassia amara	Linn.	quassia
Quercus	(Tourn.) Linn.	oak
Quercus alba	Linn.	white oak

Rafflesia	R. Br.	rafflesia
Ranunculus	(Tourn.) Linn.	ranunculus
Raphanus	(Tourn.) Linn.	crucifer
Rapidophora	Hassk.	
Rhagodia	R. Br.	chenopod
Rhipsalis	Gaertn.	cactus
Rhizophora mangle	Linn.	mangrove
Rhododendron	Linn.	rhododendron
Rhynia		fossil
Romulea	Maratti.	iris
Roripa	Scop.	crucifer
Rosa	Tourn. ex Linn.	rose
Rosmarinus officinalis	Linn.	rosemary
Rumex	Linn.	sorrel
Rutidosis	DC.	composite
Sagina	Linn.	alsinid
Salacia reticulata	Wight	liane
Salix	[Tourn.] Linn.	willow
Salvia	(Tourn.) Linn.	labiate
Samanea saman	Merrill	
Santalum	Linn.	sandalwood
Santalum album	Linn.	monkeypod
Sansevieria	Thumb.	bow-string hemp
Sarchochilius	Vidal	orchid
Sarcochilus	R. Br.	orchid
Scabiosa	(Tourn.) Linn.	scabiosa
Scaevola	Linn.	scaevola
Schefflera aromatica	Harms	
Schismus	Beauv.	grass
Schizostachyum brachycladium	Kurz	grass
Schoenus	Linn.	rush
Scirpus	Linn.	sedge
Sebaea	Soland ex R. Br.	gentian
Semecarpus	Linn.	pepper tree
Senecio	(Tourn.) Linn.	composite
Sesbania grandiflora	Poir.	sesbania
Sequoia sempervirens	Endlicher	redwood
Sherardia	Dill. ex Linn.	
Silene	Linn.	silene
Silybum	Vaill. ex Adans.	composite
Sisymbrium	(Tourn.) Linn.	tumbleweed
Solanum	(Tourn.) Linn.	solanum
Solanum tuberosum	Linn.	potato
Sonchus	(Tourn.) Linn.	milk-thistle
Sonneratia acida	Benth.	tree-vegetable
Sparaxis	Ker-Gawl.	iris
Spergularia	J. et C. Presl	spergularia
Spondias	Linn.	
Spondias pupurea	Linn.	
Sporobolus	R. Br.	grass
Stachys	(Tourn.) Linn.	labiate
Stackhousia	Sm.	stackhousia
Stellaria	Linn.	chickweed
Stipa	Linn.	grass
Swainsona	Salisb.	pea
Syzygium aromaticum	Thunb.	clove
Tagetes minuta	Linn.	stinking roger
Tamarindus indica	Lindl.	tamarind

Taraxacum	Linn.	composite
Taxus	[Tourn.] Linn.	needle-leafed taxus
Tectona grandis	Linn.	teak
Teline	Medic.	
Terminalia catappa	Linn.	country almond
Teucrium	(Tourn.) Linn.	labiate
Themeda	Forsk.	grass
Theobroma cacao	Linn.	cacao
Thuja plicata	D. Don	red cedar
Thysanotus	R. Br.	lily
Tragopogon	(Tourn.) Linn.	composite
Trema	Lour.	urticale
Trevesia sundaica	Miq.	
Tricholoma aggregatum	Benth.	
Tricoryne	R. Br.	lily
Trifolium	(Tourn.) Linn.	trefoil
Tsuga canadensis	Carriere	eastern hemlock
Ulex	Linn.	gorse
Urtica	(Tourn.) Linn.	nettle
Vaccaria	Medic.	caryophyll
Vaccinium	Tourn.	blueberry

Vaccinium corymbosum	Linn.	blueberry
Vanda	Jones	orchid
Vanilla	Plum. ex Mill.	vanilla
Vanilla planifolia	Plum. ex Mill.	vanilla
Velleia	Sm.	
Verbascum	Tourn. ex Linn.	verbascum
Veronica	(Tourn.) Linn.	speedwell
Vicia	Tourn. ex Linn.	vetch
Viola	Tourn. ex Linn.	violet
Virola	Aulb.	
Vittadinia	A. Rich.	composite
Vitis	[Tourn.] Linn.	grape
Vitis vinifera	Linn.	grape
Vulpia	C.C. Geml.	grass
Wahlenbergia	Schrad.	bell-flower
Westringia	Sm.	labiate
Wilkiea	F. Muell.	
Xanthium	(Tourn.) Linn.	composite
Zingiber officinale	Rosc.	ginger

REFERENCES

Achmad, H.G., Mortadihardja, A. and Suharto (1979). *Social and Cultural Aspects of Home-gardens.* 1-5. Proceedings Vth International Symposium of Tropical Ecology. Kuala Lumpur.

ACIL, Australia Pty. Ltd. (1983). *Causes, Extent and Effects of Salinity in Victoria.* A Report to the Salinity Committee of the Victorian Parliament.

Adamson, D.A. and M.D. Fox (1982). Change in Australian vegetation since European settlement, 109-146 In: J.M.B. Smith (ed.) *A History of Australian Vegetation*. McGraw-Hill, Sydney.

Adis, J. (1988). Abundance and density of arthropods in central Amazonian dry land forests. *Journal of Tropical Ecology.* **4**, 19-24. CUP, Cambridge.

Ahern, D.L. and A.L. Yen (1977). A comparison of the invertebrate fauna under *Eucalyptus* and *Pinus* forests in the Otway ranges, Victoria. *Proceedings of the Royal Society of Victoria.* **89**,127-136.

Aho, P.E. (1974). Distribution, enumeration and identification of nitrogen-fixing bacteria associated with decay in living white-fir trees. *Phytopathology.* **64**,1413-1420.

Allison, F.E. (1973). *Soil Organic Matter and its Role in Crop Production.* Elsevier Scientific Publishing Co., New York.

Almon, D. (1991). A plot study of forest litter floor frogs, central Amazon, Brazil. *Journal of Tropical Ecology.* **7**, 503-523.

Altieri, M. (1983). *Agroecology.* University of California, Berkeley, California.

Altieri, M. and L.C. Merrick (1988). Agroecology and *in situ* conservation of native crop diversity in the third world. In: E.O. Wilson (ed.) *Biodiversity*, 361-369. National Academic Press, Washington D.C.

Anderson, J.R.(1978). Pesticide effects on non-target and soil microorganisms. In: I.R. Hill and S.J.L. Wright *Pesticide Microbiology*, 313-504. Academic Press, London.

Anon, (1966). *The Oxford Dictionary of Current English.* Oxford University Press, London.

Anon, (1971a). *Webster's New World Dictionary.* The World Publishing Co., New York.

Anon, (1971b). *Encyclopedic World Dictionary.* The Hamlyn Publishing Group, Griffin Press, Netley, South Australia.

Anon, (1978). *The American Heritage Dictionary.* Houghton Mifflin Co., Boston.

Anon, (1979). Forest biomass as an energy source. In: *Study Report of a Task Force of the Society of American Foresters.* 1-7. Society of American Foresters, Washington D.C.

Anon, (1985). *National Parks for a New Generation.* The Conservation Foundation, Washington, D.C.

Anon, (1986). *The Master Plan for Forestry in Sri Lanka.* Jaakko Poyry Oy. (JPI) and Ministry of Land and Land Development, Colombo, Sri Lanka.

Anon, (1990). *International Visitor Survey.* Bureau of Tourism Research, Canberra, ACT.

Anon, (1991). *Decade of Landcare Plan: Commonwealth Component.* Department of Primary Industry and Energy, Canberra.

Anon, (1991a). *Farm Forestry Register.* Department of Conservation, Forests and Lands, Melbourne, Victoria, Australia.

Anon, (1992). Neem: a tree for solving global problems. In: *Report of an Ad Hoc Panel of the Board of Science and Technology of International Development National Research Council.* 141. National Academy Press, Washington D.C.

Anon, (1994). *World Almanac and Book of Facts.* Funk and Wagnalls Co, New Jersey.

Armstrong, G. (1992). A necessary evil? *Veld and Flora.* March, 10-13.

Arnason, T. R., Hebda, J. and T. Jhons (1981). Use of plants as food and medicine by native peoples of eastern Canada. *Canadian Journal of Botany.* **59**, 2189-2325.

Ashton D.H. (1981a). The ecology of the boundary between *Eucalyptus regnans* F. Muell. and *E. obliqua* l'Herit in central Victoria. *Proceedings of Royal Ecological Society of Australia.* **ll**, 75-94.

Ashton, D.H. (1981b). Tall open-forests. In: R.H. Groves (ed.) *Australian Vegetation*, 121-151. Cambridge University Press, Sydney.

Attiwill, P. and D. Chambers (1994). Ash bed effects. *Australian Journal of Botany.*January. **42**, 739-749.

Attiwill, P.M. and G.W. Leeper (1987). *Forest Soils and Nutrient Cycles.* Melbourne University Press, Melbourne.

Baker F.S. (1950). *Principles of Silviculture.* Mc Graw-Hill, New York.

Banks, H.P. (1970). *Evolution and Plants of the Past.* McMillan Press Ltd., London.

Barghoon, E.S. (1964). Evolution of the Cambrian in geologic time. In: M.H. Zimmerman (ed.) *The Function of Wood in Forest Trees.* 3-17. Academic Press, New York.

Barrow, N.J. (1969). The accumulation of soil organic matter under pasture and its effect on soil properties. *Australian Journal of Experimental Agriculture & Animal Husbandry.* **9**, 9-16.

Barson, M.M. and R.M. Gifford (1990). Carbon dioxide sinks: the potential role of tree planting in Australia In: D.J. Swaine (ed.) *Greenhouse and Energy.* 433-443. CSIRO, Melbourne.

Baur, G. (1974). Multiple use of the forest resource. *Search.* **5**,374-380.

Beck, C.B. (1970). *Biological Review.* **45**, 379-400.

Beckermann, G.G and G.D. Hubble (1974). The significance of radio carbon measurements of humus from krasnozems (ferrasols) from sub-tropical Australia. *International Congress of Soil Science.* **6**, 362-371.

Beckermann, G.G. and R.J. Coventry (1987). Soil erosion losses: squandered withdrawals from a diminishing account. *Search.* **18,** 21-26.

Behan, R.W. (1975). Forestry and the end of innocence. *American Forester.* **81,**16-19.

Berg, R.Y. (1975). Mymercochorous plants in Australia and their dispersal by ants. *Australian Journal of Botany.* **23,** 475-508.

Bhadauria, T. and P.S. Ramakrishnan (1991). Population dynamics of earthworms and their activity in forest ecosystems of north-east India. *Journal of Tropical Ecology.* **7**, 305-318.

Bird, E.C.F. and M.L. Schwartz eds. (1985). *The World's Coastline.* van Nostran-Reinhold, Strasbourg.

Bird, R. (1981). The benefits of tree planting and factors which influence the effectiveness of shelterbelts. *Trees -Victoria's Resources.* **23,** 4-6.

Blainey, G. (1980). *The Tyranny of Distance: How Distance Shaped Australia.* Macmillan, Melbourne.

Blanford, H.R. (1958). Highlights of one hundred years of forestry in Burma. *Empire Forestry Review.* **37**, 33-42.

Board on Science and Technology for International Development (BOSTID)(1979). *Tropical Legumes: Resources for the Future.* National Academic Press, Washington, D.C.

Boonkird, S.A. Fernandes, E.C.M., and P.K.R. Nair (1984). Forest villages: an agroforestry approach to rehabilitating forest land degraded by shifting cultivation in Thailand. *Agroforestry Systems.* **2**, 87-102.

Bourke, S. and R. Youl (1990). The revegetation of Victoria: the first stages. *Proceedings of Ecological Society of Australia.* **16**,135-140.

Bowles, J.B. (1963). *Ornithology of changing forest stands on the western slopes of the Cascade Mountains in central Washington.* Unpublished M.S. Thesis University of Washington, Seattle.

Brandani, A., Hartshorn, G.S. and G.H. Orians (1988). Internal heterogeneity of gaps and species richness in a Costa Rican tropical wet forest. *Journal of Tropical Ecology.* **4,** 99-119.

Bren, L.J., Flinn, D.W., Hopmans, P. and C.J. Leitch (1979). The hydrology of small forested catchments in north-eastern Victoria. *Forests Commission of Victoria Bulletin.* **27.** Melbourne.

Bridgewater, P.B. (1988). Synthetic plant communities: problems in definition and management. *Flora.* **180**, 139 -144.

Broadman, R. (1986). The history and evolution of South Australia's forests and woodlands. In: H.R.Wallace (ed.) *Ecology of Forests and Woodlands in South Australia,* 16-32 Handbooks Committee, Government Printer, Adelaide.

Brown, A. and N. Hall (1968). *Growing Trees on Australian Farms.* Department of National Development, Canberra.

Brown, G. (1971). Water temperature in small streams as influenced by environmental factors and logging. In: J.T. Krygier and J.D. Hall (eds) *Proceedings of a Symposium. Forest Land Uses and Stream Environment,* 175-181. Oregon State University, School of Forestry, Corvallis, Oregon.

Brunig, E.F. (1983). Designing ecologically stable plantations. In: K.F. Wiersum (ed.) *Strategies and Designs for Afforestation, Reforestation and Tree Planting,* 384-359. Pudoc, Wageningen.

Budowski, G. (1984). Biological diversity and forestation in the tropics. In K.F. Wiersum (ed.) *Strategies and Designs for Afforestation, Reforestation and Tree Planting,* 115-126. Pudoc, Wageningen.

Campbell, A., Jack, J. and P. Mathews (1989). *Potter Farmland Plan Project.* Report to Ian Potter Foundation, Melbourne.

CDIAC (1990). *Trends '90: A Compendium of Data on Global Change.* T.A. Boden, P. Kanciruk and M.P. Farrell (eds) Carbon Dioxide Information Analysis Center, Oak Ridge, Tennessee.

Cerra, R., Marks, G.C. & Kassaby, F.Y. (1987). *Effect of Herbicides on* Phytophthora cinnamomi *Root Disease and Associated Soil Microflora in a Radiata Pine Nursery.* Department of Conservation, Forests and Lands, Victoria, Australia.

Clark, R.L. (1983). Pollen and charcoal evidence for the effects of aboriginal burning on the vegetation of Australia. *Archaeology Oceania.* **28**, 32 -7.

Clark, R.L. (1990). Ecological history for environmental management, 1-21. In: D.A. Saunders, A.J.M. Hopkins and R.A. How, (eds) Australian ecosystems: 200 years of utilisation, degradation and reconstruction. *Proceedings of Ecological Society of Australia.* **16, i-viii,** 1-602.

Clark, W.C. (1971). *Place and People: Ecology of a New Guinea Community.* University of California and ANU Press, Berkeley.

Clark, W.C. (1976). Maintenance of agriculture and human habitats within tropical forest ecosystem. *Human Ecology.* **4**, 247-259.

Coffey, S.G. and G.M. Halloran (1979). Higher plants as possible sources of petroleum substitutes. *Search.* **10,** 423-428.

Conklin, H.C. (1980). *Ethnographic Atlas* Hernani Agriculture, London.

Conran, J.G. and R.W. Rogers (1983). Lichen succession on leaves of *Wilkiea macrophylla* in southern Queensland, *Lichenologist.* **56,** 347-353.

Coomaraswamy, A.K. (1947). *The Bugbear of Literacy.* Dennis Dobson Ltd., London.

Coomaraswamy, A.K. (1979). *The Bugbear of Literacy.* Perennial Books, Middlesex.

Cornelissen, J.H.C. and H. Ter Steege (1989). Distribution and ecology of epiphytic bryophytes and lichens in dry evergreen forest in Guyana. *Journal of Tropical Ecology.* **5**.131-150.

Corner, E.J.H. (1964). *The Life of Plants.* Weidenfeld and Nicholson, London.

Cribb, A.B. and J.W. Cribb (1981). *Wild Medicine in Australia.* Collins Books, Sydney.

CSIRO (1986). Forests and their products. *CSIRO Research for Australia,*12. Canberra, ACT.

Cummings, W.H. (1941). A method of sampling the foliage of a silver maple tree. *Journal of Forestry.* **39**, 282-384.

Curtis, A. (1995). Landcare in Victoria. *Johnstone Centre of Parks Recreation and Heritage Report*, 24. Charles Sturt University, Albury.

Dale, V.H., Gardener, R.H. and M.G. Turner (1989). Predicting across scales - comments of the guest editors of Landscape Ecology. *Landscape Ecology.* **3**, 147-152.

Davis, S. (1983). *Dukarv; the East Arnhem Road Proposal,* Report Prepared by Landsearch for Aboriginal Advisory and Development Services. United Church, Northern Synod, Darwin.

Davis, W. (1945). Great Britain. In: Establishment and early management of sown pastures. *Imperial Bureau of Pastures and Forage Crops, Bulletin* **34.** Aberystwyth, Great Britain.

Dennison, W.C. (1973). Life in tall trees. *The Scientific American.* **228**, 75-81.

Donnelly, M.A. (1988). Demographic effects of reproductive resource supplementation in a territorial frog, *Dendrobates pumilio. Ecological Monographs.* **59**, 207-221.

Douglas, J. and R.A. de Hart (eds) (1973). *Forest Farming.* UNESCO, Paris.

Downing, D.J. (1988). *Country of My Spirit.* Australian National University, Darwin.

Driscoll, P.V. (1977). Comparison of bird counts from pine forests and indigenous vegetation. *Australian Wildlife Research.* **4,** 281-288.

Dunham, K.M. (1991). Comparative effects of *Acacia albida* and *Kigelea africana* on soil characteristics in Zambesi riverine woodlands. *Journal of Tropical Ecology.* **7**, 215-220.

DWRV (1986). Salinity in Victoria: physical control options. *Department of WaterResources, Victoria, Technical Report.* **15**. Melbourne.

Edwards, C. (1969). Soil pollutants and soil animals. *Scientific American.* **220**, 88-99.

Erwin, T.L. (1983). Beetles and other arthropods of the tropical forest canopies at Manaus, Brazil, sampled with insecticidal fogging techniques. In: S.L. Sutton, T.C. Whitmore and A.C. Chadwick. (eds) *Tropical Rainforests: Ecology and Management,* 59-75. Blackwell Scientific Publications, Oxford.

Erwin, T.L. (1988). The Tropical forest canopy. In: E.O. Wilson (ed.) *Biodiversity,* 23-129. National Academic Press, Washington, D.C.

Erwin, T.L. and J.C. Scott (1980). Seasonal and size patterns, trophic structure, and richness of Coleoptera in the tropical arboreal ecosystem: the fauna of the tree *Lucuma seemannii,* Triana and Planch, in the canal zone of Panama. *Coleoptera Bulletin.* **34,** 305-322.

Evans, J. (1984). Soil and water management aspects of forestation. In: K.F. Wiersum (ed.) *Strategies and Designs for Afforestation, Reforestation and Tree Planting,* 96-114. Pudoc, Wageningen.

Ewel, J. (1976). Litterfall and Leaf Decomposition in a Tropical Succession in Eastern Guatemala. *Journal of Ecology.* **64**, 293-308.

FAO (1988). An Interim Report on the State of Forest Resources in the Developing Countries. *Forest Resources Division, Forest Department. FO:Misc.* **88,7,** FAO, Rome.

Farmer, E. (1973). Relative detachability of soil particles by simulated rainfall. *Soil Society of America Proceedings.* **37**, 629-633.

Fernow, B.E. (1902). *Economics of Forestry.* Crowell, New York.

Fish, D. (1983). Phytotelmata: flora and fauna. In: J.H. Frank and L.P. Louinbos (eds) Phytotelmata *Terrestrial Plants as Hosts of Aquatic Insect Communities,* 1-27. Plexus, Melford, New Jersey.

Fogel, R. (1980). Mycorrhizae and nutrient cycling in natural forest ecosystems. *New Phytologist.* **86**, 199-212.

Foreman, R.T.T. and M. Godron (1986). *Landscape Ecology.* John Wiley and Sons, New York.

Foster, A.S. and E.M. Gifford Jr. (1959). *Comparative Morphology of Vascular Plants.* W.H. Freeman and Company, San Francisco and London.

Forster, R.R. and C.L. Wilson (1973). The spiders of New Zealand, Part IV. *Otago Museum Bulletin.* **4**, Dunedin.

Forsyth, A, and K. Miyata (1984). *Tropical Nature: Life and Death in the Rainforests of Central and South America.* Scribner's, New York.

Franklin, J. F. (1988). Structural and functional diversity in temperate forests. In: E.O. Wilson (ed.) *Biodiversity,* 166-175. National Academic Press, Washington, D.C.

Franklin, J.F., Spies, T., Perry, D., Harmon, M. and A. Mc Kee (1986). Modifying Douglas-fir management regimes for non-timber objectives. In: C.D.Oliver, D.P.Hanley and J.A. Johnson (eds) *Douglas-fir Stand Management for the Future, 373-379.* College of Forest Resources, University of Washington, Seattle.

Frawley, K.J. (1989). 'Cultural landscapes' and National Parks : philosophical and planning issues, *Australian Parks and Recreation.* **25**, 16-23.

Gans, C. (1973). Uropeltid snakes- survivors in a changing world. *Endeavour.* **32**, 60-65.

Garland, K.R, Fisher, W.W. and P.J. Greig (1984). Agroforestry in Victoria. *Technical Report Series* **93**. Department of Agriculture, Melbourne.

Gaussen, H., Viart, M., Legris, P. and I. Labroue (1968). *Explanatory Notes on the Vegetation Map of Ceylon,* 1-69. Government Press, Ceylon.

Ghilarov, M.S. (1963). On the interrelations between soil dwelling invertebrates and soil micro-organisms. In: J. Doeksen and J. Van Der Drift (eds) *Soil Organisms,* 255-259. North Holland Publishing Company, Amsterdam.

Gholz, H.L. (1987). Introduction. In: H.L. Gholz (ed.) *Agroforestry: Realities, Possibilities and Potentials,* 1-6. Martinus Nijhoff Publishers, Dordrecht, Netherlands.

Gilbert, F.A. and R.F. Robinson (1957). Microbial chemicals. *Economic Botany.* **11**,141-144.

Gilbert, F.S. (1980). The equilibrium theory of island biogeography: fact or fiction? *Journal of Biogeography.* **7**,209-35.

Gilmour, D.A. (1968). Hydrological investigations of the soil and vegetation types in the lower Cotter catchment. *Australian Forestry.* **32**, 243-256.

Goldsmith, E. (1982). Traditional agriculture in Sri Lanka. *The Ecologist.* **12**, 209-216.

Goldstein, I.S., Holley, D.L. and E.L. Deal (1978). Economic aspects of low-grade hardwood utilisation. *Forest Products Journal.* **28**, 53-56.

Grantham, J.B. (1974). Energy and raw material potentials of wood residue in the Pacific Coast States - a summary of a feasibility investigation. *General Technical Report, PNW*-18. Department of Agriculture and Forest Service, California.

Grinell, J. and H.S. Swarth (1913). An account of the birds and mammals of the San Jacinto area of southern California, with remarks upon the behaviour of geographic races on the margins of their habitats. *University of California Publication, Zoology.* **10**. 197-406.

Hailey, L. (1957). *An African Survey.* Oxford University Press, Oxford.

Halle, F. and R.A.A. Olderman (1970). *The Architectural Dynamics of Tropical Forests and Trees* . B.C. Stone (transl.), Penerbit University of Kula Lumpur, Malaysia.

Halle, F., Olderman, R.A.A. and P.B. Tomlinson (1978). *Tropical Trees and Forests.* Springer-Verlag, New York.

Halliday, J. and P.L. Nakao (1982). *The Symbiotic Affinities of Woody Species Under Consideration as Nitrogen Fixing Trees*, 76pp. Niftal Project Report. University of Hawaii, Hawaii.

Hamilton, L.S. (1989). Some soil and water concerns associated with commercial biofuels operations. *Tiger Paper.* **XVI**, Forest News Vol III(1)1-5 FAO Bangkok.

Hamilton, L.S. and P.N. King (1983). *Tropical Watersheds: Hydrologic and Soil Response to Major Uses or Conversions.* Westview Press, Boulder, Colorado.

Harmon, M.E. and C. Hua (1990). Coarse woody debris dynamics in two old-growth ecosystems. *Bioscience.* **41**, 604-610.

Harr, H.D. (1982). Fog drip in the Bull Run municipal watershed. *Oregon Water Research Bulletin.* **18**, 785-789.

Harris, L.D. (1984). *The Fragmented Forest.* University of Chicago Press, Chicago.

Harris, L.D., Maser, C. and A. Mc Kee (1982). Patterns of old-growth harvest and implications for Cascades wildlife. *Transactions of the North American Wildlife Natural Resources Conference.* **47**, 374-392.

Hart, R.D. (1980). A natural ecosystem analog approach to the design of a successional crop system for tropical forest environments. *Biotropica.* **12**, 73-83.

Heisler G.M. and D.R. Dewalli (1988). Effects of windbreak structure on wind flow. In: *Agricultural Systems and Environment,* 22/23, 41-69. Elsevier Science Publications, B V, Amsterdam.

Henderson, C.L. (1981). *Landscaping for Wildlife.* Minnesota Department of Natural Resources, St. Paul, Minnesota.

Henning, D.H. (1991). Tropical forest values of protected areas. *Tiger Paper.* **XVII**, 24-32 FAO, Bangkok.

Hobbs R.J. and A.J.M. Hopkins (1990). From frontier to fragments: European impact on Australia's vegetation. *Proceedings of Ecological Society of Australia.* **16**, 93-114.

Holland, H.D. (1984). *The Chemical Evolution of the Atmosphere and the Oceans.* Princeton University Press, Princeton, New Jersey.

Holland, P.G. (1969). The maintenance of structure and shape in three mallee Eucalypts. *New Phytologist.* **68**, 411-421.

Holzworth, P. (1991). Foresters- ancient and modern. *Institute of Foresters of Australia, Newsletter.* **32**, 23-24.

Hooker J.D. (1860). On some of the naturalised plants of Australia. In: The Botany (of) the Antarctic Voyage, part III. *Flora Tasmaniae* **I**. Lovell Reeve, London.

Howett, S. and A. Lothian (1988). *Benefits of Tree Establishment on Farms; A Survey of Landholders' Experiences.* Department of Environment and Planning, South Australia.

Hsiung, W. (1988). Prospects for bamboo development in the world. *Proceedings of International Bamboo Conference.* Development of Bamboo in the World, Paris, France.

Hughes, L. (1990). Seed dispersal by ants in sclerophyll vegetation. *Australian Journal of Ecology.* **17**, 112-114.

Hutchinson, G.E. (1965). *The Ecological Theater and the Evolutionary Play.* Yale University Press, New Haven, Connecticut.

Iltis, H. (1988). Serendipity in the exploration of biodiversity. In: E.O. Wilson (ed.) *Biodiversity*, 98-105. National Academic Press, Washington, D.C.

Jackman, I. (1960). Organic matter stability and nutrient availability in Taupo pumice. *New Zealand Journal Agricultural Research.* **3**, 6-23.

Jackson, W.D. (1968). Fire, air, water and earth: an elemental ecology of Tasmania. *Proceedings of the Ecological Society of Australia.* **3**, 9-16.

Jacob, V.J. and W.S. Alles (1987). The Kandyan gardens of Sri Lanka. *Agroforestry Systems.* **5**,123-137.

Jambulingam, R and E.C.M. Fernandes (1986). Multipurpose trees and shrubs on farmlands in Tamil Nadu State (India). *Agroforestry Systems.* **4**,17-23.

Jayaweera, D.M.A. (1979). *Medicinal Plants Used in Ceylon, Pt 1-4.* National Science Council, Sri Lanka, Colombo.

Jeffries, M (1991). The ecology and conservation value of forestry ponds in Scotland, United Kingdom. *Biological Conservation.* **58,** 191-211.

Jehne, W. and C.H. Thompson (1981). Endomychorrhizae in plant colonisation on coastal sand-dunes at Cooloola, Queensland. *Australian Journal of Ecology.* **6**, 221-30.

Jenkins, B. and R.L Kitching (1990). The ecology of water-filled treeholes in Australian rainforests: food web reassembly as a measure of community recovery after disturbance. *Australian Journal of Ecology.* **15**, 199-205.

Jenkins, R.E. Jr. (1988). Information management for the conservation of biodiversity. In E.O. Wilson (ed.) *Biodiversity.* 231-239. National Academic Press, Washington, D.C.

Jenny, H. (1961). *The Factors of Soil Formation.* McGraw-Hill, New York.

Jones, H.G. (1976). Crop characteristics and the ratio between assimilation and transpiration. *Journal of Applied Ecology.* **13**, 605-622.

Karunaratne, P.B. (1993). *Personal Communication to Author on a Survey of the Sinharajah Forest, Sri Lanka.* WCMC, Forest Department, Battaramulla, Sri Lanka

Keast, A. (1981). *Ecological Biogeography of Australia.* **1**, 196-206. W. Junk, The Hague.

Kean, J.S., G. Richardson and N. Trueman (1988). *Aboriginal Role in Nature Conservation.* Emu Conference, Emu, South Australia.

Kenkel, N.C. and G.E. Bradfield (1986). Epiphytic vegetation on *Acer macrophyllum:* a multivariate study of species-habitat relationships. *Vegetatio.* **68**, 43-53.

Kershaw A.P. (1986). Climatic change and aboriginal burning in north-east Australia during the last two glacial/inter-glacial cycles. *Nature.* **322**, 47-49.

King, K.F.S. (1968). Agri-silviculture. *Bulletin* **1.** Department of Forestry, University of Ibadan, Nigeria.

King, K.F.S. (1989). The history of agroforestry. In: P.K.R. Nair (ed.) *Agroforestry Systems for the Tropics.* 3-11. Kluwer Academic Publishers, Dordrecht.

Knudtson P. and D. Suzuki (1992). *Wisdom of the Elders.* Allen and Unwin, London.

Koch, N.R.E. and J.J. Kennedy (1991). Multiple-use forestry for social values. *Ambio.* **20**, 330-333.

Kohlmaier, G.H., Brohl, H., Fischback, U., Kratz, G., and E.O. Shire, (1983). Role of the biosphere in the carbon cycle and biota models. In: W. Bach, A.J. Crane, A.L.Berger and A. Longhetto (eds) *Carbon Dioxide, Current Views and Developments in Energy/Climate Research.* 93-144. D. Reidel Company, Dordecht.

Kozlowski, T.T. (1971). *Growth and Development of Trees.* Vol I. Academic Press, New York.

Kramer, N.B. and Johnson, F.D. (1986). Mature forest seed banks of three habitat types in central Idaho. *Canadian Journal of Botany.* **65**,1961-1968.

Kramer, P.J. and T.T. Kozlowski (1960). *Physiology of Trees.* McGraw-Hill, New York.

Kriek, P.N. and P.J. O'Shaughnessy (1974). Some initial effects on water quality and quantity of an experimental roading and timber harvesting operation in a Victorian mountain catchment. *MMBW-W*-0002. Melbourne.

Kuchler, A.W. and I.S. Zonneveld (1988). *Vegetation Mapping.* Kluwer Academic Publishers, Dordrecht.

Kuczera, G. (1985). Prediction of water yield reductions following a bushfire in ash-mixed species eucalypt forest. *MMBW-W*-0014. Melbourne.

La Fontaine, B. (1995). Forest certification and ISO 14001 for the forest manager. *Institute of Foresters Australia, Newsletter.* **36**, 2-8. Canberra, ACT.

Laan, R. and B. Verboom (1990). Effects of pool size and isolation on amphibian communities. *Biological Conservation.* **54**, 251-262

Laessle, A.M. (1961). A micro-limnological study of Jamaican bromiliads. *Ecology.* **42**, 499-517.

Langford, K.J. and P.J. O'Shaughnessy (1977). Catchment management research. *Water Research Foundation of Australia, Victoria Branch. Report No* **49**. Melbourne.

Lantz, R. (1971). Fish population impacts -Alsea watershed case study. In: J.T. Krygier and J.D. Hall (eds) *Proceedings of a Symposium, Forest Land Uses and Stream Environment,* 182-193. Oregon State University, School of Forestry, Corvallis, Oregon.

Lawson G.W., Armstrong-Mensah, K.O. and J.B. Hall (1970). A catena in tropical moist semi-deciduous forest near Kade, Ghana. *Journal of Ecology.* **58**, 371-379.

Lefroy, E.C. and R.J. Hobbs (1992). Ecological indicators for sustainable agriculture. *Australian Journal of Soil and Water Conservation.* **5**, 22-28.

Lembaga Ekologi (1980). *Report on the Study of Vegetation and Erosion in the Jatilhur Catchment.* Institute of Ecology, Bradenburg.

Lesica, P., McCune, B., Cooper, S.V. and W.S. Hong (1991). Differences in lichen and bryophyte communities between old growth and managed second growth forests in the Swan Valley, Montana. *Canadian Journal of Botany.* **69**,1745-1755.

Leuis, K. (1960). Attractiveness of different foods and flowers to the adults of some Hymonopterous parasites. *Canadian Entomologist.* **92**, 369-376.

Leuis, K. (1967). Influence of wild flowers on parasitism of tent caterpillars and codling moth. *Canadian Entomologist.* **99**, 444-446.

Lohani, S. (1989). Editorial, *Bangladesh Bulletin.* **9**, 1-4.

Lopez, B. (ed.) (1991). *Helping Nature Heal.* Whole Earth Catalogue/Ten Speed Press, Berkeley, California.

Lovelock, J. (1988). *The Ages of Gaia.* W.W. Norton, New York.

Low, T. (1968). *Wild Food Plants of Australia.* Angus and Robertson, New South Wales.

Lowenthal, D. (1976). Perceiving the Australian environment : a summary and commentary. In: G. Seddon and M. Davis (eds) *Man and Landscape in Australia. Towards an Ecological Vision,* 357-65. Australian Government Publishing Service, Canberra.

Lundgren, B. (1987). ICRAF's first ten years. *Agroforestry Systems.* **5**, 197-217.

Macmillan, H.F. (1935). *Tropical Planting and Gardening.* Macmillan and Company, London.

Main, B.Y. (1987). Ecological disturbance and conservation of spiders: implications for biogeographic relics in south-western Australia. In: J.D. Majer (ed.) The role of invertebrates in conservation and biological survey. *Western Australian Department of Conservation and Land Management*

Report, 89-97. Perth, Western Australia.

Maitland, P.S., Newson, M.D. and G.A. Best (1990). The impact of afforestation and forestry practices on freshwater habitats. *Focus on Nature Conservation.* **23.** Nature Conservancy Council, Peterborough.

Malherbe, H.L. (1968). *Report of the Interdepartmental Committee of Investigation into Afforestation and Water Supplies in South Africa.* Department of Forestry, Republic of South Africa, Johannesburg.

Malinowski, B. (1935). *Coral Gardens and Their Magic,* 2 vols. George Allen and Unwin, London.

Manskaya, S.M. and T.V. Drodova (1968). In: L.Shipiro and I.A. Berger (transl, & ed.), *Geochemistry of Organic Substances.* 347. Pergamon Press, Oxford.

Mantalbano, W. (1990). Defending a lifestyle against guns and money. *Sunday Age,* 16 December, p13, Melbourne.

Marten, G.C. (1986). *Traditional Agriculture in South-east Asia: A Human Ecology Perspective.* Westview Press, Boulder.

Martin, J.P. and K. Haider (1978). Microbial degradation and stabilisation of carbon-14 labelled lignins, phenols, and phenolic polymers in relation to humus formation. In: T.K. Kirk, T. Higuchi and H.M. Chang (eds) *Lignin Biodegradation; Microbiology, Chemistry, Potential Application. Proceedings International Symposium.* **1**,77-100. CRC, Boca Raton, Florida.

Mathers, J and J. Brown (1989). *Spotting Soil Salting, a Victorian Field Guide to Salt Indicator Plants.* Department of Conservation Forests and Lands, Melbourne, Victoria.

Mattson, W.S. (1976). *The Role of Arthropods in Forest Ecosystems.* Springer-Verlag, New York.

McNeely J., Miller, K.R., Reid, W.V., Mittermeier, R.A. and T.B. Werner (1990). *Conserving the Worlds' Biological Diversity.* IUCN, Gland, Switzerland.

McArthur, R.H. and E.O. Wilson (1967). An equilibrium theory of insular zoogeography. *Evolution.* **17**, 373-387.

McLeese, D.W. (1956). Effects of temperature, salinity and oxygen on the survival of the American lobster. *Journal of the Fisheries Resources Board of Canada.* **26,** 247-272.

Macmillan, H.F. (1962). *Tropical Planting and Gardening.* Macmillan and Company, London.

McPhail M.K. (1980). Regeneration processes in Tasmanian forests. *Search.* **11,** 184-190.

Meher-Homji, V.M. (1989). Trends of rainfall in relation to forest cover In: N.D. Jayal (ed.) *Deforestation, Drought and Desertification,* 48-59. INTACH, New Delhi.

Meiring, P. (1977). *Energy and Agriculture: Striking a Balance.* University of Natal Press. Natal, South Africa

Mendelsohn, R. (1993). Non-timber products. *Tropical Forestry Handbook.* **2**, 1424-1447. Springer-Verlag, New York.

Merrill, R. (1976). Towards a self sustaining agriculture. In: R. Merrill (ed.) *Radical Agriculture,* 284-327. Harper and Row, New York.

Michon, G., Mary, F. and J. Bompard (1986). Multistoryed agroforestry garden system in West Sumatra, Indonesia. *Agroforestry Systems.* **4**, 315-338.

Milliman, J.D. and R.H. Meade (1983). Worldwide delivery of river sediment to the oceans. *Journal of Geology.* **91**, 1-21.

Minroe, D. (1974). Germination and early growth of coastal tree species on organic seedbeds, *Research Paper PNW*-135. Department of Agriculture and Forest Services, Oregon.

Mittermeier, R.A. (1988). Primate diversity and the tropical forest. In: E.O. Wilson (ed.) *Biodiversity.* 145-154. National Academic Press, Washington. D.C.

Moles, J. (1995). The earth market place: trading in sustainability. *Ecoforum.* **19**, 18-19. ELCI, Nairobi.

Mollison, B. (1988). *Permaculture, a Designer's Manual.* Tagari Publications, Tyalgum, New South Wales.

Mollison, B. and D. Holmgren (1978). *Permaculture One: A Perennial Agriculture for Human Settlements.* Talgari Publications, Maryborough, Victoria.

Monk, C. (1966). Ecological importance of root/ shoot ratios. *Bulletin of the Torrey Botany Club.* **93**, 402-406.

Morley, P.R. (1973). *How Trees Grow. Studies in Biology.* Edward Arnold, London.

Muston, R. (1987). Fabricate or rehabilitate?: an ecological approach to the tree vegetation of degraded landscapes. *Landscape Australia.* **2,** 93-98.

Myers, N. (1991). Miracle in a lifeless pit. In: B. Lopez (ed.) *Helping Nature Heal,* 106-109. Whole Earth Catalogue/Ten Speed Press, Berkeley, California.

Nair, P.K.R. (ed.) (1989). *Agroforestry Systems in the Tropics.* Kluwer Academic Publishers, London.

Narver, D. (1971). Effects of logging debris on fish production. In: J.T. Krygier and J.D. Hall (eds) *Proceedings of Symposium on Forest Land Uses and Stream Environments,* 104-107. School of Forestry, Oregon State University, Corvallis. Oregon.

National Academy of Sciences (NAS) (1975). *Under-exploited Tropical Plants withPromising Economic Value.* National Academy of Sciences, Washington, D.C.

Naveh. Z. (1991). Some remarks on recent developments in landscape ecology as a transdisciplinary ecological and geographical science. *Landscape Ecology.* **5**, 66-73.

Naveh. Z. and A.S. Lieberman (1984). *Landscape Ecology: Theory and Application.* Springer-Verlag, New York, Inc.

Neumann, F.G. (1979). Beetle communities in eucalypt and pine forests in northern Victoria. *Australian Forest Research.* **9**, 277-293.

Neumann, F.G., Collett, N.G. and K.G. Tolhurst (1995). Coleoptera in litter of dry sclerophyll eucalypt forest and the effects of low-intensity prescribed fire on their activity and composition in west-central Victoria. *Australian Forestry.* **58**, 83-98.

New, T.R. (1983). Systematics and ecology : reflections from the interface. In: E. Highley and R.W. Taylor (eds) *Australian Systematic Entomology: A Bicentenary Perspective,* 50-79. CSIRO, Melbourne.

Nielsen, P.E., Nishimura, H., Otros, J.W. and M. Calvin (1977). Plant crops as a source of fuel and hydrocarbon-like materials. *Science.* **198,** 942-944.

Ninez, V.K. (1984). Household gardens: theoretical considerations on an old survival strategy. *Potatoes In Food Systems Research Series. Report* **1**. International Potato Center, Lima, Peru.

Nixon-Smith, W.F. (1983). The forecasting of chill risk ratings for newborn lambs and off-shear sheep by the use of a cooling factor drawn from synoptic data. *Bureau of Meteorology Working Paper, 40.* New South Wales.

NSRC (1991). *Annual Report for 1989-1990.* Neo Synthesis Research Centre, Mirahawatte, Sri Lanka.

Nulsen, R.A., Bligh, K.J., Baxter, L.N., Solin, E.J. and D.H. Imre (1986). The fate of rainfall in a mallee and heath vegetated catchment in southern Western Australia. *Australian Journal of Ecology.* **11**, 361-371.

O'Brien, B.J. and J.D. Stout (1978). Movement and turnover of soil organic matter as indicated by carbon-isotope measurements. *Soil Biology and Biochemistry.* **10**, 309-317.

O'Connell, A.M. and Menage, P.M.A. (1982). Litter-fall and nutrient-cycling in karri (*Eucalyptus diversicolor* F. Muell.) forest in relation to stand age. *Australian Journal of Ecology.* **7**, 49-62.

O'Connell, M.J. and P.J. O'Shaughnessy (1975). The Wallaby Creek fog drip study. *Melbourne and Metropolitan Board of Works. Report No.* M.M.B.W.-W-0004.

O'Loughlin, C.L. and R.R. Ziemer (1982). The importance of root strength and deterioration rates upon edaphic stability in steep land forests In: R.H. Waring(ed.) *Carbon Uptake and Allocation: A Key to Management of Subalpine Ecosystems,* 70-78. Forest Research Laboratories, Oregon State University, Corvallis, Oregon.

Ochse, J.J. (1977). *Vegetables of Dutch East Indies.* (in collaboration with R.C. Bakmuzen van den Bunk). Australian National University Press, Canberra.

Odum, E.P. (1969). The strategy of ecosystem development. *Science.* **164**, 262-270.

Odum, E.P. (1993). *Ecology and Our Endangered Life Support Systems.* Sinauer Associates Inc., Sunderland, Massachusetts.

Odum, H.T. (1983). *Systems Ecology: An Introduction.* Wiley Interscience, New York.

Odum, H.T. and E.C. Odum (1981). *Energy Basis for Man and Nature.* McGraw-Hill, New York.

Ojo, G.J.A.(1966). *Yoruba Culture.* University of Life and London Press, London.

Oosting, H.J. (1942). An ecological analysis of the plant communities of Piedmont, North Carolina. *American Midland Naturalist.* **28**, 1-126.

Ormerod, J.S., Weatherly, N.S. and W.J. Merrett (1990). The influence of conifer plantations on the distribution of the golden ringed dragonfly (*Cordulegaster boltoni* [Odonata]) in upland Wales. *Biological Conservation.* **53**, 241-251.

Paoletti, M.G., Taylor, A.A.J., Stinner, B.R., Stinner, D.H. and D.H. Benzig (1991). Diversity of soil fauna in the canopy and forest floor of a Venezuelan cloud forest. *Journal of Tropical Ecology.* **7**, 373-383.

Paranjpye, V. (1989). Deorai (sacred grove). In: N.D. Jayal (ed.) *Deforestation, Drought and Desertification,* 42-44. INTACH, New Delhi.

Paravi, A. (1937). The influence of the mediterranean forest on climate, L'Alpe. **24**, 45-57. *U.S. Forest Service Translation No. 319.*

Parsons, M.J. (1992). Butterfly farming and trading industry in the Indo-Australian region and its role in tropical forest conservation. *Journal of Tropical Lepidopthera.* **3**, Supp. 1, 1-31.

Parsons, R.F (1981). *Eucalyptus* scrubs and scrublands In: R.H. Groves (ed.) *Australian Vegetation,* 291-319. Cambridge University Press, Melbourne.

Peard, J.L. (1983). Distribution of corticolous non-crustose lichens on trunks of Rocky Mountain junipers in Boulder County, Colorado. *Bryologist.* **86**, 244-250.

Pearman, G.I. (1989). The greenhouse effect, global and Australian perspectives. *Proceedings: Conference on Energy and Greenhouse Effect.* Australian Institute of Energy, Melbourne.

Peck, R.B. (1984). Traditional forestation strategies of local farmers in the tropics. In: H.L. Gholz (ed.) *Agroforestry: Realities, Possibilities and Potentials,* 205-216. Martinus Nijhoff Publishers, Dordrecht, Netherlands.

Pereira, H.C. (1967). Summary of forests and runoff section. In: W.E. Sopper and H.W. Lull (eds) *International Symposium on Forest Hydrology. Proceedings of National Science Foundation Advanced Science Seminar,* 543-565. Pergamon Press, New York.

Pereira, H.C. and P.H. Horsegood (1962). Comparative water use of softwood plantations and bamboo forest. *Journal of Soil Science.* **13**, 299-314.

Perera, N.P. (1975). A physiognomic vegetation map of Sri Lanka (Ceylon). *Journal of Biogeography.* **2**, 185-203.

Pianka, E.R. (1970). On r- and K- selection. *American Naturalist.* **106**, 592-597.

Pianka. E.R. (1974). *Evolutionary Ecology.* Harper and Row, New York.

Plotkin, M.J. (1988). The outlook for new agricultural and industrial products from the tropics In: E.O. Wilson (ed.) *Biodiversity,*106-116. National Academic Press, Washington, D.C.

Purdie, R.W. and R.O. Slatyer (1976). Vegetation succession after fire in sclerophyll woodland communities in south-eastern Australia. *Australian Journal of Ecology.* **1,** 223-236.

Quyn, B.St.H. (1991). Orchid collecting in the jungle at Corbett's Gap, Rangala. *Sri Lanka Horticulturist.* June/July, 17-23.

Raghavan, M.S. (1960). Genesis and history of the Kumri system of cultivation. In: *Proceedings of the Ninth Silvicultural Conference. Forest Research Institute.* Dehra Dun, India.

Rao, P.B. and S.P. Singh (1989). Germination of certain climax and successional Himalayan trees as affected by moisture gradient: implications for revegetation of bare areas. *Tropical Ecology.* **38**, 274-284.

Rao, Y.S. (1991). Non-wood forest products in the Asia-Pacific region: an overview. *Tiger Paper.* 5-17.

Rappaport, R.A. (1971). The flow of energy in an agricultural society. *Scientific American.* **224**, 116-132.

Read, J and R.S. Hill (1988). The dynamics of some rainforest associations in Tasmania, *Journal of Ecology.* **76**, 558-584.

Recher, H.F. (1969). Bird species diversity and habitat diversity in Australia and North America. *American Naturalist.* **103**, 75-80.

Reid, R. and G. Wilson (1986). *Agroforestry in Australia and New Zealand.* Goddard and Dobson, Victoria.

Remezov, N.P. and P.S. Pogrebnyak (1969). *Forest Soil Science.* Israel Programme for Scientific Translations, Jerusalem.

Resch, H. (1967). Considering the physical properties of wood in managing forest trees. In: *Proceedings of a Conference on Young-growth Forest Management in California,* 12-25. University of California, Department of Forest and Resource Management, Berkeley, California.

Rice, R.M., Rothacher, J.S. and W.F. Megahan (1972). Erosional consequences of timber harvesting: an appraisal. In: *Proceedings of a Symposium on Watersheds in Transition,* 321-329. Department of Agriculture and Forest Services, Fort Collins, Colorado.

Richards, F.C. (1969). The quantitative analysis of growth. In: F.C. Steward (ed.) *Plant Physiology. A Treatise,* Vol VA, 3-76. Academic Press, New York.

Ricklefs, R.E. (1973). *Ecology.* Chiron Press, Newton, Massachusetts.

Riley, J.G. (1976). Development of a small institutional heating plant to utilize forest residual fuels. *American Society of Agricultural Engineers,* 1-28. St Joseph, Michigan.

Risser, P.G. (1987). Landscape ecology : state of the art. In: M.G. Turner (ed.) *Landscape Heterogeneity and Disturbance,* 3-14. Springer-Verlag, New York.

Robinette, G.O. (1972). *Plants, People and Environmental Quality, Washington D.C.* U.S. Department of the Interior, National Parks Service, and American Society of Landscape Architects Foundation, U.S. Government Printing Office.

Robinson, G, (1988). *The Forest and the Trees.* Island Press, Washington, D.C.

Ronan, N.M. (1986). The hydrological effects of fuel reduction burning and wildfire at Wallaby Creek. *Melbourne and Metropolitan Board of Works Report.* MMBW-W-**9915**. Melbourne.

Rose, F. (1976). Lichenological indicators of age and environmental continuity. In: D.H. Brown, D.L. Hawksworth and R.H. Bailey (eds) *Woodlands Lichenology: Processes and Problems*, 271-307. Academic Press, London.

Rosenberg, N.J., Blad, B.L. and S.B. Verma (1983). *Microclimate: The Biological Environment.* Wiley, New York.

Rothacher, J.S., Blow, F.E. and S.M. Potts (1954). Estimating the quantity of foliage in oak stands in the Tennessee Valley. *Journal of Forestry.* **52**,169-173.

Rudder R.J. (1978). *Religion in Aboriginal Studies.* Mimeo Report, Department of Anthropology, ANU, Canberra.

Smith, J. Russel (1926). *Tree Crops, a Permanent Agriculture.* Harcourt, Brace and Co., New York.

Russo, R. (1983). *The Effect of Pruning of* Erythrina poeppigiana *(Wlapers) O.F. Cook on Nodulation, Biomass, Production and Nitrogen Content of the Soil in a Coffee-Poro Agroforestry System.* M.S. Thesis CATIE, Turriabla, Costa Rica.

Ruthenberg, H. (1980). *Farming Systems in the Tropics.* Oxford University Press, London.

Sagreiya, K.P. (1967). *Forests and Forestry.* National Book Trust, New Delhi.

Saldarriaga, J.G., West, D.C., Tharp, M.L. and C. Uhl (1988). Long-term chronosequence of forest succession in the upper Rio Negro of Colombia and Venezuela. *Journal of Ecology.* **76**, 938-958.

Samraj, P., Chinnamani, S. and B. Haldorai (1977). Natural versus man made forests in Nilgiris with special reference to run off, soil loss and productivity. *Indian Forester.* **10**, 460-465.

Samways, M.J. and S.D. Moore (1991). Influence of exotic conifer patches on grasshopper (Orthoptera) assemblages in a grassland matrix at a recreational resort, Natal, South Africa. *Biological Conservation.* **57**, 117-137.

Sayer J.A. and T.C. Whitmore (1991). Tropical moist forest: destruction and species extinction. *Biological Conservation.* **55**, 199-213.

Schery, R.W. (1972). *Plants for Man.* Prentice Hall, Englewood Clifts, New Jersey.

Schultes, R.E. (1969). Hallicinogens of plant origin. *Science.* **163**, 245-254.

Schumacher, E.F. (1973). Foreword. In: J. Sholto Douglas and R.A. de Hart (eds) *Forest Farming,* 207. UNESCO, Paris.

Schuon, S.F. (1976). *Understanding Islam.* Allen and Unwin, London.

Senanayake, F.R. (1975). Effects of felling in the Kanneliya rain-forest, Sri Lanka. *Muir Special Projects Thesis.* University of California, San Diego.

Senanayake, F.R. (1983). The ecological, energetic and agronomic systems of ancient and modern Sri Lanka. *Lanka Guardian*, **5**, 2-8.

Senanayake, F.R. (1987a). Some strategies for effective communication on tropical forest issues. *Loris Journal.* WLNPS. **17**, 191-195.

Senanayake, F.R. (1987b). Analog forestry as a conservation tool. *Tiger Paper.* **XIV**, 25-29. FAO, Bangkok.

Senanayake, R.F. (1989). The tropical forest register In: N.D. Jayal (ed.) *Deforestation, Drought and Desertification,* 134-140. INTACH, New Delhi.

Senanayake, F.R. (1991a). Sustainable agriculture: definitions and parameters for measurement. *Journal of Sustainable Agriculture.* **1**, 7-28.

Senanayake, F.R. (1991b). Analog forestry: a strategy to reverse some trends in forest loss. *Tirra Lirra.* **2**, 16-18.

Senanayake, F.R. in press. The evolution of the major landscape categories in Sri Lanka and distribution patterns of some selected taxa: ecological implications. In: W. Erdelen, Ch. Preu, N. Ishwaran and Ch. Santiapillai (eds) *Ecology and Landscape Management in Sri Lanka.* Verlag Josef Margraf, Weikersheim.

Senanayake, F.R. and P.B. Moyle (1981). Conservation of freshwater fishes in Sri Lanka. *Biological Conservation.* **22**,191-195.

Shaffer, M.L. (1981). Minimum population sizes for species conservation. *Bioscience.* **3**,131-34.

Shea, S.R., McCormick, J. and C.C. Portlock (1979). The effect of fires on regeneration of leguminous species in the northern jarrah (*Eucalyptus marginata* Sm) forests of Western Australia. *Australian Journal of Ecology.* **4**,195-205.

Sholto Douglas and de Hart (1985). *Forest Farming.* Intermediate Publications, London.

Singh, G., Kershaw, A.P. and R. Clark (1980). Quaternary vegetation and fire history in Australia. In: A.M. Gill, R.H. Groves and I.R. Noble (eds) *Fire and the Australian Biota,* 23-54. Australian Academy of Science, Canberra.

Smith, D.M. (1962). *The Practice of Silviculture.* Wiley & Co., New York.

Smith, J.R. (1977). *Tree Crops: A Permanent Agriculture.* Devin-Adair Co., New York.

Smith, M.K., Watson, K.K. and Pilgrim, D.H. (1974). A comparative study of the hydrology of radiata pine and eucalypt forests at Lidsdale, New South Wales. *Transactions of Institute of Engineers (Aust) CE.* **16**,82.

Soulé, M. and B. Wilcox (1980). *Conservation Biology.* Sinauer Associates, Sunderland, Massachusetts.

Soulé, M.E. (1986). Conservation biology and the 'real world'. In: *Conservation Biology: the Science of Scarcity and Diversity,* 1-12. Sinauer Associates, Inc., Sunderland, Massachusetts.

Soulé, M.E. (1993). Introduction. In: M.E. Soulé (ed.) *Viable Populations for Conservation,* 1-10. Cambridge University Press.

Soulé, M.E. and K.A. Kohm (eds) (1989). *Research Priorities for Conservation Biology.* Island Press, Critical Issues Series, Washington D.C.

Spears, J.B. (1984). Role of forestation as a sustainable land use and strategy option for tropical forest management and conservation and as a source of supply for developing country wood needs. In: *Strategies and Designs for Afforestation, Reforestation and Tree Planting,* 29-46. Pudoc, Wageningen.

Spies, T.A., Franklin, J.F. .and J.B. Thomas (1988). Coarse woody debris in Douglas-fir forests of eastern Oregon and Washington. *Ecology.* **69**, 1689-1702.

Sponsel, L.E. and P. Natadecha (1992). Buddhism, ecology and forests. *The New Road.* **21**, 4-5.

Springett, J.A. (1976). The effect of prescribed burning on the soil fauna and on litter decomposition in Western Australian forests. *Australian Journal of Ecology.* **1**, 77-82.

Staple, W.J. and J.J. Lehane (1955). The influence of field shelterbelts on wind velocity, evaporation, soil moisture and crop yield. *Canadian Journal of Agricultural Science.* **35**, 440-453.

Stewart, G.A., Gartside, G., Gifford, R.M., Nix, H.A., Rawlings, W.H.M. and J.R. Siemon (1979). *The Potential for Liquid Fuels from Agriculture and Forestry in Australia.* CSIRO, Melbourne.

Stirton, C. H. (1978). *Plant Invaders, Beautiful but Dangerous.* Cape Department of Nature and Environmental Conservation, Cape Town.

Stork, N.E. (1988). Insect diversity: fact, fiction and speculation. *Biological Journal of the Linnean Society.* **35,** 321-337.

Strehlow, T.G.H. (1964). *Assimilation Problems; the Aboriginal Viewpoint.* Aboriginal Advancement League of South Australia, Adelaide.

Swanston, D. (1971). Principal mass movement processes influenced by logging, road building and fire. In: J.T. Krygier and J.D.

Hall (eds) *Proceedings of a Symposium: Forest Land Uses and Stream Environment,* 36. Oregon State University, School of Forestry, Corvallis, Oregon.

Tate, R.L. III. (1989). *Soil Organic Matter.* John Wiley & Sons, New York.

Tennent E. (1856). *Ceylon, an Account of the Island, Physical, Historical and Topographical.* Vols 1 and 2. Longmans, London.

Tesch, S.D. (1975). *The Composition and Dynamics of the Tree Strata Within an Old Growth Douglas-fir Forest in Western Montana.* Unpublished M.S. thesis, University of Montana, Missoula.

Tewari, M., Upreti, N., Pandey, P. and S.P. Singh (1985). Epiphytic succession on tree trunks in a mixed oak-cedar forest, Kumaun Himalaya. *Vegetatio.* **63**, 105-112.

Thomas, J.W. (1979). Wildlife habitats in managed forests: The Blue Mountains of Oregon and Washington, *USDA Agricultural Handbook* 553. U.S. Department of Agriculture, Washington, D.C.

Tobias, D. and R. Mendelsohn (1991). Valuing ecotourisim in a tropical rain-forest reserve. *Ambio.* **20**, 91-94.

Toky, O.P. and P.S. Ramakrishnan (1983). Secondary succession following slash and burn agriculture in north-eastern India. *Journal of Ecology.* **71**, 735-745.

Trappe, J.M. (1971). Biological control- forest diseases. *Proceedings of the Annual Meeting of the Western Forest Pest Committee 16-19. Western Forestry and Conservation Association.* Portland, Oregon.

Tresner, H.D., Backus, M.P. and J.T. Curtis (1954). Soil microfungi in relation to the hardwood forest continuum. *Mycologia.* **216**, 314-333.

Uhl, C., Buschbacher, R. and E.A.S. Serrao (1988). Abandoned pastures in eastern Amazonia. I. Patterns of plant succession. *Journal of Ecology* **76**,663-681.

Ulliuwishewa, R. (1991). Modernisation versus sustainability: disintegrating village agro-complexes in the dry zone of Sri Lanka. *Environmental Conservation.* **18**, 103-109.

Ulrich, B., Benecke, P., Harris, W.F., Kanna, P.K. and R. Mayer (1981). Soil processes. In: D.E. Reichle (ed.) *Dynamic Properties of Forest Ecosystems,* 265-339. Cambridge University Press, Cambridge.

Uphof, J.C.T. (1968). *Dictionary of Economic Plants.* Stechert-Hafner, New York.

Veneklaas, E.J., Zagt, R.J, Van Leerdam, A., Van Ek, R., Broekhoven, A.J. and M. Van (1990). Hydrological properties of the epiphyte mass of a montane tropical rain-forest, Colombia. *Vegetatio.* **89**, 183-192.

von Clemm, M. (1963). Agricultural productivity and settlement on Kilimanjaro. *Economic Botany.* **18**, 99-121.

Waksman, S.A. (1952). *Soil Biology.* Wiley and Sons, New York.

Waksman, S.A. (1926). Origin and nature of the soil organic matter or soil "humus": III. The nature of substances contributing to the formation of humus. *Soil Science.* **22**, 323-333.

Walker, J. (1979). Aspects of fuel dynamics in Australia, *CSIRO Australia, Division of Land Use Research, Technical Memo.* **79**/7.

Watson, H.R. (1988). Manual on how to farm your hilly land without losing your soil. *MBRLC Series* **1**, 1-21. Davao del Sur, Philippines.

Weber, C. (1964). Edible mushrooms. *Economic Botany.* **18**, 253-256.

Wescott, G.C. (1991). Australia's distinctive national park system. *Environmental Conservation.* **18**, 333-336.

Whittaker, R.H. (1960). Vegetation of the Siskiyou Mountains, Oregon and California. *Ecological Monographs.* **30**, 279-338.

Whittaker, R.H. and G.M. Woodwell (1968). Dimension and production relations of trees and shrubs in the Brookhaven forest, New York. *Journal of Ecology.* **56**,1-25.

Wiersaum, K.P. (1982). Tree gardening and Taungya on Java: examples of agroforestry techniques in the humid tropics. *Agroforestry Systems.* **1**, 53-70.

Wiersum, K.F. (1984). Surface erosion under various tropical agroforestry systems. In: C.L.O'Loughlin and A.J. Pearce (eds) *Symposium on Effects of Forest Land Use on Erosion and Soil Stability,* 231-239. East-West Center, Honolulu, Hawaii.

Wilde, S.A. (1958). *Forest Soils.* The Ronald Press Company, New York.

Wilde, S.A. and D.P. White (1939). Damping-off as a factor in the natural distribution of pine species. *Phytopathology.* **29**, 367-369.

Wilken, G.C. (1977). Integrating forest and small scale farm systems in middle America. *Agro-ecosystems.* **3**, 291-302.

Wilson, E.O. (1988). The current state of biological diversity. In: E.O. Wilson (ed.) *Biodiversity,* 3-18. National Academic Press, Washington, D.C.

Wilson, W.L. and A.D. Johns (1982). Diversity and abundance of selected animal species in undisturbed forest, selectively-logged forest and plantations in East Kalimantan, Indonesia. *Biological Conservation.* **24,** 205-218.

Wingate, D (1991). The restoration of an island ecology. In: B. Lopez (ed.) *Helping Nature Heal,* 78-95. Whole Earth Catalogue/Ten Speed Press, Berkeley, California.

Wolseley P.A. and B. Aguirre-Hudson (1991). Lichens as indicators of environmental change in tropical Thailand. *Global Ecological and Biogeographical Letters.* **1**, 170-175.

Wood, P.A. and M.J. Samways (1991). Landscape element pattern and continuity of butterfly flight paths in an ecologically landscaped garden, Natal, South Africa. *Biological Conservation.* **58**,149-166.

Wood, P.J., Burley, J. and A. Grainger (1982). *Technologies and Technology Systems for Reforestation of Degraded Tropical Lands.* Report to United States Congress of Technology Assessment, Washington, D.C.

Wuorenrinne, H. (1988). Wood ant reserves in the USSR. *Species.* **11**, 23.

Yang, C.J. and H. Insam (1991). Microbial biomass and relative contributions of bacteria and fungi in soil beneath tropical rain forest, Hainan Island, China. *Journal of Tropical Ecology.* **7**, 385-393.

Yarranton, G.A. (1972). Distribution and succession of epiphytic lichens on black spruce near Cochrane, Canada. *Bryologist.* **75**, 462-480.

Yeomans, P.A. (1968). *Water for Every Farm.* K.G. Murray, Publishing Company, Sydney, New South Wales.

Zaman, M. (1983). River basin development. In *Proceedings of International Symposium on River Basin Development,* 57-63. Tycooly International, Dublin.

Zimmerman, B.L. and R.O. Bierregard (1986). Relevance of the equilibrium theory of island biogeography and species-area relations to conservation, with a case from Amazonia. *Journal of Biogeography.* **13**,133-43.

Zonneveld, I.S. (1990). Scope and concepts of landscape ecology as an emerging science. In: I.S. Zonneveld and R.T. Foreman (eds) *Changing Landscapes: An Ecological Perspective,* 3-20. Springer-Verlag, New York.

Zoysa, N. de and R. Raheem (1990). Sinharaja, A rainforest in Sri Lanka. *March for Conservation.* Colombo.

ISSN 0313 8410

ISBN 0 909685 58 4