# Decline and dieback of trees and forests

## A global overview

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FAO FORESTRY PAPER
120



Food and Agriculture Organization of the United Nations

Rome, 1994

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M-34
ISBN 92-5-103502-4

## FOREWORD

The periodic occurrence of loss of tree vigour, branch dieback and tree mortality for reasons unknown or difficult to determine is a phenomenon which has frustrated resource managers and intrigued scientists for many years. Referred to as "dieback" or "decline", it has become a subject of intensified interest as forest scientists attempt to achieve a better understanding of the dynamics of forest ecosystems. There is also great concern on the part of general public and the scientific community that many instances of decline or dieback may be the result of human activities.

Most cases of decline have been reported from Europe, North America, Australia and the Pacific Region. However decline is by no means restricted to these regions. There are reports of trees and forests affected by decline throughout the world. While the symptoms of decline may be strikingly similar, they can be the result of many different abiotic and biotic factors, often interacting in a complex manner. Some declines are the result of processes which are an integral part of the dynamics of forest communities. Others may be related to human activities including land management practices, emissions from motor vehicles or industrial processes. In many instances the causal factors responsible for decline are not known.

The frequency of occurrence, pattern and intensity of decline or dieback may adversely affect the sustainable flow of goods and services from forests and influence forest management. Declines may also serve as indicators of forest response to climate change, an issue which is currently in the forefront of scientific and public interest. It is important, therefore, that foresters, ecologists, biologists and scientists from related disciplines understand the mechanisms and factors involved in declines so that appropriate forest monitoring and management systems can be implemented.

The purpose of this paper, which is based on surveys of the published literature, unpublished reports, correspondence, personal experience and review by a number of specialists, drawn from developed and developing countries worldwide, is to provide an overview of declines and diebacks in a global context. Similarities and differences between decline events are examined, as are the mechanisms which are believed to cause decline. This paper is intended to serve as a reference source which describes case histories of declines from most of the world's forest regions and is designed for use by foresters, forest scientists, policy analysts and decision makers.

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## ACKNOWLEDGEMENTS

The constructive comments and additional information kindly provided by the many people who reviewed the draft paper, "Dieback and Decline in Forests: A Global Overview (FAO Misc. FO/2/5) are gratefully acknowledged. They were; ARGENTINA - Jose Luis Darraidou, AUSTRALIA - R.C. Ellis, Glen Kyle and Kenneth M. Old, BANGLADESH - Mohammed Abdur Rahman, BURKINA FASO - Laurent Magliore Some, CANADA - Jean Claude Mercier and J. Peter Hall, CHILE - Hernan Peredo, COLOMBIA - Cielo Orozco Jaramillo and Wendy Arenas Wightman, COMISSION OF EUROPEAN COMMUNITIES - Bernard Mallet, COSTA RICA - Felix E. Scorza Reggio, GERMANY - U. Hoenish and O. Kandler, ISRAEL - O. Bonneh, KENYA - Garry Hill, MALTA - Joseph Borg, NEW ZEALAND - P.G. Cannon and Gordon Hosking, PAKISTAN - Bashir Ahmed Wani, PHILIPPINES - Emilio Rosaria, SEYCHELLES - W. Andre, SIERRA LEONE - E.K. Alieu, SPAIN - Santiago Marraco and Fernando Robredo Junco, SWITZERLAND - R. Volz, TRINIDAD - S. Faizool, UNITED KINGDOM - Eric Boa, J.N. Gibbs, UNITED STATES - Allan Auclair, Dieter Mueller-Dombois, Paul Hennon, Paul Manion, A.J. Rebertus and C.G. Shaw III, ZAMBIA - O. Shakacite and ZIMBABWE - G.D. Piearce.

Jim Ball, Klaus Janz, Michel Malagnoux, Christel Palmberg-Lerche and Paul Vantomme, FAO, Forest Resources Division, Forestry Department in Rome also provided information, review comments and suggestions. Shingo Shibata, FAO, Forestry Operations, Asia Desk, arranged for the acquistition of photographs of fir waves in Japan.

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# CHAPTER 1

# INTRODUCTION

Good forest health is essential for sustainable forestry. A forest is considered healthy when biotic and abiotic factors do not threaten resource management objectives now or have the potential to do so in the future. Many factors influence forest health. These include climate, soil, available moisture, management practices and the effects of fire, insects and disease.

Decline or dieback of trees and forests is a condition characterized by episodes of premature, progressive loss of tree or stand vigour without obvious evidence of physical injury or attack by a primary disease or pest. This condition has affected the health of many forest ecosystems and has been the subject of widespread concern by foresters, scientists and the general public. The factors responsible for many decline events have remained elusive, despite years of study. Decline has been considered a symptom of disease, a distinct class of disease and as a part of forest dynamics.

Episodes of decline have been the subject of intensified study during the past two decades. This is partially due to the efforts of forest scientists to gain a better understanding of the role of declines in forest dynamics. It is also due to an increased awareness and concern for the potential effects of human activities (e.g. emissions from motor vehicles or industrial sources and land management practices) on forest health. Furthermore, there is great interest worldwide in reducing the risk of decline and other forest health problems in forest plantations through proper nursery and planting techniques and the matching of species and provenences to sites.

An indication of the current level of interest and concern about decline and dieback is reflected in the number of symposia and reviews which have been dedicated to this subject in recent years. These include:

A symposium "Eucalypt Dieback in Forests and Woodlands" held in Canberra Australia in 1980 (Old et al 1981).

A symposium "Canopy Dieback and Dynamic Processes " held in conjunction with the 15th Pacific Science Congress. (Papers published in Pacific Science 37 (4),1983).

A workshop "Forest Decline and Reproduction: Regional and Global Consequences" sponsored by IASA, Laxenburg Austria and held in Krakow, Poland in 1987 (Kairiuskstis et al 1987).

A symposium "Stand Level Dieback and Ecosystem Processes: A Global Perspective" held in conjunction with the 15th International Botanical Congress, Berlin, 1987 (Papers published in GeoJournal 17(2) 1988).

A collection of papers in New Zealand Journal of Forestry Science (19:2-3 1989).

A historical review of hardwood declines in the eastern United States (Millers et al 1989).

A symposium "Forest Decline Concepts" held in conjunction with the joint meeting of the American Phytopathological Society and the Canadian Phytopathological Society, August 1990 (Manion and Lachance 1992).

Two IUFRO symposia on oak decline:

Kornik, Poland, May 1990 (Siwecki and Leise 1991).
Brindisi, Italy, September 1992.

A review of Mediterranean forest tree decline (Raddi 1992)

The publication "Forest Decline in the Atlantic and Pacific Region" (Huettl and Mueller-Dombios 1993).

These symposia and reviews have concentrated largely on decline events in Europe, North America, Australia and the Pacific Region and make relatively few references to decline in Asia, Africa, Latin America and the Caribbean.

The purpose of this paper is to provide an overview of decline and dieback in a global context. It begins with a review of some basic terminology with regard to forest diseases and an examination of the evolution of the concept of decline. Case histories of decline events from various forest regions throughout the world are presented. This is followed by an analysis of these case histories from which conclusions are drawn to provide a better understanding of the causes of decline, its role in forest dynamics, effects on forest health and to aid in the development of management strategies to minimize their impacts on the sustained use of forest ecosystems.

## CHAPTER 2

## DECLINE: WHAT IS IT?

### 2.1. DEFINITION OF TERMS.

What is decline? Several definitions have been developed but there is still disagreement as to exactly what constitutes decline. It is perhaps best described as: *an episodic event characterized by premature, progressive loss of tree and stand vigour and health over a given period without obvious evidence of a single clearly identifiable causal factor such as physical disturbance or attack by an aggressive disease or insect.*

The terms "dieback, decline, forest dieback, stand level dieback, canopy level dieback, *Waldsterben* and *Waldschäden*" have been used, more or less interchangeably, to describe this condition. Decline is characterized by the presence of symptoms such as reduced growth, shortened internodes, root necrosis, premature fall coloring (temperate forests), yellowing and loss of foliage, dieback of twigs and branches generally beginning in the upper crown, sprouting from adventitious buds, and (or) increased prevalence and pathogenicity of root decay fungi (Manion 1991). Another feature of decline is its progressive nature and differences in the progression of symptoms between trees in the same stand. Some trees may have slight symptoms while others are in an intermediate condition and still others are dead.

Additional terminology helpful in understanding decline is defined as follows:

A. PLANT DISEASE - *Any deviation in the normal function of a plant caused by a persistent agent.*

B. AETIOLOGY (ETIOLOGY) - *The science associated with determining or assigning the causes of disease.*

C. ABIOTIC FACTOR - *A non-living or non-infectious factor capable of causing disease. Examples include non-anthropogenic agents such as climatic factors (e.g. drought, high winds, excessive rainfall), salt spray from oceans or mechanical injury and anthropogenic (human caused) factors such as air pollution from emissions of toxic chemicals or the burning of fossil fuels, forest management practices, construction, etc.*

D. BIOTIC FACTOR - *A living or infectious disease causing agent. Non-anthropogenic biotic factors include fungi, bacteria, mycoplasma-like organisms (MLOs), virus, insects, mites, nematodes and parasitic higher plants. Anthropogenic factors include introduced pests, grazing of livestock in forests, the presence of artificially high populations of game animals for hunting interests or forest management practices which place forests under stress or favour certain pests or disease.*

E. SYMPTOM - *An expression of disease by the host plant. Some diseases have unique symptoms which are helpful in identification of the pathogen. Other diseases are characterized by less specific symptoms. Examples of symptoms include reduced growth, dead branches, decay, yellowing* *or chlorotic foliage and abnormal growth such as cankers or witches' brooms.*

F. SIGN - *The visible presence of a biotic pathogen such as the fruiting stage of a fungus, the occurrence of a parasitic plant or a damaging insect. Signs of disease are not always present.*

G. STRESS - *Factors which weaken trees and increase their susceptibility to disease. Examples of stress include soil deficiencies, drought, excess moisture, mechanical injury, or aging. Stress factors may occur periodically or be present continuously.*

H. SYNDROME - *A combination of symptoms and signs which characterize a disease.*

In this chapter, decline will be examined from three points of view - as a symptom of disease, a type of disease and as a part of the dynamics of forest ecosystems.

## 2.2. DIEBACK AND DECLINE AS SYMPTOMS OF DISEASE.

The terms "decline" and "dieback" have both been used to describe disease symptoms. "Dieback" refers to death of branches and can be associated with changes in soil moisture or with virulent pathogens. Cankers caused by the chestnut blight fungus, Endothia parasitica, or the white pine blister rust fungus, Cronartium ribicola, for example, kill branches and entire trees. Dieback can also be the result of attack by insects as exemplified by larvae of the mahogany shoot borers, Hypsypyla sp., which bore into and kill the terminal shoots of trees of the family Meliaceae.

"Decline" is a term often used to describe a more general set of symptoms or syndrome associated with loss of tree vigour. These include reduced growth, reduction in size and quantity of foliage, chlorotic foliage, death of twigs and branches and, in some cases, tree death. Dieback can be part of the decline syndrome.

Symptoms of decline can be associated with a number of diseases caused by a single factor. For example, chlorotic foliage and reduced growth are common symptoms of soil nutrient deficiencies. Sparse, smaller than normal foliage, branch dieback and epicormic branching are associated with prolonged periods of drought, foliar injury by insects or mites, or infection by parasitic plants.

## 2.3. DECLINE AS A CLASS OF DISEASE.

A number of forest pathologists consider decline as a distinct class of disease, one which is strongly influenced by factors which predispose trees under stress to invasion by agents which are unable to cause disease in vigorous trees. Because of the complex interaction between host, site, climate and one or more pathogens, it is often difficult to identify the factors involved. The idea of decline as a class of disease is discussed by Houston (1967, 1981, 1992), Manion (1991) and Sinclair (1965, 1966).

2.3.1. THE HOST, STRESS, SAPROGEN CONCEPT - Houston (1967, 1981, 1992) considers declines as diseases caused by the successive action of stress factors followed by organisms of secondary action (saprogens) which can only successfully attack weakened hosts. Under this conceptual framework, healthy trees are affected by some form of environmental stress. Tree tissues altered by that stress are subsequently invaded by saprogens. The disease condition develops, tissues and trees decline and may ultimately die.

These events can be summarized in a series of word equations (Houston 1992):

| | | | |
|---|---|---|---|
| *1.* | *Healthy trees + Stress* | = | *Altered trees (tissues) (dieback begins)* |
| *2.* | *Altered trees + More Stress* | = | *Trees (tissues) altered further (dieback continues)* |
| *3.* | *Severely altered trees + More Stress* | = | *Tree (tissues) altered further (dieback continues)* |
| * | | | |
| * | | | |
| * | | | |
| *n.* | *Severely altered trees + organisms of secondary action* | = | *Trees (tissues) invaded. (Trees lose ability to respond to improved conditions, decline and perhaps die.)* |

Using this approach, a decline of sugar maple, Acer saccharum, in North America, which is initiated by insect defoliation followed by secondary invasion of fungi, is described as follows:

| | | | |
|---|---|---|---|
| *1.* | *Healthy sugar maple trees + defoliation* | = | *Sugar maples altered (dieback begins)* |
| * | | | |
| * | | | |
| * | | | |
| *n.* | *Altered trees + secondary fungi* | | |
| | *Stegonosporium ovatum* | = | *Twig dieback accelerated* |
| | *Armillaria sp.* | = | *Roots, root collars invaded, trees decline, die.* |

The host/stress/saprogen concept implies that stress creates conditions favourable for *invasion* of trees by secondary biotic agents. This is not always the case. Certain endophytic fungi may infect trees and be present for long periods without causing disease. Disease symptoms do not appear until after trees are exposed to stress. This is true of several foliage diseases in Europe. In addition, certain fungi, such as those which invade root systems, may be present on trees for many years and not have visible adverse effects on tree growth and vigour even though rootlet mortality has occurred. When a stress, such as a prolonged drought occurs, trees infected by root disease are more likely to develop decline symptoms or be attacked by bark beetles.

2.3.2. THE PREDISPOSING, INCITING AND CONTRIBUTING FACTORS CONCEPT - This concept developed from research efforts to identify causes of three decline in the United States: ash dieback, maple decline and oak decline (Manion 1991). Sinclair (1965) was the first to suggest that maple decline and similar problems was the result of the interaction of three or more sets of factors (Table 2.1):

> *Predisposing Factors* are long term, slowly changing factors such as soil, site and climate. These factors alter the tree's ability to withstand or respond to injury-inducing agents.
>
> *Inciting factors* are of short duration and may be physiological or biological in nature. They generally produce dieback of small branches. Examples of incitants are defoliating insects, late spring frost, drought and salt spray.
>
> *Contributing factors* are those factors which subsequently further weaken and ultimately kill the tree. Examples include bark beetles, canker fungi and root decay fungi. These factors are persistent and visible and are often wrongly blamed for the death of trees. This is especially true of bark beetles (Coleoptera: Scolytidae), some species of which can reach epidemic levels in response to stress and kill large numbers of trees, many of which may not have been directly affected by the stress.

2.3.3. DECLINES AS DISEASES OF POORLY UNDERSTOOD AETIOLOGY - The concept of decline as a class of disease is not totally accepted by forest pathologists. Manion (1993) acknowledges that some experts consider declines as a collection of diseases with incompletely understood aetiology and many situations were initially designated as declines or diebacks because their causes were unknown. Some diseases initially classified as declines have eventually been shown to have specific single causal agents and were subsequently renamed. For example, when a portion of a decline of ash, Fraxinus sp. in eastern North America was attributed to infection by a mycoplasma or mollicute like organism (MLO), it was renamed "ash yellows" (Mattenoni and Sinclair 1985). Similarly when a decline of live oak, Quercus virginiana fusiforme, in central Texas, USA, was found to be caused by the oak wilt fungus Ophiostoma (=Ceratocystis) fagacearum, it was considered to be a form of oak wilt (Lewis 1977). In a more recent attempt at characterizing decline, Sinclair and Hudler (1988) indicate that decline can, in fact, be the result of a chronic irritation by a single factor (e.g., the MLO involved in the ash dieback complex).

TABLE 2.1

EXAMPLES OF PREDISPOSING, INCITING AND CONTRIBUTING FACTORS WHICH INFLUENCE OCCURRENCE OF DECLINE *

| PREDISPOSING *(Long Term Factors)* | INCITING *(Short Term Factors)* | CONTRIBUTING *(Long Term Factors)* |
|---|---|---|
| Genetic potential | Insect defoliation | Bark beetles |
| Age | Frost | Canker fungi |
| Viruses | Drought | Root decay fungi |
| (interacting with) | Salt | |
| Climate | Air pollutants | |
| Soil factors | Mechanical injury | |
| Air pollution | | |

* Adapted from Manion (1991).

## 2.4. DECLINE AS A PART OF FOREST DYNAMICS.

Mueller-Dombois (1983, 1986, 1992a), working with a decline of Metrosideros polymorpha in the Hawaiian Islands, USA, concluded that diebacks are not necessarily a disease, but an integral part of forest dynamics and succession. He considers decline as a complex condition which involves a number of interacting factors but argues that the primary and predisposing cause of decline is synchronous senescence of a number of trees in one place which he describes as *cohort senescence*. A sudden trigger or perturbation is required to initiate decline (e.g., drought, flood or wind). Recovery may occur if factors such as insects or fungi do not play a subsequent major role. He defines *decline* as a stand or population level phenomenon, which is manifested in the loss of vigour of a forest stand. He considers *dieback* to mean a further progression of decline which leads to stag-headedness of many trees. Trees with dieback can recover but in most cases the condition leads to the death of many trees. He further defines *canopy dieback* as all forms of stand-level dieback or forest decline, wherever the canopy and/or sub-canopy trees are involved. Situations where the undergrowth vegetation is dying and where the overstorey remained intact, are not included. He excludes all forms of stand-level death which have obvious causes. Canopy dieback can take on two forms:

A. *Tree-to-Tree Dieback*, where many adjacent trees are affected.

B. *Salt-and-Pepper Dieback*, where dying trees occur repeatedly in a matrix of healthy trees.

The concept of synchronous cohort senescence can be fit into the Predisposing, Inciting and Contributing Factors concept of Sinclair and Manion by considering four generic causal factors (Mueller-Dumbois 1992a):

A. Simplified forest structure leading to instability.

B. Edaphically extreme sites.

C. Periodically recurring perturbations. (e.g. weather disturbances or catastrophic events)

D. Biotic agents.

These can be related to the Sinclair/Manion concept as follows:

A. Predisposing factors:

1. Simplified cohort structure and senescence.

2. Extreme edaphic and evolutionary stresses.

3. Pulse perturbations, (e.g. periodic shocks from extreme weather or from seismic disturbances.

B. Inciting factor:

Pulse perturbation factor (same as above) which triggers canopy breakdown in demographically weakened stands.

C. Contributing factor:

Biotic agents, such as pathogenic fungi or insect pests which may overpower a stand weakened by the preceding three causes.

The role of climatic perturbations as a universal inciting factor for decline is discussed by Auclair et al (1992). They suggest that in boreal and temperate forests, decline is initiated by a winter thaw/freeze event. Thaws cause trees to become physiologically active and result in premature bud swelling, sap ascent, rehydration of tissues and partial loss of frost resistance. The onset of subsequent deep freezes results in xylem injury by cavitation which renders trees more sensitive to drought. Analysis of the onset of decline in relation to climatic records indicate that this scenario was common to several decline events in eastern Canada, western North America and Europe (Auclair et al 1990, 1992, Auclair, in press). Analysis of decline events in the Pacific Rim and Southeast Asia indicate that they were associated with prolonged periods of wet, cloudy weather followed by periods of clear, bright, hot weather. In these cases, the likely initiating mechanism was rapid tree growth accompanied by deposition of relatively thin walled vessels and tracheids which cavitate under a subsequent period of moisture stress (Auclair 1992, Auclair et al 1992).

Sinclair and Hudler (1988) consolidate the ideas of Sinclair, Houston, Manion and Mueller-Dombois and describe decline as a premature, progressive loss of tree vigour and health. They indicate that decline can be explained in one of four ways:

A. A tree may decline primarily as the result of a chronic irritation by a single agent.

B. A tree may decline because of damage by secondary agents after an event such as defoliation or wounding. The same agents would not cause decline in an uninjured tree and the injury alone would not cause decline.

C. Chronic irritation by one or more agents may diminish the tolerance or resistance of a tree to another agent that incites decline. Various factors, including those which predisposed the tree and incited decline may then contribute to further decline.

D. Trees of similar age growing in groups tend to display group behaviour including premature senescence (synchronous cohort senescence) in response to stress.

In the sections which follow, a number of case histories of decline events are described. Since most decline events in Europe and North America have been well documented in the scientific and popular literature, they are discussed briefly. Descriptions of decline events in Africa, Asia, The Pacific Region and Latin America and the Caribbean, are given in greater detail. For these regions, causal factors associated with decline events are summarized in a series of tables using the Sinclair/Manion concept of predisposing, inciting and contributing factors (Tables 5.1, 6.1, 6.2, 7.1, 7.2, 7.3, 8.1).

# CHAPTER 3

# EUROPE

The existence of trees expressing symptoms of decline has been widely reported in Europe. Some reports date to the early part of the 18th century. Summaries of forest decline events which have caused concern among scientists, resource managers and the general public are presented in the following sections.

## 3.1 SILVER FIR DECLINE

One of the oldest known and widely reported declines of European trees is the *Tannensterben* (fir-death) associated with Abies alba. This is a disease of unknown aetiology which has spread in epidemic cycles across central Europe since the beginning of the 19th century. There are reports of *Tannensterben* as early as 1810 (Ruzicka 1937).

This condition is characterized by defoliation and dying of branches beginning from the lower crown and gradually ascending to the top of the tree and an abrupt, long lasting increment reduction. The apex of the crown is flattened into a "stork's nest" formation and remains green until late in the syndrome when many trees die (Fig 3.1). Others recover and show an increase in incremental growth.

The most recent occurrence of *Tannensterben* began in the 1950s and 1960s and peaked in the 1970s when a series of dry summers occurred. Recovery of incremental growth began about 1980 but improvement of crown conditions was delayed 4 to 6 years (Kandler 1990, 1992, 1993).

## 3.2. HARDWOOD DECLINES

Declines of hardwoods have been reported throughout Europe. Of particular concern is a recent increase in the incidence of the decline of various species of oaks, Quercus spp. These have been discussed in two recent international symposia; one held in 1990 in Kornik, Poland and another in 1992 in Selva di Fasano, Brindisi, Italy. The proceedings of the first of these symposia has recently been published and provides an excellent overview of the complexity of oak decline in Europe (Siwecki and Liese 1991).

Hartmann and Blank (1992) indicate that outbreaks of oak decline have been recorded in northern Germany during the periods 1739 - 1748, 1911 - 1924, 1929 - 1934 and 1939 - 1944. These were attributed to cumulative and interactive effects of insect defoliation, extreme weather conditions, powdery mildew and other biotic agents. A more recent episode of oak decline in northern Germany began in 1982, increased markedly after 1985 and culminated in 1987 - 1989. Affected trees were characterized by marked reductions in tree ring width between 1985 and 1987, repeated insect

Figure 3.1 - Abies alba in Bavaria, Germany, with symptoms of silver fir decline (Photo by W.M. Ciesla).

defoliation, drought and deep winter frost. The only factor of simultaneous regional occurrence was an unusually deep frost late in the winters of 1985, 1986 and 1987. Winter freeze damage of trees weakened by defoliation and drought is believed to be the primary cause of dieback. Weakened trees were subsequently attacked by Agrilus biguttatus (Coleoptera: Buprestidae) and two fungi which caused secondary bark lesions (Hartmann and Blank 1992).

According to Marcu and Tomiczek (1989), symptoms of a current episode of oak decline first appeared in eastern Austria, near the Hungarian border in 1983. Detailed studies indicated that the occurrence of oak decline was associated with prolonged periods of below normal precipitation from 1975 - 1983. Extremely cold winters from 1985 to 1987 may have led to a further weakening of trees. More recently, Tomiczek (1990) has recovered sapwood nematodes of the genus Bursaphelenchus from oaks with symptoms of decline. These are believed to be transmitted by insect vectors in the families Buprestidae, Cerambycidae and Scolytidae. The role of these nematodes in the decline syndrome is not yet understood.

Orlov and Osipov (1989), in their review of Quercus robur forests in the forest-steppe zone of central Russia, discuss the occurrence of decline and mortality which was observed during the 1970s. Factors thought to be involved in the decline include drought, frost, insect defoliation and fungal diseases. Atmospheric pollution and deposition of agricultural chemicals in the soil are also considered to be possible causal factors. The most significant factor responsible for the decline is considered to be droughts which occurred during the 1960s and 70s, insects and a powdery mildew fungus. A significant recovery was observed in 1980-1985, a period of higher rainfall.

In Romania, a form of oak decline is characterized by reduction of annual shoot growth and leaf size and by yellowing, wilting and loss of foliage. MLOs have been detected in the phloem of symptomatic trees by electron microscopy. When these were transferred to other plants, similar symptoms appeared, suggesting MLO as a possible causal factor. These findings have not been confirmed for oak decline in central Europe (Kandler 1990).

Decline and mortality of Q. ilex and Q. suber is occurring in portions of Italy, Morocco, Portugal, Spain and Tunisia. This has been attributed in the past to drought, pollution and to secondary attacks by insects and fungi (Brasier 1992). Symptoms include sudden death within one or two seasons, root and rootlet necrosis, epicormic shoots and a tarry exudation. In southern Spain, dying trees often occur in groups and large foci are distributed along streams, valleys or depressions. Decline is also associated with standing water during winter months or with recent soil disturbances such as ploughing or road construction. The root fungus, Phytophthora cinnamomi, has been isolated from the root systems of symptomatic trees occurring on moist sites. It is suggested that this fungus has recently been introduced into the region and is interacting with the effects of winter drought and changing land use patterns to bring about decline (Brasier et al 1993).

Key points which were made at an international conference on oak decline in Selva di Fasano, Brindisi, Italy, during September 1992 are (IUFRO 1993):

A. Oak decline is a complex syndrome reported to have periodically occurred in the last 100 years in many European and overseas countries. Its aetiology is still not completely known. Nevertheless, the phenomenon seemed to decrease in intensity during the last two years.

B. While there are several common features of symptoms of oak decline across Europe and even in North America, there are also strong regional differences in factors (frost, drought, air pollution, root disease, etc.) that are associated with the problem.

C. The available results of intensive research carried out until now seem to prove that all stress factors can reduce vitality of trees, which may be easily damaged by secondary organisms (fungi, insects, etc.).

D. Lack of silvicultural management led to excessive stocking of oak trees. On dry sites, this predisposes oaks to decline, especially in southern Europe. Sanitary felling should be carried out at the appearance of decline symptoms, in order to recover stump viability.

E. The possible roles in the decline syndrome of endophytic fungi that may be normally present in asymptomatic trees were mentioned by several papers. This presents a challenging new avenue of investigation.

F. The role of several weak pathogens has been pointed out. The epidemiological aspects of Armillaria spp. still needs to be clarified.

G. A potential primary pathogen, Phytophthora cinnamomi, has been found in association with the recent rapid oak declines in Iberia. Its role needs to be investigated.

H. The results obtained from interdisciplinary studies presented during the Congress helped to clarify some aspects of this complex disease and marked the necessity to emphasize this kind of collaboration.

*Buchensterben* is a decline of beech, Fagus sylvatica, which occurs in England, France, Germany, Switzerland and Poland. The decline is characterized by brown to black spots on the bark and branches of trees underneath which the cambium has died. The condition is caused by the beech scale, Cryptococcus fagisuga (Homoptera: Coccididae), which attacks the bark and builds up following periods of drought. This predisposes trees to attack by fungi of the genus Nectria and secondary bark and ambrosia beetles (Coleoptera: Scolytidae). Affected trees are subject to wind breakage (Schwerdtfeger 1981). The beech scale has been introduced into North America and is now a factor in a condition known as "beech bark disease" which affects American beech, F. grandifolia (see section 4.6).

## 3.3 ACUTE YELLOWING OF NORWAY SPRUCE

An acute chlorosis or yellowing of the foliage of Norway spruce, Picea abies, has been reported from central Europe since the early 1970s. The symptom associated with this condition is a yellowing of older needles which begins at the needle tip and progresses to the base. The discolouration generally occurs on the upper or illuminated side of the needles. Symptoms are confined to mountainous areas with acid soil derived from granite, sandstone or other rocks poor in available magnesium (Mg).

This condition has been diagnosed as an Mg deficiency through studies which demonstrate that needle yellowing is closely correlated with Mg content of the needles and available Mg in the soils. In addition, trees recover rapidly when fertilizers containing magnesium are applied.

Some workers believe that the onset of acute yellowing is at least indirectly due to increases in levels of air pollution. Two hypotheses have formulated:

A. Increased levels of atmospheric ozone and/or other photochemical oxidants trigger oxidative damage to cell membranes and chloroplast pigments. This in combination with acid rain enhances leaching of minerals. Because of the low levels of soil Mg, the plant cannot compensate for loss of Mg.

B. The acidification/aluminum toxicity hypothesis assumes an increased soil acidification by deposition of pollutants. This would lead to an enhanced cation exchange and a shift in the ratio of calcium to aluminum and subsequent inhibition of both Ca and Mg uptake by the roots.

Kandler (1992) points out that neither hypothesis has been proven experimentally under ecologically relevant conditions. In addition, he argues that the development of acute yellowing during the past decade is not consistent with either of these hypotheses. Increased yellowing would be expected as a result of continuous exposure to pollutants. Acute yellowing, on the other hand, shows an episodic development with frequent spontaneous re-greening and a low rate of tree mortality.

## 3.4. REGIONAL DECLINE OF CONIFERS AND HARDWOODS.

Beginning in the late 1970s, a regional decline of both conifers and hardwoods was reported in Europe. This decline received a great deal of attention by the scientific community, political leaders and the general public and has been widely reported. Declines described in the preceding sections (3.1 - 3.3) have frequently been included as part of the regional decline. The condition was most frequently reported from and most intensively studied in Germany but occurs in many other countries as well. In the German literature, this decline was initially designated as *Waldsterben* (forest death) and later as *neuartige Waldschäden* (a new type of forest damage). General reviews of this decline are provided by Schutt and Cowling (1985), Niesslein and Voss (1985), Plochmann (1985), Steinbeck (1984), Kandler (1990, 1992, 1993) and Raddi (1992).

Symptoms associated with the regional decline include foliage loss and discolouration, feeder root mortality, radial growth reduction, premature senescence, abscission of foliage and shoots, altered leaf and branch morphology, abnormally heavy seed and cone crops and formation of bacterial wetwood.

Causal factors are still not well understood but several hypotheses have been formulated to explain the decline. These consider the deposition of toxic, nutrient, acidifying and/or growth altering substances from anthropogenic sources as a causal factor and are summarized by Schutt and Cowling (1984) as follows:

A. Increased acidification of forest soils due to deposition of acidic substances from the atmosphere which results in increased concentrations of soluble aluminum ions and in turn results in the death of fine roots.

B. Increased levels of ozone in the atmosphere resulting in foliage loss and growth reduction.

C. Accelerated leaching of calcium and magnesium from foliage and soils due to acid deposition which results in soil nutrient deficiencies.

D. Increased levels of atmospheric pollution which leads to a decrease in net photosynthesis and reduced nutrient reserves making trees more susceptible to drought and other stress.

E. Air transport of growth altering substances.

Kandler (1985), on the other hand, rejects the hypothesis of abiotic factors such as atmospheric pollutants as causal agents of the current wave of decline and proposes an alternative "epidemic" hypothesis. He postulates that the decline symptoms may be the result of a separate and distinct complex of environmental factors and unknown biotic agents. He bases this on the fact that many of the present decline symptoms were previously described as separate and distinct conditions. A prime example is the decline of Abies alba (*Tannensterben*), which was first described when levels of air pollutants were much lower than they are today. In more recent papers, Kandler (1990, 1992) criticises European researchers for lumping symptoms of decline from a number of tree species and attributing the damage to an undefined complex of air pollutants.

Concern about *neuartige Waldschäden* and the future of Europe's forests prompted annual surveys to assess forest condition. These were begun in Germany in 1983 and are now conducted in many European countries. Trees are classified according to standardized damage categories based on defoliation and discoloration (Tables 3.1 & 3.2). These surveys are helpful for monitoring change in tree and forest condition from year to year but they do not relate tree condition to causal factors. Results are published on an individual country basis, by the Commission for the European Community (CEC 1991) and by the United Nations Economic Commission for Europe (GEMS 1991).

Results of surveys of regional forest decline in the former West Germany are summarized by Kandler (1992). These indicate an increase in forest damage from 1983 to 1984. From 1984 to the present, the level of damage has remained relatively constant. He suggests that the sharp increase in damage levels between 1983 and 1984 may have been due to the fact that not all states in the former West Germany were using the same survey methods and that field personnel were not fully acquainted with the classification system.

TABLE 3.1

DAMAGE RATING SYSTEM FOR ASSESSMENT OF TREE CONDITION IN EUROPE BASED ON DEGREE OF DEFOLIATION *

| CLASS | DEGREE OF DEFOLIATION | PERCENTAGE OF NEEDLE/LEAF LOSS |
|---|---|---|
| 0 | Not defoliated | 0 - 10% |
| 1 | Slightly defoliated | 11 - 25% |
| 2 | Moderately defoliated | 26 - 60% |
| 3 | Severely defoliated | > 60% |
| 4 | Dead | |

TABLE 3.2

DAMAGE RATING SYSTEM FOR ASSESSMENT OF TREE CONDITION IN EUROPE BASED ON DEGREE OF DISCOLOURATION *

| CLASS | DEGREE OF DISCOLOURATION | PERCENTAGE OF DISCOLOURATION |
|---|---|---|
| 0 | Not discoloured | 0 - 10% |
| 1 | Slightly discoloured | 11 - 25% |
| 2 | Moderately discoloured | 26 - 60% |
| 3 | Severely discoloured | > 60% |
| 4 | (dead) | |

* Source, CEC (1991).

Landmann (1993), in a review of forest decline in France, concludes that the large majority of declines recently studied in the context of "novel forest decline" (*neuartige Waldschäden)* present strong similarities with decline events studied earlier. Natural factors (e.g. climatic perturbations, stand dynamics) and past forest management (in particular inappropriate selection of species or provenances planted on certain sites) play a major role in these declines.

# CHAPTER 4

# NORTH AMERICA

Decline and dieback events have been documented in both Canada and the United States since the early 1900s. The following sections provide a brief review of some of the more well known decline events.

## 4.1. BIRCH DIEBACK

A dieback of yellow birch, Betula allegheniensis, paper birch, B. papyrifera, and grey birch, B. populifolia, emerged as a forest problem between 1930 and 1950 in eastern Canada and the northeastern United States.

According to Auclair (1987), birch dieback had three noteworthy features in Canada:

A. Dieback was preceded by a reduction in radial growth.

B. There was a pronounced east-west gradient in the intensity of dieback with most severe damage occurring in the eastern-most Provinces.

C. By the 1950s, recovery was apparent.

The bronze birch borer, Agrilus anxius (Coleoptera: Buprestidae), attacks and kills trees weakened by birch dieback. The root fungus, Armillaria sp.,[1] contributes to intensification of birch dieback by invading the root systems of weakened trees (Manion 1981).

This decline is believed to be the result of a prolonged warming trend which increased average summer temperatures in eastern Canada by 1° C over a 10 to 20 year period (Hepting 1963). This resulted in increased soil temperature which caused rootlet mortality. Stand opening by logging, defoliation and leaf skeletonizing and late spring or early fall frosts can incite birch dieback in localized areas.

## 4.2. POLE BLIGHT OF PINUS MONTICOLA

Western white pine, Pinus monticola, is a fast growing, commercially important tree species which is found in the Pacific coastal regions of British Columbia, Canada, Idaho, Oregon, Montana and Washington, USA. This species is a major component of mixed conifer forests in a sub-region known as the "Inland Empire", which comprises portions of eastern Washington, northern Idaho, western Montana in the USA and adjoining portions of British Columbia, Canada.

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[1] Most citations refer to Armillaria mellea which, until recently, was considered to be a single variable or polymorphic species with worldwide distribution. More recently, the genus has been reclassified into a number of species (Watling et al 1991). Therefore the designation Armillaria sp. is used throughout this paper.

A condition referred to as "pole blight" was first noted in Idaho in 1927 and was eventually found to occur throughout the Inland Empire. Symptoms intensified during the 1930s and continued until the 1950s when they subsided. Assessment of the causes and magnitude of losses incurred by pole blight were complicated by the presence of white pine blister rust, Cronartium ribicola, an introduced pathogen, which was also causing high levels of damage to P. monticola.

Recent reviews of pole blight are provided by Auclair et al (1990), Hennon (1990) and Manion (1991). Symptoms consist of chlorosis of needles, reduction in radial and height growth and bole lesions associated with resinosis. Death usually began at the tops of trees and progressed downward. Several species of fungi, including Leptographium sp. and Armillaria sp. were found to be associated with affected trees but were not the primary cause of the blight. Tree mortality was confined to even-aged (pole-sized) stands ranging from 40 to 100 years of age. Older stands were unaffected.

Studies on the aetiology of this disease indicated that a period of hot, dry weather prevailed in the Inland Empire from 1916 to 1940. This represented the most adverse growth conditions for this species during the past 280 years. It was hypothesized that moisture stress was the primary cause of pole blight, causing fine roots to die. Moisture stress was brought about by the combination of drought, soils with poor water holding capacity and young pines in maximum growth phase having a high demand for water.

## 4.3. ASH DIEBACK

Dieback of ash, Fraxinus americana, and to a lesser degree, F. pennsylvanica, was first observed in the northeastern United States and adjoining Canada in the 1930s but developed into a serious concern in the 1950s and early 1960s.

The onset of ash dieback is signalled by reduced growth of stems and twigs. This is followed by death of terminal buds and branches and the presence of small, sparse and chlorotic foliage. Affected crowns often appear thin and tufted. On some trees, premature fall colouring and early seasonal foliage loss. Epicormic shoots develop as the trees progressively die back. Eventually trees die.

Reddish-brown to orange-yellow cankers develop on the branches and on the smooth bark of the main stem. These cankers girdle twigs or stems and contribute to the dieback process. At least two canker fungi, Cytophoma pruinosa and Fusicoccum sp, attack bark tissues made susceptible by water deficits.

One form of ash dieback is believed to be the result of stress associated with moisture deficit followed by the invasion of secondary canker fungi. Other factors which may be involved in the dieback include virus, mycoplasmas and air pollution (Houston 1981, 1992). A condition known as "ash yellows" is caused by an MLO. Matteoni and Sinclair (1988) indicate that ash yellows is probably the primary cause of ash dieback in New York State. Similar symptoms occur following defoliation by a rust fungus, Puccinia sparganiodes (Houston 1992).

## 4.4. MAPLE DECLINE

Decline of sugar maple, Acer saccharum, and other species of maple, has been reported from a variety of situations in eastern Canada and the United States (Fig 4.1). Maples growing along roadsides, in sugar bushes (stands of maple from which sap is extracted for sugar production) and in forests are affected (Manion 1991).

Many causal factors have been associated with maple decline including road salt, soil compaction, poor drainage, air pollution, drought, defoliating insects and root fungi. Different combinations of causal factors have been suggested for individual episodes of maple decline. For example, decline of roadside maples is believed to be the result of road salting during winter, overmaturity and water stress. Drought, defoliation, heavy grazing and overtapping are believed to be associated with mortality and dieback of sugar bush maples. In natural forests, maple decline is the result of insect defoliation followed by invasion of secondary fungi (Houston 1981).

A regional decline of sugar maple over portions of Ontario and Quebec, Canada began to appear during the late 1970s and increased in intensity during the early 1980's. Many hypotheses were suggested for the cause of this decline including harvesting accompanying tree species, tree age, tapping for syrup, livestock grazing and soil and air pollution. Short term factors included adverse weather and insect defoliation. A popular causal hypothesis was acid rain because the region receives high loadings of acid deposits with the annual total being 40 km/ha/yr of wet sulphate (Linzon 1988). A causal relationship between acid deposition and decline has not been established however.

The results of a cooperative Canada - United States study on sugar maple decline shows an apparent improvement in the health of this species since 1988 in areas affected by decline (NAPAP 1992).

## 4.5. OAK DECLINE

Periodic events of decline and mortality of oaks, Quercus sp., have been recorded in the eastern United States since 1900 (Fig. 4.2). Trees are weakened by environmental stress such as drought, excess water, frost or from feeding injury caused by defoliating or sucking insects. In recent years, defoliation by gypsy moth, Lymantria dispar (Lepidoptera: Lymantridae), an insect which was introduced into North America during the 19th century, has been a major inciting factor associated with oak decline. The two lined chestnut borer, Agrilus bilineatus (Coleoptera: Buprestidae), and the root disease fungus, Armillaria sp., are often associated with declining trees, but are not the primary cause of decline. Usually the progression of the decline is slow, occurring over a period of several years (Wargo et al 1983).

In the central United States, oak decline is attributed partially to fire exclusion which has resulted in the invasion of prairie groves of fire resistant Quercus macrocarpa by species more sensitive to both fire and drought. In addition, clearing of oak forests from the 1880s to the 1920's, followed by attempts to farm these lands which ended in failure, resulted in the formation of even age Quercus forests, many of sprout origin. These cohorts may be developing senescence making them especially susceptible to drought, insect defoliation or other incitants which could cause stand level decline.

Figure 4.1 - Acer saccharum with symptoms of maple decline (Vermont, USA).
(Photo by W.M. Ciesla)

Figure 4.2 - Oak decline in western North Carolina, USA. (Photo by W.M. Ciesla)

## 4.6. BEECH BARK DISEASE

Beech bark disease affects American beech, Fagus grandifolia, in eastern North America. Symptoms include chlorotic foliage, thin crowns, branch dieback and tree mortality. The disease is initiated when the beech scale, Cryptococcus fagisuga (Homoptera: Coccididae), feeds on the bark of beech trees. Feeding causes cracks in the bark tissue which are subsequently invaded by a canker fungus, Nectria coccinea faginata. The fungus kills patches of bark which are subsequently invaded by wood borers and decay fungi. Branches and sometimes entire trees may break off at these points (Houston 1981). Beech scale is native to Europe, where it is also associated with a dieback of beech (See section 3.2.). This insect was accidentally introduced into Nova Scotia, Canada. It has since spread over much of the natural range of beech in eastern Canada and the northeastern United States.

## 4.7. LITTLELEAF DISEASE OF SHORTLEAF PINE

The most serious disease of shortleaf pine, Pinus echinata, a tree indigenous to the southern United States, is a condition known as littleleaf disease. This condition is prevalent on abandoned cotton growing lands which have regenerated naturally to P. echinata. This condition was first reported in the 1930s. Affected trees have shorter than normal needles which often have a yellowish cast and reduced radial and shoot growth. Trees can die within six years of the first appearance of symptoms (Manion 1991, Mistretta 1984).

The disease is the result of a complex of factors which include the soil fungus, Phytophthora cinnamomi, low soil nitrogen and poor internal soil drainage. In some cases nematodes and fungi of the genus Pythium are associated with diseased trees.

Littleleaf disease is present over 35% of the commercial range of P. echinata and is severe enough to influence management decisions on 560,000 ha of forests dominated by P. echinata (Mistretta 1984).

## 4.8. DECLINE AND MORTALITY OF RED SPRUCE

Beginning in the late 1970s and early 1980s, a decline of red spruce, Picea rubens, was reported in the high elevation forests of the eastern United States (Sicamma et al 1982, Johnson and Sicamma 1983, Friedland et al 1984). Symptoms include a reduction in the number of all size classes of P. rubens in high elevation forests, a reddening and loss of needles from the tips of branches and necrotic spotting on the older foliage (Bartuska 1990). Subsequent studies indicate that the appearance of decline symptoms was preceded by a period of reduced growth of both P. rubens and Abies balsamea beginning in the 1960s. Hardwoods growing in the same stands did not have reduced growth (Hornbeck and Smith 1985, Hornbeck et al 1986).

Reams and Peterson (1992) conducted an analysis of radial growth chronologies of Picea rubens in Maine, USA and detected two periods of growth reduction over the past 60 years. In the early 1930s, decreased radial growth followed growth increases in the 1920s. The 1920s increase was attributed to the release of understorey trees and recovery of trees following an outbreak of spruce budworm, Choristoneura fumiferana (Lepidoptera: Tortricidae) which killed many overstorey trees. The trend of reduced radial growth in the 1960s was preceded by a growth increase in the 1940s which coincided with a regional decline of Betula spp.

The possible role of climatic influences, winter injury and air pollution as causal factors in the decline of P. rubens is discussed by a number of workers (Sicamma et al 1982, Johnson and Sicamma 1983, Friedland et al 1984, Pearl et al 1991). Several workers suggest that the primary mechanism of pollutant impact on P. rubens is through alteration of the cold hardening process leading to increased winter injury (Friedland et al 1984, Friedland and Battles 1987, Bartuska 1990, Adams and Eagar 1992).

Surveys of the condition of high elevation spruce-fir forests in the eastern United States indicated significant involvement of a number of biotic agents in the decline of these forests. These included periodic outbreaks of the spruce beetle, Dendroctonus rufipennis (Coleoptera: Scolytidae), a dwarf mistletoe, Arceuthobium pusillum, the root disease fungus, Armillaria sp, and a canker fungus, Valsa kunzei, on P. rubens (Weiss and Rizzo 1987). Larvae of a swift moth, Kotscheltellus gracilis (Lepidoptera: Hepialidae) has been found feeding on roots of A. balsamea and P. rubens in high elevation forests in Vermont (Tobi et al 1992). Extensive mortality of Abies fraseri in the southern Appalachian Mountains is largely due to infestations of the introduced adelgid, Adelges piceae (Homoptera: Adelgidae) (Dull et al 1989).

Discovery of the decline of red spruce was roughly synchronous with that of *neuartige Waldschäden* in Europe. This increased speculation that long distance transport of anthropogenic pollutants might be a causal factor. In addition, as in Europe, there was a tendency to lump damage by a number of different causal factors across the natural range of Picea rubens into a single type of decline which was then attributed to air pollution.

## 4.9. FIR WAVES

Mature, even age, high elevation forests of balsam fir, Abies balsamea, in eastern North America are subject to a phenomenon known as "fir or regeneration waves". These are bands of dieback and mortality which occur generally parallel to the contour of the slope (Fig 4.3). The dieback gradually progresses up slope. In some cases, several parallel bands of waves occur on the same slope. A new stand of A. balsamea regenerates in areas where trees have been killed.

Fir waves are believed to be an integral part of the dynamics of high elevation A. balsamea forests. They are triggered by cold winter winds striking exposed forest margins (Sprugel 1976, Sprugel and Bormann 1981) and serve as an example of synchronous cohort senescence in temperate forests (Mueller-Dombois 1986) (See also section 6.1.2.

## 4.10. YELLOW CEDAR DECLINE

Yellow-cedar, Chamaecyparis nootkatensis, has bright yellow, aromatic heartwood and is a highly prized timber species. It is presently the most valuable wood grown in the state of Alaska, USA. Its decay resistant wood allow yellow-cedar to

Figure 4.3 - Fir waves on the slopes of Lookout Mountain, Adirondack Mountains, New York, USA. (Photo by W.M. Ciesla)

attain great longevity. Despite these characteristics, yellow cedar is experiencing extensive decline and mortality on over 230,000 ha. of unmanaged forest in coastal Alaska (Hennon et al 1992).

Decline is concentrated on wet, poorly drained soils at low elevations (Hennon et al 1990a). Yellow-cedar is generally thought to be tolerant and well adapted to these conditions. Symptoms of decline include death of fine rootlets, necrotic lesions on coarse roots and boles, reduced radial growth and foliage thinning throughout the crown (Hennon et al 1990c). Fine root death may be the initial symptom that leads to slow tree death, often over a period of 15 years or more. More than 50 species of fungi, a species of bark beetle (Coleoptera: Scolytidae), several nematodes and brown bears have been investigated as possible causal factors.

Studies on the epidemiology of yellow-cedar decline indicate that a high rate of mortality began in about 1880 and continues on the same sites today (Hennon et al 1990 a,b). An average of 65% of the volume of yellow-cedar has been killed in affected stands. Trees which died over 100 years ago frequently remain standing as snags and this has allowed for a reconstruction of mortality patterns over time. Declining stands are not composed of cohort (same age) individuals and mortality is not synchronous. Trees die at various ages, often between 100 and 400 years. This is well before the 1,000 or more years of age when they are considered to naturally reach a stage of senescence.

Some abiotic factor is thought to be the primary stress mechanism. Several are now under investigation. Two hypotheses are:

A. Soil toxins, produced during anaerobic decomposition in the wet, organic soils damage fine roots of yellow-cedar.

B. Climatic warming, which began about 100 years ago, causes more winter precipitation to fall as rain rather than snow, thereby reducing the insulating snowpack at lower elevations each winter where the shallow, fine roots of yellow-cedar are exposed and damaged by freezing during periods of cold continental weather.

The remote location, pristine forest conditions and early onset of yellow-cedar decline suggest that this is an example of a forest decline whose development is independent of human activities.

## 4.11. X - DISEASE OF PINE IN SOUTHERN CALIFORNIA

A condition known as X - Disease of Pinus ponderosa and P. jeffreyii has been known from the San Bernadino mountains of southern California, USA since the mid 1950's. The condition is characterized by a yellowing and loss of foliage accompanied by reduced growth and tree mortality (Little 1992).

Studies by Miller et al (1982) implicated ozone ($O_3$) as the causal agent for this decline. During the mid 1970's, they recorded 24 hour $O_3$ concentrations during May to September in the San Bernadino Mountains ranging from a background level between 0.03 and 0.04 ppm to a maximum of 0.10 - 0.12 ppm. Source of the elevated ozone levels is motor vehicle emissions from the heavily populated San Bernadino Valley. These emissions are trapped by the mountains and react with sunlight to produce $O_3$. P. ponderosa was found to be sensitive to 24 hour $O_3$ levels of 0.05 - 0.06 ppm. Foliar injury and premature leaf fall caused decreased photosynthetic capacity resulting in reduced increment, seed production and nutrient retention. The pines became more susceptible to root disease caused by the fungus Heterobasidium annosum (= Fomes annosus) and the bark beetle, Dendroctonus brevicomis (Coleoptera: Scolytidae). Mortality rates reached 2 - 3% in some years. A long term effect of the decline is the replacement of the pine dominated forest by more $O_3$ tolerant species such as Libocedrus decurrens and Abies concolor (Little 1992).

# CHAPTER 5

# AFRICA

Forest decline events in the forests of the African continent are not well documented. However, a search of both the published literature and of reports by national research institutes and international consultants indicates that the phenomenon is widespread. The following sections detail case histories of decline from Benin, Botswana, Cote D'Ivoire, The Gambia, the Sahel Region of West Africa, The Sudan, South Africa, Tanzania, Uganda, Zambia and Zimbabwe (Table 5.1).

## 5.1. DECLINE OF AZADIRACHTA INDICA IN THE SAHEL

Neem, Azadirachta indica, is an important multipurpose tree native to the Indian subcontinent (Fig 5.1). The tree is highly valued as a shade tree, for fuel wood, construction and local crafts. The fruit, foliage and branches have a number of medicinal and insecticidal properties (National Research Council 1992). Neem has been widely planted in the tropics and is an especially important species for shade, forest and windbreak plantings in the west African Sahel.

During November 1990, neem expressing symptoms of decline were reported from south central Niger. The condition was subsequently found to be widespread in Niger and has also been confirmed in several neighbouring countries including the Cameroon, Chad, Mali and Nigeria (Boa 1992, US AID/Niger 1992).

The most conspicuous symptom of neem decline is a loss of older foliage. This is often preceded by a yellowing of older leaves. The foliage loss gives the normally dense crowns an open appearance with clumps of foliage occurring at the branch apices. In advanced cases, only a small tuft of foliage remains at the branch tip. This condition has been described as a "giraffe neck" (Fig. 5.2). New foliar growth is abnormally small and often has a yellow cast (Boa 1992).

Other symptoms associated with neem decline include shortened internodes near the apex of the branches, exudation of gum from branch tips, branch dieback and tree mortality.

Some workers have reported the occurrence of a deep red colour in the cambium layer on branches greater than one cm. in diameter as being associated with the decline. There is disagreement however if this is a symptom of the decline or a normal characteristic of the tree (Hodges and Beatty 1992)[1].

When initially discovered, decline of neem was confused with damage caused by a scale insect, Aonidiella orientalis (Homoptera: Diaspididae), which attacks the leaves and young stems of neem. This insect was first recorded on neem in Africa in the Cameroon

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[1] Recent observations in Indonesia and the Sudan indicate that individual neem trees have a cambium with a deep red colour. These trees did not express symptoms of decline (Ciesla, unpublished data).

Figure 5.1 - Foliage of a healthy neem in Niamey, Niger. (Photo by W.M. Ciesla)

Figure 5.2 - Declining neem in Niamey, Niger with "giraffe neck" symptoms.
(Photo by W.M. Ciesla)

in 1972 and later in the Sudan where it is believed to have been introduced on citrus trees. During the 1980s the insect spread into the Lake Chad Basin where it caused heavy damage (National Research Council 1992). Infestations cause the foliage to have a burnt appearance. Recent investigations concluded that the neem scale and the neem decline are two distinct conditions and the neem scale is not involved as a causal factor in the decline of neem (Batra 1991, Boa 1992).

The occurrence and severity of decline roughly follows the following pattern (Ciesla 1993a):

A. Trees of all ages are affected.

B. Single trees tend to have fewer symptoms than trees growing in groups.

C. Most severe symptoms appear in forest plantings followed by windbreaks.

D. Trees growing in villages tend to be least affected although decline symptoms do appear, especially areas which have heavy use such as outdoor market places.

E. Trees which have been pollarded tend to have healthy foliage and dense crowns.

F. At the present time, tree mortality attributable to the decline is minimal.

There is some question as to whether the observed decline is a new phenomenon or whether it has been going on for some time and only detected recently. There are photos of neem plantations in the Sahel exhibiting thin crowns and abnormally small foliage dating as far back as 1963. (Centre Technique Forestier Tropical 1963)

At present there is no evidence of a pathogen associated with this decline. It is currently believed to be the result of one or more environmental stresses. These could include long dry periods, competition for available moisture, use of weakened planting stock, poor planting technique and localized soil nutrient deficiencies. There is also some evidence of a long term trend in reduced precipitation which may have stressed trees over a wide area (Hodges and Beatty 1992). In addition, neems planted in the Sahel are believed to be from a narrow genetic base with little variability in susceptibility to stress. Several fungi, including Nigrospora sphaerica and Curvularia eragrostidis have been recovered from neems with symptoms of decline but they are secondary, recorded from other trees and crops and not known to cause serious damage.

## 5.2. DIEBACK OF ACACIA NILOTICA IN THE SUDAN.

Sunt, Acacia nilotica, is the most valuable timber producing species in the northern Sudan. It is widely used for railroad sleepers, structural lumber, fuel wood and other purposes. This tree occurs in pure, even age stands which have been artificially regenerated by direct seeding in flood plains and remnants of oxbow lakes along major river systems (Fig 5.3). Along the Blue Nile and its tributaries, A. nilotica plantations are managed intensively on 20 or 30 year rotations.

Decline or dieback of A. nilotica was reported as early as the 1930s and attributed to attack by a cambium and wood boring beetle, Sphenoptera chalcicroa arenosa (Coleoptera: Buprestidae) (Peake 1956). During the 1980s, decline was detected in high value plantations along the Blue Nile between Sennar Reservoir and Er Roseires Dam. Occurrence of decline increased following a major flood in 1988 which deposited up to 2 meters of silt in some plantations. These plantations are the country's primary source of railroad sleepers and the decline is considered to be the most important forest health problem in the Sudan (El Atta 1988).

Decline is expressed as an overall thinning of the crown. Other symptoms include abnormally small foliage, branch dieback and broken branches (Fig 5.4). There may be some recovery during the rainy season but symptoms reappear with the subsequent dry season. The decline is progressive and eventually leads to tree death.

The most abundant biotic factor associated with the decline is a complex of cambium and wood boring beetles which attack and eventually kill the branches of declining trees. At least two species are involved; a buprestid, presumably Sphenoptera chalcicroa arenosa (Fig 5.5), and a large cerambycid. In addition, there is evidence of a stem boring lepidoptera. Some areas of declining trees also have been defoliated by unidentified lepidoptera.

Ciesla (1993c) proposes the following "working hypothesis" to explain the events leading up to the occurrence of decline of Acacia nilotica in the Sudan:

*Predisposing factors* - A. nilotica occurs in pure, even age "cohort" plantations. This stand structure has been perpetuated and intensified by the management system presently in place. Use of seed of unknown or mixed origin in the establishment of some plantations may have resulted in establishment of certain provenances of A. nilotica in areas to which they are not suited. While the soils of these sites may be relatively rich in nutrients, they are constantly changing with every year's deposit of silt. Silt deposition gradually reduces the depth of the oxbow lakes. Consequently they hold less water and tend to dry out earlier. Over time they are no longer suitable for growth of A. nilotica. Periodic droughts are a more or less regular event in the Sudan. Silt deposition and periodic drought stress affects the larger, older stands to a greater extent because they there is more competition for available moisture. Any of these factors could contribute to premature senescence of A. nilotica and predispose trees to decline.

*Inciting factors* - The most likely incitant for the current episode of decline is the massive flooding and silt deposition which occurred in 1988. Outbreaks of defoliating insect(s) and periods of drier than normal weather could also incite decline.

*Contributing factors* - The complex of cambium and wood boring beetles which are invading the affected trees are considered to be contributing factors. Insects of the families Buprestidae and Cerambycidae typically attack trees which have been recently killed, however some species attack living trees which have been severely weakened by drought or site related factors. The role of root diseases in the decline complex is presently not known.

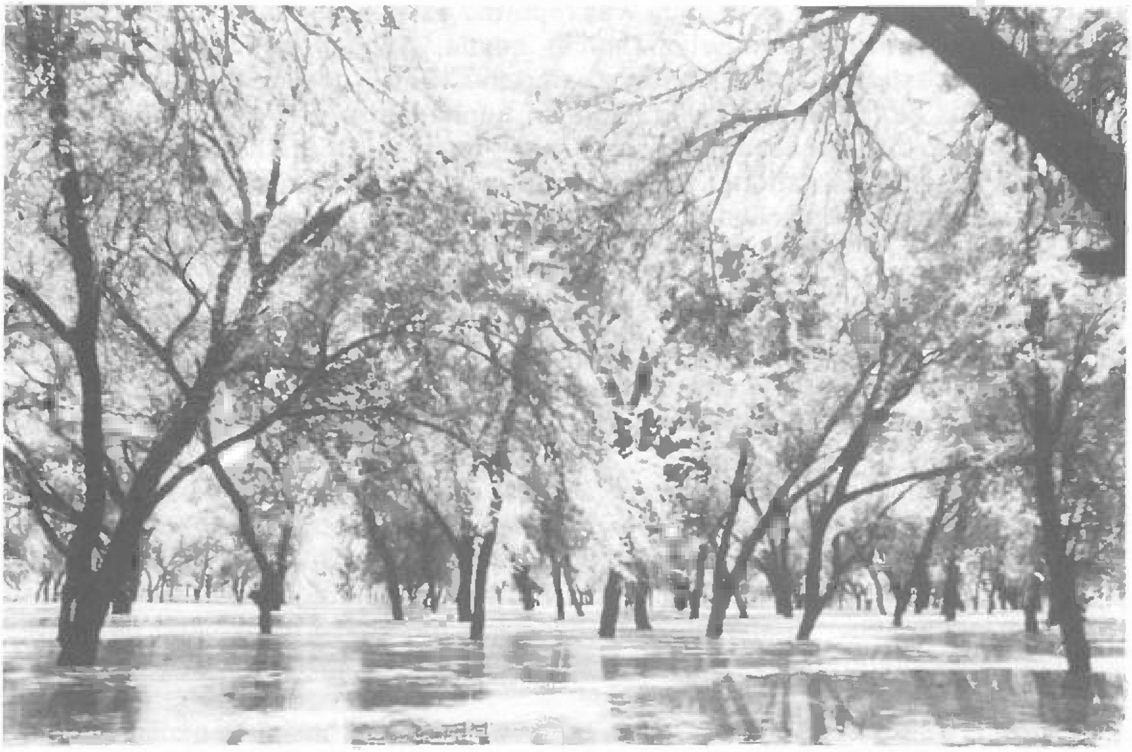

Figure 5.3 - Healthy Acacia nilotica plantation in the remnant of an oxbow lake along the Blue Nile in the Sudan (Photo by W.M. Ciesla).

Figure 5.4 - Acacia nilotica in varying stages of decline near Ed Damazin, the Sudan (Photo by W.M. Ciesla).

Figure 5.5 - Buprestid larva and damage in branch of a declining Acacia nilotica in the Sudan (Photo by W.M. Ciesla).

## 5.3. DIEBACK OF TERMINALIA IVORENSIS IN COTE D'IVOIRE AND GHANA

Terminalia ivorensis is a tropical hardwood indigenous to Cote D'Ivoire, Ghana and other West African countries in areas which receive from 1150 to 1900 mm. of rainfall per year and have one distinct dry season. This species became a popular tree for reforesting cut-over lands during the 1950s and 60s. The tree produces a good lumber for general construction, has a high growth rate, is easy to propagate and has other desirable silvicultural characteristics.

Growth in plantations of this species was apparently normal until the early 1970s when dieback was observed in plantations in Cote D'Ivoire and Ghana. Symptoms, as described by Brunck and Malagnoux (1976) and Ofosu-Asiedo and Cannon (1976), included branch dieback beginning at the crown apex, chlorotic and wilting foliage, crown thinning and sapwood staining. Other symptoms less frequently associated with the dieback, were bark necrosis, exudation of a black gummy liquid from the trunk, development of epicormic branches and attacks by bark beetles and wood boring insects (Families Cerambycidae, Platypodidae and Scolytidae).

Studies conducted in Cote D'Ivoire indicated that there was a marked reduction in foliar nutrient content associated with trees expressing dieback. This led to speculation that the dieback was caused by a malfunction of the roots or vascular system (Brunck and Malagnoux 1976).

Studies in Ghana indicate that there were no biotic agents which could be identified as the cause of the dieback. Onset of dieback appeared to be correlated with six years of drought which began in 1969, following a year of exceptionally high precipitation. Incidence of ground fires were also shown to have a deleterious effect on the survival rate of T. ivorensis (Cannon et al no date).

## 5.4. DIEBACK OF CASUARINA EQUISETIFOLIA IN BENIN.

Dieback and decline of Casuarina equisetifolia plantations is described from the People's Republic of Benin by Kaupenjohann and Zech (1988). Symptoms are a slow, progressive dieback leading to tree mortality. Symptoms occur in groups of trees in 5 to 10 year old plantations on coastal sandy sites in their third rotation of C. equisetifolia.

Studies on causes of the condition indicate shallow root development due to a high water table in the rainy season. In addition, analysis of soils showed increased acidification and low levels of nitrogen, phosphorus, potassium and calcium. Foliar content of phosphorus and potassium was 0.04% and 0.28% respectively for symptomatic trees and 0.21% and 0.85% for healthy trees.

## 5.5. DECLINE OF OCOTEA BULLATA IN SOUTH AFRICA.

Stinkwood, Ocotea bullata, is the most economically important indigenous tree species in the forests of the southern Cape and is widely used in furniture production. This tree is the dominant component of these forests and regenerates easily through coppice. Stinkwood has a thick bark which makes it fire resistant.

A group dieback of stinkwood occurs in portions of southern Cape forests. This dieback is associated with the root fungus, Phytophthora cinnamomi, waterlogging, fluctuating water availability and drought stress. P. cinnamomi was recovered from areas of obvious dieback as well as from areas of healthy forest where no dieback was observed. This fungus has the characteristics of a secondary pathogen in that affected stands and trees have a history of stress or disturbance. Dieback is worse in indigenous forests which are disturbed by road building or plantation forestry activities. These activities frequently affect natural drainage patterns and may assist in introducing the fungus into the soil (Lübbe and Geldenhuys 1990, Lübbe and Mostert 1991).

## 5.6. DECLINE OF PTEROCARPUS ANGOLENSIS IN BOTSWANA, ZAMBIA AND ZIMBABWE.

Pterocarpus angolensis, locally known as muninga, mtumbati, mukulu, mukwa or bloodwood, is a common tree of savannas of South Central Africa. It is found in Angola, Botswana, Malawi, Mozambique, Tanzania, Zambia and Zimbabwe where it is highly prized for furniture production, doors, joinery, turnery, carvings and a variety of other purposes.

A decline of this tree, which has occurred in portions of Botswana, Zambia and Zimbabwe, is reviewed by Piearce (1979) and Piearce and Calvert (1992). The condition is characterized by wilting and chlorosis of foliage followed by defoliation, progressive dieback and formation of epicormic shoots leading to tree death in a single season (Fig. 5.6). Serious losses first caused concern during the late 1950s and after 10 years, up to 60% of the merchantable trees were affected within a 40 km radius of Victoria Falls.

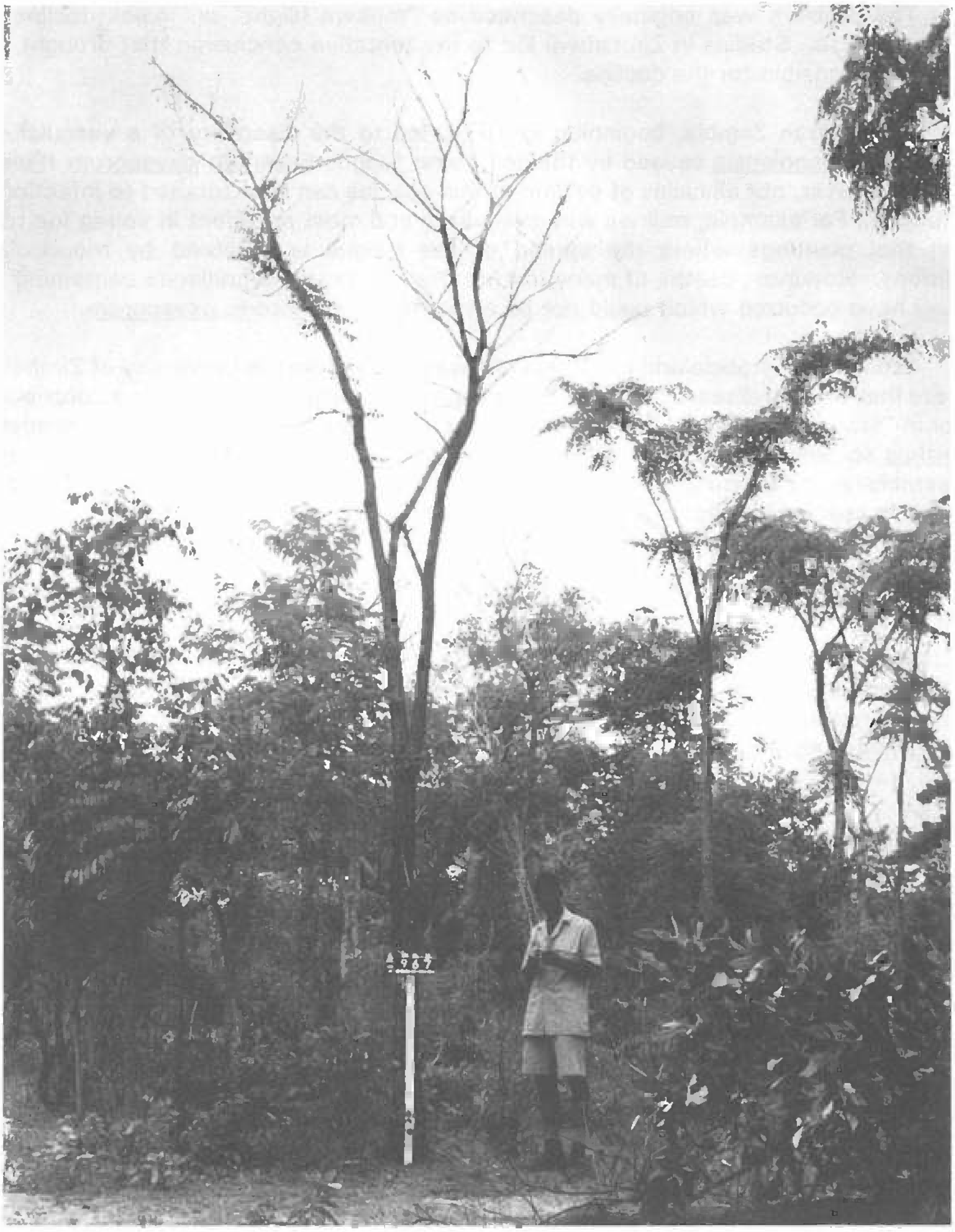

Figure 5.6 - Decline of Pterocarpus angolensis in Zambia. (Photo by G.D. Piearce, Courtesy of O. Shakacite, Zambia Forest Department, Kitwe, Zambia)

The problem was originally described as "mukwa blight" or "quick decline" of unknown cause. Studies in Zimbabwe led to the tentative conclusion that drought was primarily responsible for the decline.

Research in Zambia, beginning in 1973, led to the discovery of a vascular wilt disease of P. angolensis caused by the soil borne fungus Fusarium oxysporum (Piearce 1979). However, not all cases of decline of this species can be attributed to infection by this fungus. For example, mukwa wilt is localized and most prevalent in young (up to 30 years) trial plantings where the spread of the fungus is favoured by monoculture conditions. However, deaths of many mature trees in natural woodlands containing this species have occurred which could not be attributed entirely to F. oxysporum.

Studies in Matabeleland by a team of researchers from the University of Zimbabwe indicate that the wilt disease caused by F. oxysporum should be regarded as a contributing factor in "stand level dieback" and that drought, frost, fire and infections by a mistletoe, Loranthus sp. were seen as predisposing or inciting factors. In addition to slow growth and establishment difficulties, this decline is considered to be a further disincentive to the use of this species in industrial forest plantations.

## 5.7. DIEBACK AND MORTALITY OF TROPICAL RAIN FORESTS IN UGANDA.

Dieback and mortality of several tropical rain forest species was recorded in the Kibale Forest adjacent to exotic conifer plantations. Within a restricted area of mortality, nearly all mature Newtonia buchananii had died by 1984 and nearly 90% of Lovoa swynnertonii and 45% of the Aningeria altissima had died by 1986. Two associated canopy trees, Mimusopts bagshawi and Celtis africana had low rates of mortality.

The factor most highly correlated with the dieback was the downslope proximity to exotic conifer plantations of Pinus caribaea, P. patula, P. radiata and Cupressus lusitanica. There is no explanation given as to why the proximity of exotic conifer plantations would cause dieback and tree mortality in the native forest (Struhsaker et al 1989)

## 5.8. DIEBACK AND MORTALITY IN MANGROVES ON THE GAMBIA RIVER.

Jimenez et al (1985) review an epidemic dieback and mortality of mangrove forests along the Gambia River. The mortality was attributed to a gall causing fungus, similar to Cyclindrocarpon didymum which occurs in mangroves in Florida, USA (Teas and McEwan 1982). Rhizophora spp. was the primary group of trees affected.

Work by other investigators indicates that the mortality may be due to hydrological changes in the river basin (Jimenez 1985). The Gambia watershed has a seasonal climate which is dominated by a 7 month dry period. This allows for a buildup of salinity in the soils and mangroves. Salinity is flushed during the rainy season by fresh water. Mortality has been attributed to a drought which occurred from 1972 -1976. Changes in the tidal regime have also been suggested as a possible cause of the mortality. The high incidence of gall fungus infection may be related to stress induced by hydrologic changes.

## 5.9. DIEBACK OF PINUS PATULA, SAO HILL PLANTATIONS, TANZANIA

In 1975, The World Bank financed an afforestation programme on 33,000 ha. at Sao Hill, located in the highlands of southern Tanzania. The programme was designed to provide a source of raw material for domestic production of pulp, paper and lumber. Several species of Eucalyptus and Pinus were planted. The predominant species planted was P. patula, a pine native to Mexico which has been widely planted in eastern and southern Africa.

One of the problems encountered in the implementation of this programme was the occurrence of dieback. On P. patula, dieback was confined to the terminal leader which is killed back to the most recent whorl of lateral branches. Dieback results in the formation of crooked stems or trees with multiple leaders and a subsequent reduction in the volume of useable timber. Tree mortality directly attributable to this dieback was minimal (Cannon 1985 a,b).

An early investigation of the problem by Waring (1982) suggests that the dieback is the result of the combined effects of soil, light, water and competition from weeds. He recommended complete cultivation, planting of trees early during the rainy season, application of fertilizers, removal of competing weeds and thinning at age 5 to 7 years as a means of reducing incidence of dieback.

Later studies by Cannon (1985 a,b) indicated that dieback was rare in stands less than 5 years old. However between ages 5 and 10, incidence of dieback increased markedly. After age 10, incidence of decline continued to increase, but at a slower rate. Analyses of soils showed that incidence of dieback was highest on soils with a high bulk density in the B horizon or with ferricite or saprolite parent rock near the surface. These conditions inhibit root development and predispose terminal leaders to dehydration during extended droughts. Pruning of trees appeared to add an additional stress.

Proposed management solutions to this dieback problem resulting from these studies included:

A. Avoid planting land with a problematic B horizon.

B. Ripping the B horizon where it is shallow enough and where topography permits.

C. Use of species and provenances adapted to periodic loss of soil moisture.

D. Changes in pruning practices.

TABLE 5.1

SUMMARY OF FOREST DECLINE EVENTS
BY POSSIBLE CAUSAL FACTORS
AFRICA *

| DECLINE EVENT | FOREST SITUATION** | PREDISPOSING FACTORS | INCITING FACTORS | CONTRIBUTING FACTORS |
|---|---|---|---|---|
| *Azadirachta indica* (Sahel, 5.1.) | PE | Long dry season<br>Competition<br>Poor planting technique<br>Narrow genetic base | Rainfall deficit | Secondary fungi<br>Soil compaction |
| *Acacia nilotica* (The Sudan, 5.2) | PI | Senescence<br>Changing habitat | Drought<br>Flooding and siltation<br>Defoliation | Insect attack<br>Buprestids<br>Cerambycids |
| *Terminalia ivorensis* (Cote D'Ivoire & Ghana, 5.3.) | PI | Nutrient deficiency | Drought<br>Fire | Bark beetles<br>Wood borers<br>Sap stain fungus |
| *Casuarina equisetifolia* (Benin, 5.4) | PE | High water table<br>Nutrient deficiency | Unknown | None given |
| *Ocotea bullata* (South Africa, 5.5.) | N | Fluctuating water availability | Changes in water table due to logging, etc | *Phytophthora cinnamomi* |
| *Pterocarpus angolensis* (Botswana, Zambia Zimbabwe, 5.6.) | N<br>PI | Drought***<br>Frost<br>Fire<br>Mistletoe, *Loranthus* sp. | | Fungus; *Fusarium oxysporium* |
| Tropical rainforests (Uganda, 5.7.) | N | Unknown | Unknown | Unknown |
| Mangroves (The Gambia, 5.8.) | N | Long dry season<br>Soil salinity | Drought<br>Tidal change | Gall fungus |
| *Pinus patula* (Tanzania, 5.9.) | PE | Dense rocky soils | Drought | None listed |

* Causal factors are summarized according to the predisposing, inciting and contributing factors concept of Sinclair and Manion (see section 2.3.2).

** N = natural forest, PI = plantation with indigenous species, PE = plantation with exotic species.

*** Listed as "predisposing or inciting" factors.

## CHAPTER 6

## ASIA

A number of decline events have been reported from the forests of Asia. While these events have not been as widely reported in the scientific literature as have events in Europe, North America and the Pacific Region, they have been the subject of considerable local concern. Case histories from Bangladesh, Bhutan, China, Japan and India are presented in the following sections and are summarized in tables 6.1 and 6.2.

### 6.1. DECLINE IN JAPAN.

6.1.1 - DECLINE OF CRYPTOMERIA JAPONICA - Cryptomeria japonica is an important forest plantation species in Japan where it is used in the production of high quality wood products. In the Kanto Plains of the central portion of the island of Honshu, this species has been planted near religious shrines and temples and on farms for woodlots and windbreaks.

Dieback and decline of Cryptomeria japonica began to appear during the late 1970s and 1980s (Morikawa et al 1990). A report by Yokobori (1981) indicates that the decline is widespread. Damage occurs primarily in farm windbreaks and small stands near religious shrines on the Kanto Plains. Soil compaction, deposition of air pollutants, especially sulphur dioxide, and fluctuations in water table were suggested as possible causal factors.

Studies by Inoue (1988) indicated that incidence of decline was higher in small stands than in large stands. There appeared to be no relationship between incidence of decline, stem diameter or age. However, there were indications that dense stands had a higher proportion of declining trees.

Further studies by Waki (1988) indicated that there was considerable variation in decline incidence between stands with a tendency for symptoms to be most prevalent on sites with low ph soils.

Morikawa et al (1990) indicate that crown damage is observed only in mature trees and height growth is reduced. Symptoms include crown thinning, beginning in the upper crown and gradually spreading to the entire crown, top dieback and tree mortality. They report that all mature C. japonica within a radius of 60 km from central Tokyo have died. The reason for this decline has not been determined. Possible causes are reduced rainfall and relative humidity in the Kanto Plains, a complex of air pollutants from industrial sources and population centers, and the physiological characteristics of mature trees.

Decline of Cryptomeria japonica and Chamaecyparis obtusa near a coastal area was attributed to a combination of salt spray, Chlorosypha needle blight and the canker causing fungi, Guignardia cryptomeriae, Diaporthe conorum and Valsa abietis. Damaged trees eventually recovered (Suzuki et al 1987).

6.1.2. "SHIMAGARE DIEBACK" IN HIGH ELEVATION ABIES FORESTS - In Japanese, "shimagare" means stripes of dead trees. Mt. Shimagare (altitude 2,395 m) is located in the Yatsugatake Mountains in the central region of the island of Honshu. On the southwest slope, four to five bands of dieback, which run parallel to the contour, occur in natural subalpine forests of Abies veitchii and A. mariesii, at more or less even intervals of about 100 m. The name of the mountain comes from this feature of the landscape.

This pattern of dieback is commonly in the upper subalpine Abies forests in the mountains of central Honshu. Dieback fronts move gradually into pure stands of Abies (Fig. 6.1). As the dieback fronts move upslope, they become regenerated with even aged cohorts of Abies which come in the form of waves (Fig. 6.2). Studies on the dynamics of these forests suggest that desiccation and mechanical damage accelerated by prevailing winds trigger the directional dieback. Dieback is also promoted by overstocked, even aged stands (Kohyama 1988).

These waves of dieback and mortality are virtually identical to the fir waves described from high elevation Abies balsamea forests in the northeastern United States (see section 4.9) and represent a remarkable similarity of ecosystem dynamics on opposite sides of the world (Sprugel 1976).

## 6.2. DECLINE IN CHINA

According to Bain and Yu (1992), large areas of forest decline have not been found in the People's Republic of China (PRC). However there are localized areas of declining forests which have been detected near large cities, industrial areas and mining regions.

6.2.1. DECLINE AND MORTALITY OF PINUS MASSONIANA - An area of forest decline on approximately 2,000 ha, composed primarily of Pinus massoniana, near Nanshan, a suburb of Chongquing, Sichuan Province, has caused much public concern. Symptoms include tip necrosis of the needles, premature abscission, crown thinning, branch dieback and reduced radial growth.

Elevated sulphur and fluorine levels were found in pine foliage collected from damaged sites. The main source of $SO_2$ is the burning of coal for energy production. Sources of fluorides include glass, cement and brick factories. The area also has a high incidence of fog which is acidified by the industrial sources.

The affected area also has a history of insect damage. There have been outbreaks of the pine caterpillar, Dendrolimus punctatus (Lepidoptera: Lasiocampidae), during 21 of the past 36 years. In addition, there have been epidemics of bark beetles, weevils and pine sawyers. These are considered to be secondary to the anthropogenic pollutants (Bain and Yu 1992).

6.2.2. CHLOROSIS OF PINUS ARMANDI - Decline and mortality of Pinus armandi planted in 1958 on Wushan Mountain, Sichuang Province in southwestern China is described by Ma Guanging (1990 a,b). Symptoms include chlorosis of foliage beginning at age 10, followed by loss of foliage and tree mortality.

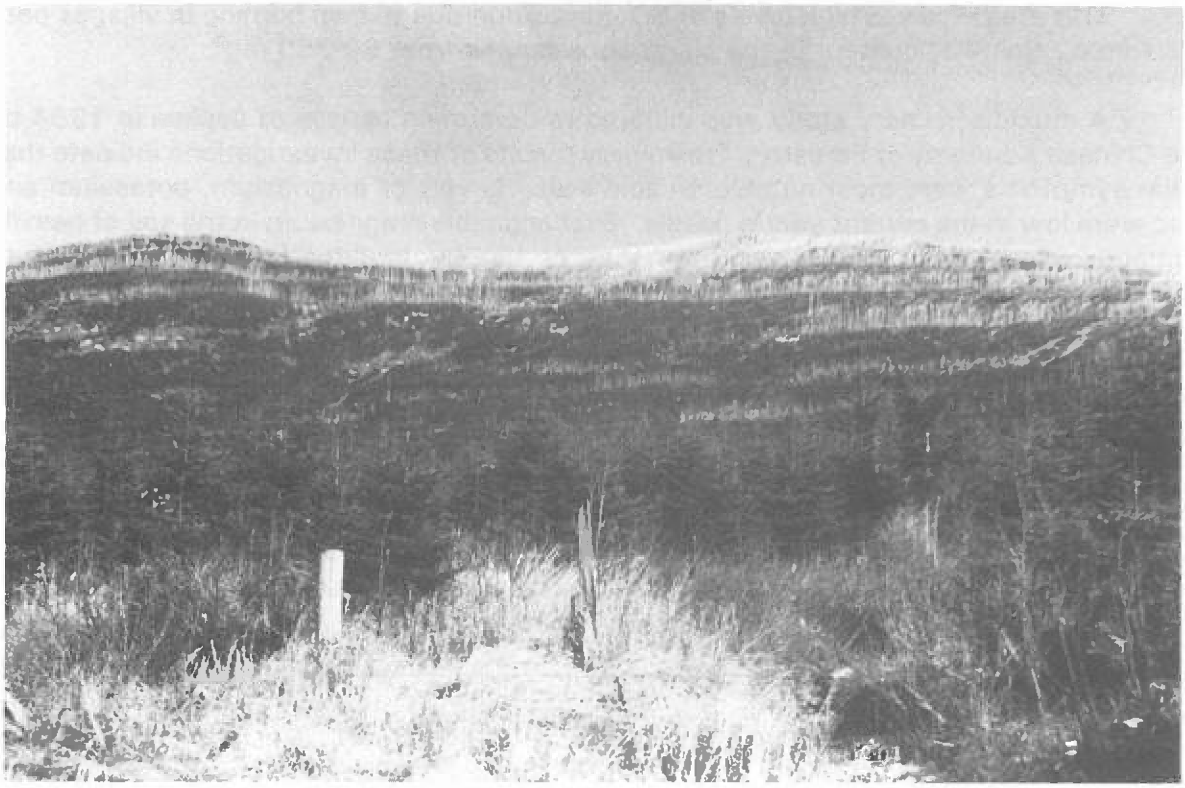

Figure 6.1 - Fir waves on the slopes of Mt. Shimagare, Japan.
(Photo courtesy of M. Yamagata, Nagano Regional Forest Office, Nagano Prefecture, Japan)

Figure 6.2 - Natural regeneration following wave mortality on high elevation Abies forests in Japan. (Photo courtesy of M. Yamagata, Nagano Regional Forest Office, Nagano Prefecture, Japan)

This area receives high levels of $SO_2$ deposition due to coal burning in villages near the forest. Soil $SO_2$ content in the plantations ranges from 90-350 $mg^3$.

A multidisciplinary study was initiated to determine causes of decline in 1984 by the Chinese Academy of Forestry. Preliminary results of these investigations indicate that foliar symptoms were most notable on acid soils. Levels of magnesium, potassium and zinc were low in the current year's needle. Exchangeable magnesium in the soil of heavily damaged plantations was lower than that of nearby healthy forests. Magnesium deficiency is believed to be the predominant cause of this decline.

TABLE 6.1

**SUMMARY OF FOREST DECLINE EVENTS BY POSSIBLE CAUSAL FACTORS JAPAN AND CHINA ***

| DECLINE EVENT | FOREST SITUATION** | PREDISPOSING FACTORS | INCITING FACTORS | CONTRIBUTING FACTORS |
|---|---|---|---|---|
| Japan (6.1.) | | | | |
| *Cryptomeria japonica* (6.1.1.) | PI | Low PH soils? | Overmature trees?<br>Air pollution?<br>Reduced rainfall? | None given |
| Fir waves (6.1.2.) | N | Cohort senescence | High winds | None given |
| China (6.2.) | | | | |
| *Pinus massoniana* (6.2.1.) | ? | Air pollution ($SO_2$) | Insect defoliation, *Dendrolimus punctatus* | Bark beetles<br>Wood borers |
| *Pinus armandi* (6.2.2.) | PI | Air pollution | Nutrient deficiency | None given |

* Causal factors are summarized according to the predisposing, inciting and contributing factors concept of Sinclair and Manion (see section 2.3.2).

** N = natural forest, PI = plantation with indigenous species, PE = plantation with exotic species.

## 6.3. DECLINE AND MORTALITY OF ABIES DENSA IN BHUTAN

The East Himalayan fir, Abies densa, occurs in Bhutan between 3000 and 4000 m. At the lower elevations it is intermixed with Picea spinulosa, Larix griffithiana and in the understorey with Juniperus recurva and Rhododendron spp. At the higher elevations it forms pure stands over large areas. Decline and mortality of Abies densa was reported in high elevation forests in Bhutan in the early 1980s. The condition was restricted to elevations above 3600-3800 meters. An estimated 10,000 to 12,000 ha of Abies forests have died during this period (Donaubauer 1993) (Fig 6.3).

Symptoms include reduction of height growth resulting in a flattening of the crown into a "storks nest", dying of branches just below the crown apex, loss of older needles, epicormic branching, wet wood and decay (Fig 6.4). These symptoms are strikingly similar to those reported for decline of A. alba in Europe (See Section 3.1.)

Analysis of radial growth patterns and meteorological data indicate that these forests may have been stressed by drought during the late 1970s and early 1980s. High elevation fir forests, characterized by a high proportion of overmature stands, decay and root disease caused by several fungi including Phellinus chonchatus and Armillaria sp. were most severely affected. An unidentified orange jelly fungus, Dacryomyces sp., was also collected from damaged trees. There was evidence of recovery of declining trees following a return to normal rainfall conditions (Donaubauer 1986, 1987).

An outbreak of a bark beetle, Ips schmutzenhoferi (Coleoptera: Scolytidae), occurred in forests of Picea spinulosa in the same location and during the same period of time that symptoms of decline appeared on A. densa. This outbreak is also believed to have resulted from prolonged dry weather (Schmutzenhofer 1987).

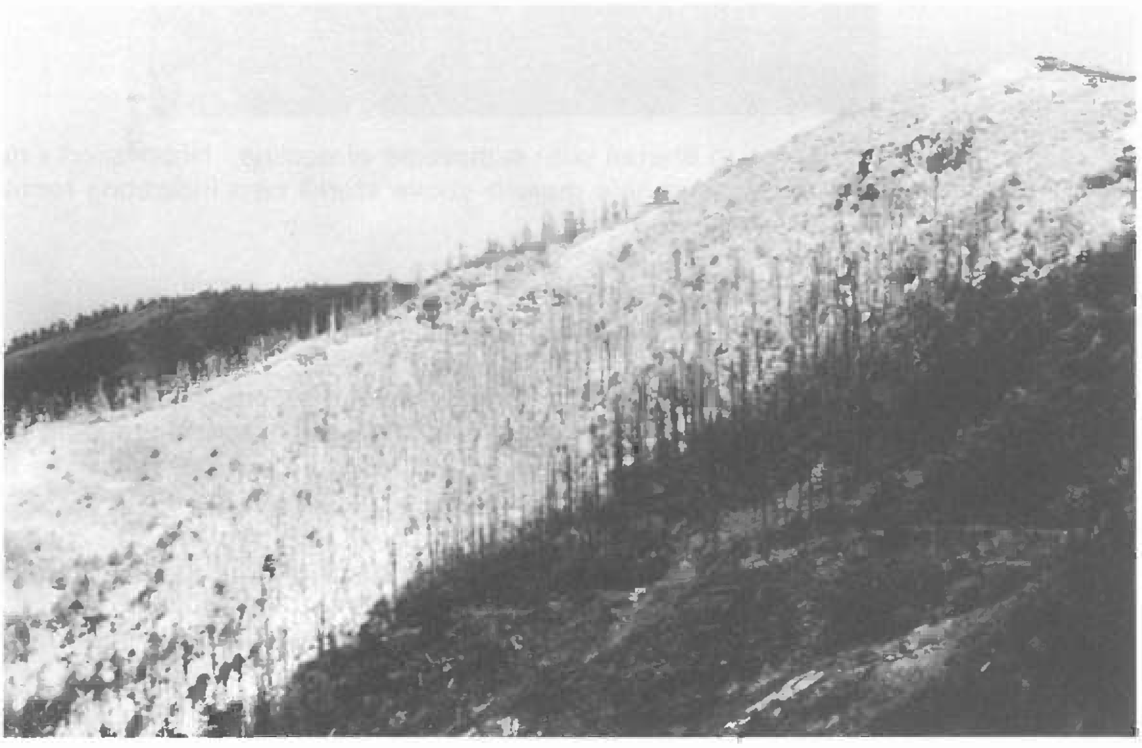

Figure 6.3 - Extensive mortality of high elevation Abies densa forests near Cheleila, Bhutan (Photo by E. Donaubauer)

Figure 6.4 - Abies densa in Bhutan with symptoms of decline. Note "storks nest" formation in upper crown and new growth above storks nest indicating recovery from decline. (Photo by E. Donaubauer).

## 6.4. DECLINE AND MORTALITY OF SHOREA ROBUSTA IN INDIA.

Decline and mortality of sal, Shorea robusta, has been reported as early as 1907 (Joshi 1988). Symptoms include dieback of branches in the upper crown extending to the lower crown over time, epicormic branching and eventual tree mortality and have been attributed to drought, overgrazing, fire and insect attack.

Extensive mortality of S. robusta began in the early 1950s in the Daltonganj Division, Bihar Province and reached catastrophic levels during the 1960s. Mortality was widespread over thousands of hectares and S. robusta ceased to be a major component of the affected forests (Boyce and Bakshi 1959, Bakshi 1976).

Studies associated with decline and mortality of S. robusta in Uttar Pradesh indicate that sites with high mortality had poorly drained soils with a high silt and clay content (Sharma et al 1983).

## 6.5. TOP DYING OF HERITIERA FOMES IN BANGLADESH.

Top dying of sundri, *Heritiera fomes*, in the Sundarbans region of Bangladesh is considered to be the most serious of all tree diseases in Bangladesh (Rahman 1990). The Sundarbans covers an area of 571,502 ha and is the largest single tract of mangrove forest in the world. Sundri is the most important tree species in the Sundarbans, covering 52.7 percent of the area and constituting about 63.8 percent of the standing tree volume. Dieback and mortality of this species was first recorded in 1915, but over the past 10-15 years, has been very damaging (Fig. 6.5). In many cases, symptomatic trees develop galls and/or cankers on the twigs and, to a lesser extent, on the main branches and trunks. Symptoms are seen on saplings as well as mature trees. A fungus, *Botryosphaeria ribis*, has been found associated with gall and canker formation. Young trees which are affected generally die.

Top dying of sundri appears as a decline and dieback of the foliage and twigs in the crown. In older trees, one or two branches may die initially. Examination of such branches do not show a clearly defined area of infection. Cracked perennial galls are often seen associated with dead branches. Symptomatic trees are also attacked by borers and wood decay fungi. Dead branches are subject to breakage by strong winds.

Possible causes of the condition are (Rahman 1990):

A. Reduction of fresh water discharge through the Sundarbans as a result of upstream diversion of water due to dams and increased use of ground water for agricultural and industrial purposes.

B. Reduction in the nutrient supply due to reduced volumes of fresh water.

C. Reduction in fresh water flush has also been accompanied by an increase in salinity. Increase in salinity has exerted an increased osmotic stress on the roots and thereby reduced availability and uptake of water and nutrients.

D. A moratorium on tree felling in the Sundarbans between 1972 and 1976 resulted in an increase of symptoms. As the number of trees with dieback increased, the population of *B. ribis* also increased and became more damaging.

E. Severely affected areas may be infected with a root pathogen.

F. A change in the depth and duration of flooding due to siltation of canal banks may have also played a role in the development of dieback.

A report by Chaffey et al (1985) indicates that the sensitivity of species distribution in the Sundarbans to long term salinity patterns makes the forest particularly susceptible to changes in fresh water availability. There is concern that the forest may be adversely affected by reduced stream flow in the Ganges River as a result of development upstream. The appearance of symptoms predates this development however.

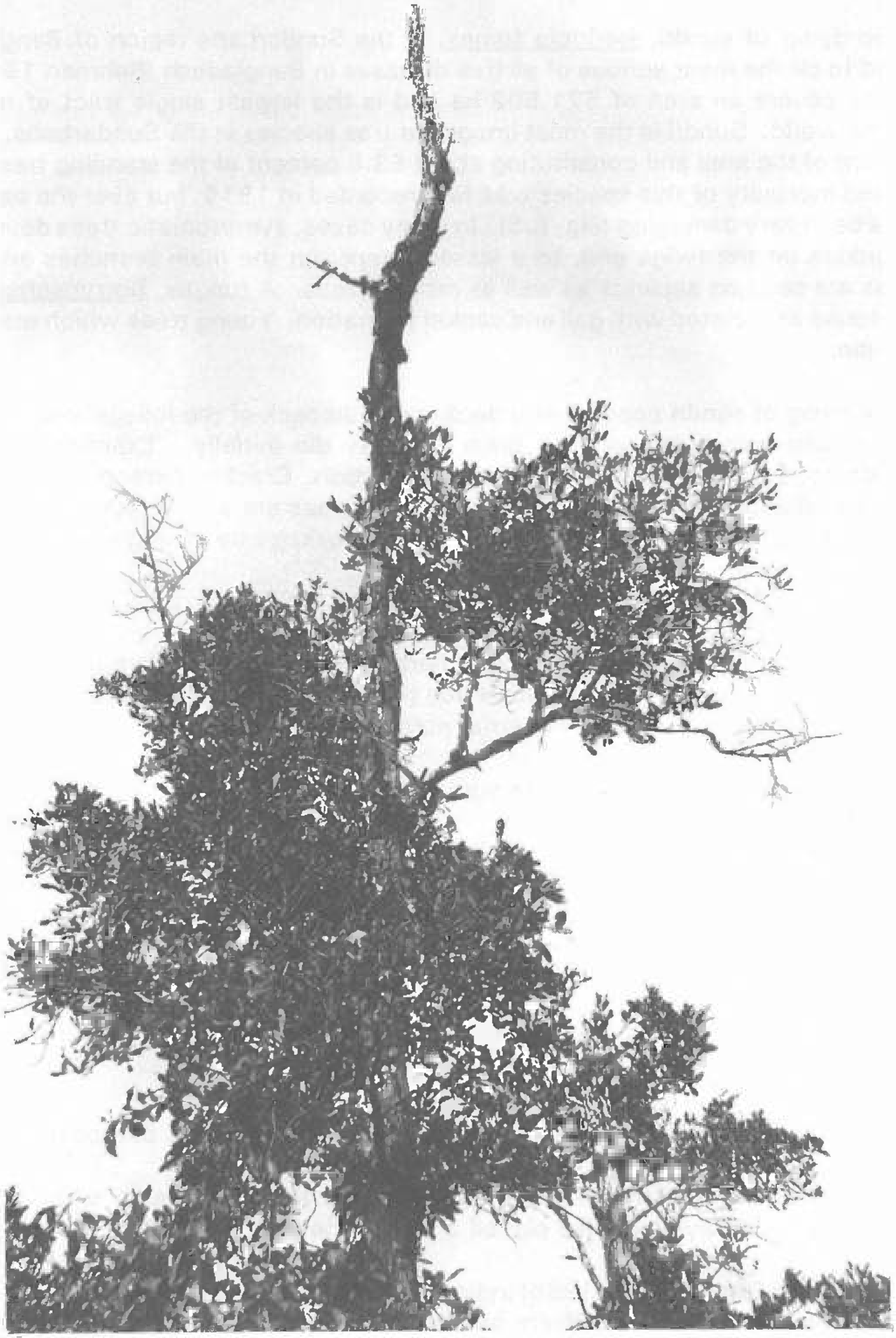

Figure 6.5 - Heritiera fomes with top dying in the Sundarbans, Bangladesh. (Photo courtesy of E. Boa, Natural Resources Institute, Overseas Development Administration, UK.)

Boa and Rahman (1988) report that B. ribis is a weak pathogen and canker development does not significantly contribute to the crown damage of sundri. They conclude that the condition is a complex disease and recommend replacement of sundri with other species.

## 6.6. CANOPY DIEBACK IN UPPER MONTANE RAIN FORESTS IN SRI LANKA

In Sri Lanka, remnants of upper montane rain forests cover the highlands above 1500 meters. These "mossy" forests occur in a zone of frequent fog and rainfall between 2000 and 5000 mm./year. Trees are umbrella-shaped with gnarled branches and coriaceous leaves. Stems and branches covered with mosses, ferns and lichens. They are stunted and generally only reach a height of from 3 to 5 meters except on sites protected from high winds where they may reach a height of 20 to 25 meters.

The dominant tree species of these forests are of the genus Calophyllum with lesser amounts of Syzygium spp. These form even-age "cohort" stands. Saplings and seedlings are scarce in the understories of these stands which are dominated by a shrub of the genus Strobilanthes.

Patches of dead and dying trees were first reported on the slopes of the mountain Thotupolakanda and other high regions above the Horton Plains in 1978 and continued into 1980/81. By 1981, virtually the entire upper canopy was killed in the affected areas.

Werner (1988) reports that the dieback occurred only in stunted and single-storied forests of slopes with a westerly exposure and a strong wind influence, shallow soils and a low water storage capacity. He concluded that the cause of this canopy dieback was not due to air pollution or disturbance of the hydrological regime due to human activities. Instead, he related the incidence of dieback to a period of exceptionally dry weather between 1971 and 1983 and suggests that this event is an example of cohort senescence triggered by drought.

An aspect of this decline event which is particularly interesting is the life cycle of Strobilanthes which is the dominant understorey plant in these montane forests. Strobilanthes growth suppresses growth of other understorey plants, including tree regeneration. The plant is characterized by cycles of synchronous flowering and seed production followed by death after a 6 to 12 year vegetative period. The occurrence of canopy dieback in 1978 coincided with a period of flowering of Strobilanthes undergrowth.

Return to normal rainfall resulted in some recovery of trees and a small amount of natural regeneration. In March 1986, an unusual frost occurred which caused further damage to the montane vegetation.

TABLE 6.2

SUMMARY OF FOREST DECLINE EVENTS
IN BHUTAN, INDIA, BANGLADESH AND SRI LANKA
BY POSSIBLE CAUSAL FACTORS *

| DECLINE EVENT | FOREST SITUATION** | PREDISPOSING FACTORS | INCITING FACTORS | CONTRIBUTING FACTORS |
|---|---|---|---|---|
| *Abies densa* (Bhutan 6.3.) | N | Overmaturity | Drought | Root disease<br>Stem decay |
| *Shorea robusta* (India 6.4.) | N | Poorly drained soils | Drought<br>Overgrazing<br>Fire | None given |
| *Heritiera fomes* (Bangladesh 6.5.) | N | None given | Reduced seasonal flushes of fresh water. | Gall fungus, *Botryosphaeria ribis* |
| Canopy dieback of montane forests (Sri Lanka 6.6.) | N | Cohort senescence<br>Shallow soils<br>High winds | Drought | None given |

* Causal factors are summarized according to the predisposing, inciting and contributing factors concept of Sinclair and Manion (see section 2.3.2).

** N = natural forest, PI = plantation with indigenous species, PE = plantation with exotic species.

# CHAPTER 7

## AUSTRALIA, NEW ZEALAND AND THE PACIFIC ISLANDS

Forest decline events have been reported from a number of forest ecosystems in Australia, New Zealand and the Pacific Islands. Many are well documented in the scientific literature. These are described in the following sections and summarized in tables 7.1 - 7.3.

### 7.1. DECLINE OF ARAUCARIA HETEROPHYLLA ON NORFOLK ISLAND.

Norfolk Island is a small, isolated island in the South Pacific which is part of Australia and home to several species of endemic plants. The best known of these endemics is Norfolk Island Pine, Araucaria heterophylla. Captain James Cook was the first to describe the island's stately Araucaria forests when he discovered it in 1774.

Crown deterioration and tree mortality of Norfolk Island pine was detected during the 1970s and early 1980s. In addition, it was noted that these forests had little or no natural regeneration. Surveys, using large-scale colour aerial photography indicated that one-third of the island's Araucaria forests were affected by dieback. Most of this area was severely damaged.

Studies into the causes of the dieback eliminated climate and the fungus, Phytophthora cinnamomi, as causal factors. It is believed that the condition is due to the manifestation of serious ecological damage due to severe competition from introduced grasses and shrubs, overgrazing and nutrient depletion on land originally cleared for agriculture (Benson 1980, Benson and Myers 1978).

### 7.2. DIEBACK OF MANGROVE FORESTS IN QUEENSLAND, AUSTRALIA.

Pegg et al (1980) report on the dying of white mangrove, Avicennia marina, in central coastal Queensland. The foliage of affected trees droops more than normal, then becomes chlorotic and finally falls. Lateral absorbing rootlets, which are borne on pneumatophores, become black and decayed. A trunk rot is also occasionally evident.

Only A. marina was affected although 12 mangrove species occur in the area. Dieback and mortality was observed only in large trees, however seedlings which appeared healthy also had decayed rootlets. Trees growing on sites subject to diurnal flooding by tides were most severely affected.

A fungus, Phytophthora sp., (near vesicula) was recovered from damaged tissue. This fungus produced dark coloured lesions when inoculated into healthy A. marina seedlings. Pegg et al (1980), however, question the role of Phytophthora as an aggressive pathogen, capable of killing vigorous trees. They suggest that since optimum salt concentration for A. marina is reported as 1.5%, the affected trees are subject to stress caused by continual exposure to high salines due to the lack of estuary flushing.

## 7.3. DIEBACKS OF EUCALYPTS IN AUSTRALIA

Diebacks affecting a number of species of Eucalyptus have been reported from Australia (Old and Podger, in press). Increased incidence of dieback during the 1970s, both in planted and natural forests, stimulated surveys and research to determine the extent and nature of the problem. Initially many of these diebacks were attributed to infection by Armillaria sp. and Phytophthora cinnamomi. These are now seen as contributing factors resulting from stress induced by a number of abiotic and biotic agents including drought, excess moisture, human activities and insect damage.

Several distinct diebacks of eucalypts have been described from Australia. These bear names reflecting the host tree affected, geographic location of the dieback, or the conditions under which the dieback is found. Examples include jarrah dieback, rural dieback, New England dieback, high altitude dieback, gully dieback and regrowth dieback.

7.3.1. JARRAH DIEBACK - A dieback of dry sclerophyll forests dominated by jarrah, E. marginata, has been known from Western Australia since 1920. This condition is reviewed by Newhook and Podger (1972), Jacobs et al (1979) and Weste and Marks (1987). Symptoms include general crown decline, foliar wilt, dieback, root necrosis and mortality.

In 1975, the area of jarrah forest affected by dieback was estimated at 282,000 ha. and was increasing at the rate of 20,000 ha annually. By 1982, an estimated 14% of the forest area was affected. In addition to jarrah, dieback and mortality has been reported from 59 indigenous plant species which occur in these forests. These represent 34 genera and 13 families (Weste and Marks 1987).

The root fungus Phytophthora cinnamomi and its role in the dieback was first established in 1965 when it was isolated from root systems of symptomatic trees and has been shown to be pathogenic. Occurrence of this fungus appears to be favoured by human activities. Damage to jarrah and other plants is associated with timber harvesting, roads, power lines and other disturbances (Jacobs et al 1979).

There is speculation that P. cinnamomi has been introduced into Australia and that the fungus enters jarrah forests via motor vehicles, tools and the clothing of forest workers. Others believe that the fungus is indigenous and that forest operations and other factors modify the environment to create conditions favourable for its development (Newhook and Podger 1972). Weste and Marks (1987) conclude that P. cinnamomi was introduced into Australia. They base this conclusion on its pathogenicity when introduced into sites which were previously free of the fungus and the fact that entire plant communities are damaged in areas where this fungus is present.

7.3.2. RURAL DIEBACK - A dieback known as "rural dieback" occurs in populated regions of humid, sub-humid and semi-arid zones of Australia. Many species of eucalypts are affected. Trees in woodland and forest communities are damaged but most concern has been expressed over dieback and mortality of trees in pastoral areas.

Symptoms of rural dieback are dead branches and development of epicormic shoots. Intensity of symptoms varies by species and the nature and duration of stress. Trees may die after a period of progressive crown dieback.

Many factors are believed to be involved in the onset of symptoms of rural dieback. These may change from one location to another and include defoliation by insects, drought, tree aging, soil salinity, mistletoe, root fungi, Armillaria sp. and Phytophthora cinnamomi, and animal damage.

Changes in environmental conditions and tree condition are believed to be predisposing factors in the occurrence of rural dieback. Cultivation and grazing reduces the probability that natural regeneration of eucalypts will survive and replace older trees. Many of the trees which presently occur in pastoral areas are overmature, in the range of 200 to 500 years (Kile 1980).

7.3.3. NEW ENGLAND DIEBACK - New England Dieback is a form of rural dieback described from the New England tablelands of New South Wales. The condition was reported as early as the 1850s. Jones et al (1990) reports that this dieback is associated with soil type, geology and certain characteristics of the woodland. Kile (1980) summarizes the causal factors involved in this dieback. He indicates that repeated defoliation by insects together with frost damage are key factors associated with tree death and decline.

Mueller-Dombois (1991) summarizes the aetiology of New England or rural dieback as follows:

The genus Eucalyptus evolved under isolation into many species but it represents the only major generic taxon that is overwhelmingly dominant in Australia. At the genus level, Australia's tree flora is taxonomically impoverished relative to other continents. Australia's soils are generally ancient and nutrient poor, particularly in phosphorus and other nutrients. Moreover, even in more humid climates, they are adapted to occasional droughts and most have evolved to cope with periodic fires. Thus, eucalypts can be generally considered hardy species.

Settlers trying to make a living on lands dominated by these poor soils in the more humid zones of eastern Australia focused on the sheep industry. This required introduction of grazing-resistant grasses from other continents. These pasture grasses were mixed with legumes to increase productivity, but particularly fertilization with superphosphate was practised in the open grazing lands. Eucalypt trees were allowed to remain in the paddocks as shade trees and as forest and woodland fragments in a formerly forested landscape converted to pastoral use.

Initially, the eucalypt trees benefitted from the addition of nitrogen and phosphorus, but their foliage became enriched with proteins. Their resistance to insect feeding was weakened by fertilization. The numbers of insectivorous birds were reduced because of forest fragmentation and loss of woodland habitat. These factors, combined with occasional drought which further favours insect feeding on eucalypts, is causing trees to die at an alarming rate.

7.3.4. EUCALYPT DIEBACKS IN TASMANIA - At least three distinct types of diebacks have been reported from Tasmania and are summarized by Felton (1980) and Old and Podger (in press).

*High altitude dieback* is a condition which affects natural forests of E. delegatensis and can result in the death of trees of all age classes. Dieback occurs in areas which have not been burned for 50 to 70 years. Soil disturbances associated with logging and fire result in recovery of symptomatic trees. Dieback and mortality of E. delegatensis allows understorey Nothofagus cunninghamii and other vegetation to become the dominant components of the stand. This dieback may be part of the natural succession of these forests when fire is excluded from the ecosystem (Ellis 1980). More recent work by Ellis and Pennington (1992) indicates that soil microbiological factors, specifically mycorrhizal associations which accompany changes in vegetative components of eucalypt stands, could be the underlying cause of dieback of all age classes of E. delgatensis.

*Gully dieback* affects natural forests of E. obliqua which grow along creeks and gullies in steeply dissected topography in northeastern Tasmania. This condition was first noted during the late 1960s and early 1970s. Studies by Palzer (1980) indicate that this dieback is the result of a severe drought accompanied by defoliation by the leaf skeletonizer, Uraba lugens (Coleoptera: Chrysomelidae), and subsequent secondary attack by Armillaria sp.

*Regrowth dieback* affects dominant and co-dominant E. regnans and E. obliqua in second growth (regrowth) forests older than 30 to 40 years. Symptoms include crown death, reduced growth, proliferation of epicormic branches and tree mortality. Despite intensive research, the aetiology of this dieback is still unresolved. There is no correlation with stand or site factors. Although there is some insect defoliation and invasion by Armillaria sp, associated with symptomatic trees, no pathogen or insect is consistently associated with the condition. There is circumstantial evidence which links symptom development with drought events (Wardlaw 1989).

## 7.4. DECLINE IN NEW ZEALAND.

7.4.1. STAND LEVEL DIEBACKS OF NOTHOFAGUS SP. - Southern beeches, Nothofagus spp., are the dominant tree cover of the montane forests of both the North and South Islands. They characteristically form even age stands consisting of from one to three species over extensive areas. Periodic episodes of dieback and mortality are a characteristic of these forests. These events are described by a number of workers including Hosking (1989) and Wardle and Allen (1984). They conclude that periodic decline and mortality is a natural process in these forests. As southern beech forests increase in age, they are predisposed to the impacts of events such as severe snow storms resulting in breakage, earthquake disturbances, windthrow and severe drought. Insects and fungi are associated with the collapse of these stands but are considered to be contributing factors. Older, even age stands are more susceptible than younger, mixed stands (Fig. 7.1)

Examples of these episodes include mortality of N. fusca in the Maruia Valley (Hosking and Kershaw 1985), decline of N. truncata on the Mamaku Plateau (Hosking and Hutcheson 1986) and decline of N. solandri var. cliffortioides in the Kaweka Range (Hosking and Hutcheson 1988). Studies on the dynamics of these forests indicate that there are three forms of stand-level dieback in New Zealand Nothofagus forests:

TABLE 7.1

SUMMARY OF FOREST DECLINE EVENTS
BY POSSIBLE CAUSAL FACTORS
AUSTRALIA *

| DECLINE EVENT | FOREST SITUATION** | PREDISPOSING FACTORS | INCITING FACTORS | CONTRIBUTING FACTORS |
|---|---|---|---|---|
| *Araucaria heterophylla* (7.1.) | N | Competition Overgrazing Nutrient depletion | None given | None given |
| *Avicennia marina* (7.2.) | N | None given | Excess salinity of water | *Phytophthora* sp. |
| Eucalypt declines (7.3.) | | | | |
| Jarrah dieback (7.3.1.) | N | ? | Introduction of *Phytophthora cinnamomi* into forest soils | ? |
| Rural/New England dieback (7.3.2.,7.3.3.) | N | Grazing Fertilization | Insect defoliation | Animal damage Root fungi |
| High altitude dieback (7.3.4.) | N | Fire exclusion | Unknown | None given |
| Gully dieback (7.3.4.) | N | Unknown | Drought Insect defoliation | Root fungus, *Armillaria* sp. |
| Regrowth dieback (7.3.4.) | N | Senescence? | Drought Insect defoliation | Root fungus, *Armillaria* sp. |

* Causal factors are summarized according to the predisposing, inciting and contributing factors concept of Sinclair and Manion (see section 2.3.2).

** N = natural forest, PI = plantation with indigenous species, PE = plantation with exotic species.

A. Stands in which there is an extensive decline of the old canopy but adequate regeneration.

B. Stands with re-establishment problems following breakdown of the old canopy.

C. Stands in which both old and young trees show clear symptoms of decline.

Hosking (1989) recommends care in planning of developments such as trails and recreation sites in natural forests of southern beech to minimize disturbances which might trigger episodes of decline and mortality.

Ogden (1988) concludes that successful regeneration of N. solandri var. cliffortoides, a short-lived, light demanding species, is dependent on the occurrence of decline and mortality of the upper canopy. Natural regeneration of N. fusca, on the other hand, can become established in small openings created by the death of small patches of trees. If these species grow in mixture with N. menzeisii, a shade tolerant species, they are destined to be replaced by it in the absence of disturbances which lead to decline and mortality of the upper canopy.

7.4.2. STAND LEVEL DIEBACK OF METROSIDEROS SP. AND WEINMANNIA RACEMOSA - Stand level dieback is a phenomenon of the *rata*, Metrosideros sp.- *kamahi*, Weinmannia racemosa, forests of New Zealand. This dieback has been studied by a number of scientists and is summarized by Batcheler (1983). The aetiology of this condition is complicated by the browsing of the Australian possum, Trichosurus vulpecula, which was introduced into New Zealand forests about 70 years ago and feeds in the canopy of these forests in epidemic numbers (Stewart 1989). For many years, the possum was regarded as the major cause of dieback. Recently, this view has been challenged and assertions have been made that some of these forests were in a poor state of health before the possums invaded and that their natural collapse was inevitable. Batcheler (1983) rejects the latter hypothesis and presents evidence that the possum is indeed the primary causal factor associated with this dieback.

According to Stewart and Rose (1988), the dieback triggered by the possum may be further accelerated by other factors which include wind damage, insect feeding, fungi and possibly drought. Dieback patterns indicate that not all forests are uniformly affected by dieback. Two major predisposing factors can be identified; the abundance of seral shrub hardwoods preferred by the possum and the proportion of old canopy trees which have a low potential for recovery from possum browsing.

7.4.3. SUDDEN DECLINE OF CORDYLINE AUSTRALIS - The cabbage tree, locally known as *ti kouka*, Cordyline australis, is a successional species which colonizes both naturally and artificially disturbed sites such as forested areas damaged by wind or fire, or affected by timber harvesting and other forest operations. During the early 1980s, there were reports of dying cabbage trees. By the late 1980s, the death and decline of this species was widespread on the northern half of the North Island.

This decline is characterized by wilted foliage, collapse of the crown and eventual tree death. Profuse flowering has also been reported. An evaluation of the decline indicated that it was strongly associated with land use, being most common on mature farmland and grazed shrub land. Its occurrence was rare in undisturbed forest and shrub lands. Symptoms were most severe in old and overmature trees while seedling and pre-flowering trees were largely unaffected. The most severe damage was associated with sudden changes in water table; areas which had been flooded or drained.

Hosking and Hutcheson (1992) conclude that sudden decline of Cordyline australis is the result of aging trees and site modification with possible secondary invasion by weak pathogenic agents. They recommend the following actions to protect individual trees and stands:

A. Protect residual trees or stands from browsing, especially by cattle.

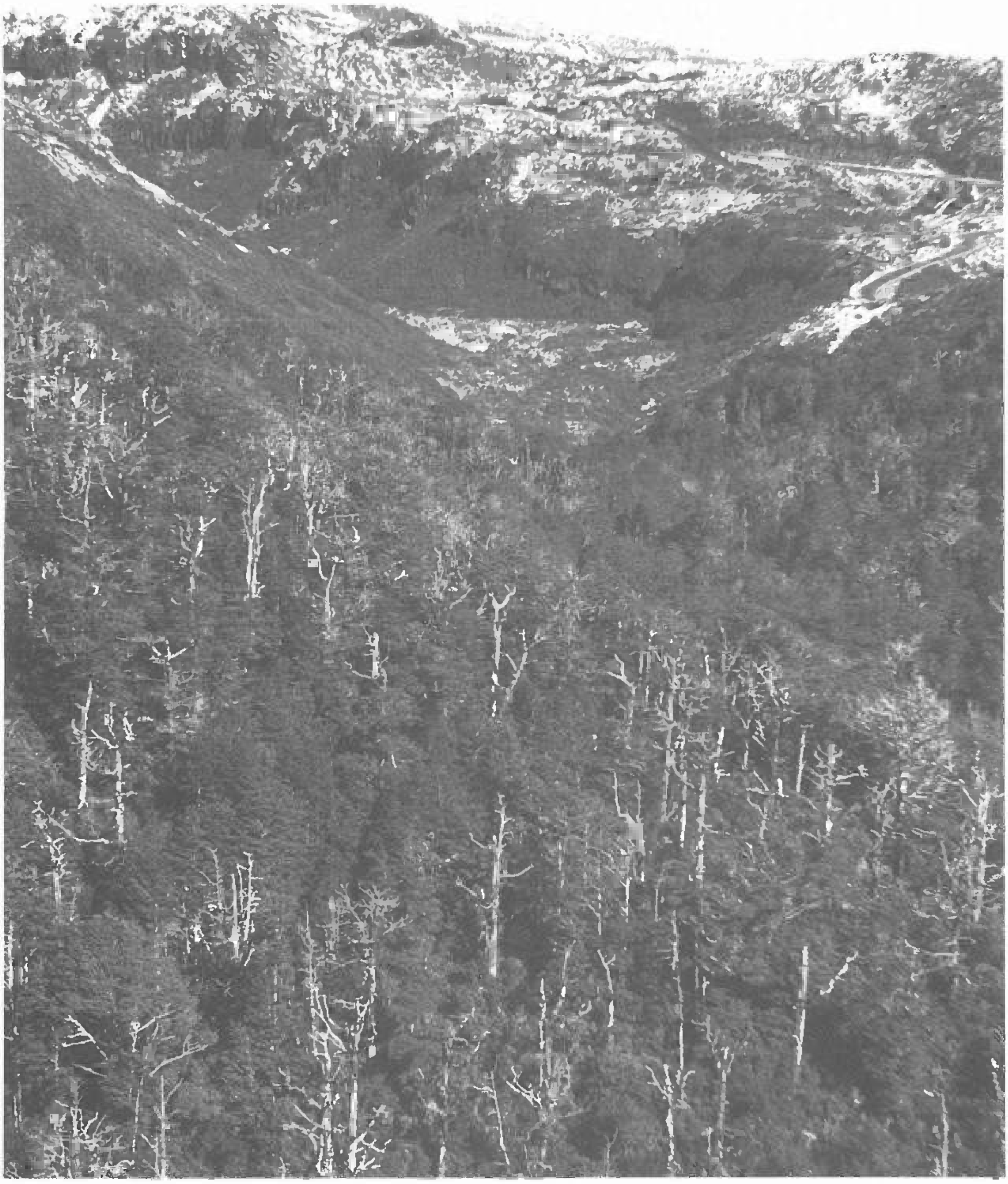

Figure 7.1 - Dieback of Nothofagus sp. in Tongariro National Park, New Zealand.
(Photo courtesy of Gordon Hosking, New Zealand Forest Research Institute, Rotorua, New Zealand)

B. Encourage the growth of natural shrub land associations within significant stands of this species to provide more stable soil moisture conditions.

C. Refrain from draining wetlands which contain major populations of this species.

D. Continued research to further investigate the causes of sudden decline.

Simpson (1993a) presents three hypothesis for the cause of this decline; a pathogen, climate change which may have triggered profuse flowering, and changes in nutrient uptake possible stimulated by profuse flowering. These hypothesis were based on observations and a cause and effect relationship which had not yet been established. More recently Simpson (1993b) reports the presence of foreign DNA belonging to a mycoplasma-like organism (MLO) in symptomatic trees but not in healthy cabbage trees. He suggests that the MLO may be an inciting factor in trees stresses by environmental factors.

TABLE 7.2

SUMMARY OF FOREST DECLINE EVENTS
BY POSSIBLE CAUSAL FACTORS
NEW ZEALAND *

| DECLINE EVENT | FOREST SITUATION** | PREDISPOSING FACTORS | INCITING FACTORS | CONTRIBUTING FACTORS |
|---|---|---|---|---|
| *Nothofagus* sp. (7.3.1.) | N | Cohort senescence | Storms<br>Earthquakes<br>High winds<br>Drought | Secondary insects and fungi |
| *Metrosideros* sp. and *Weinmannia racemosa* (7.3.2.) | N | Cohort senescence? | Defoliation by Australian possum | None given |
| *Cordyline australis* (7.3.3.) | N | Senescence<br>Grazing | Site modification<br>MLO | Secondary pathogens |

* Causal factors are summarized according to the predisposing, inciting and contributing factors concept of Sinclair and Manion (see section 2.3.2).

** N = natural forest, PI = plantation with indigenous species, PE = plantation with exotic species.

## 7.5. STAND LEVEL DIEBACK IN THE FORESTS OF PAPUA NEW GUINEA.

Arentz (1988) reviews stand level dieback in Nothofagus, mangrove and Eucalyptus deglupta forests in Papua New Guinea.

The genus Nothofagus is represented by 13 species in Papua New Guinea. They generally occur on ridge tops and upper slopes between 1000 and 3000 meters above sea level. A species may be locally dominant forming pure stands which are mosaics of groups of even age trees. Canopy trees commonly develop dead branches. Death of the upper crown may be followed by development of adventitious shoots but eventually the above ground portion of the trees die. Mortality occurs simultaneously within a group of largely even age trees. Following episodes of dieback and mortality, regeneration of the same species of Nothofagus will occur, most commonly as clumps of vegetative shoots. There is generally no evidence of chlorosis or death in the regrowth. The fungi Phytophthora cinnamomi and Armillaria sp. have been recovered from affected sites and three species of ambrosia beetles have been collected from declining trees. These agents are considered as secondary or contributing factors.

Studies of dieback of N. pullei and N. grandis on the slopes of Mt. Giluwe have led investigators to conclude that these episodes of dieback are an example of cohort senescence with soil nutrient deficiencies, drought and heavy frost associated with drought serving as triggering mechanisms (Arentz 1983, Ash 1988, Mueller-Dombois 1986).

Patches of dieback and mortality has been recorded in mangrove forests on Papua New Guinea with areas of a radius up to 25 meters affected. There is a high frequency of lightening strikes in these forests and it is suggested that these may trigger tree mortality. Two species of Phytophthora have been recovered from the soil in dieback areas but pathogenicity has not been proven. Water tests in areas affected by dieback indicated normal levels of salinity but these were taken during periods of normal precipitation. Arentz (1988) suggests that the occurrence of periods of high salinity during drought periods could be a possible factor which triggers dieback and mortality.

Eucalyptus deglupta forms extensive stands of even age forests rising terrace like along streams in coastal rain forests, primarily on the island of New Britain. There is no natural regeneration of E. deglupta in these stands and if left undisturbed, will eventually be replaced by other rain forest species. This tree is tolerant of wet sites associated with streams but will not tolerate water logging.

There are a few reports of crown decline of E. deglupta. In one instance Phytophthora palmivora was recovered from soil in dieback sites but its pathogenicity to this tree has not yet been demonstrated. E. deglupta is potentially susceptible to two opposing weather related stresses; excess water and drought. Because of its lack of tolerance to water logging, it may be placed under stress during periods of heavy rainfall. The restricted distribution of natural stands of this species to areas of high rainfall and no marked dry season suggests that this species may be susceptible to drought stress (Arentz 1988).

## 7.6. STAND LEVEL DIEBACK OF METROSIDEROS POLYMORPHA, IN THE HAWAIIAN ISLANDS, USA.

The dominant rain forest tree on the Hawaiian Islands is the *ohi'a lehua*, Metrosideros polymorpha. This species has long impressed botanists because of its morphological variability and ecological amplitude. On the island of Hawaii, *ohi'a lehua* forms nearly pure stands on lava flows on the slopes of the volcanoes Mauna Loa and Mauna Kea.

During the early 1970s, a dieback of ohi'a on the island of Hawaii became so conspicuous that a number of studies were initiated to determine its causes. Sequential aerial photographs, taken of an 80,000 ha area on the slopes of Mauna Kea indicated that an area of severe decline, with over 40% of the canopy dead or dying, increased from 120 ha in 1954 to 34,500 ha in 1972 (Stemmermann 1983).

Investigations into the cause of the dieback indicated that the fungus, Phytophthora cinnamomi, and an endemic, host specific borer, Plagithmysus bilineatus, (Coleoptera: Cerambycidae) were associated with the decline but could not be implicated as primary causal factors. Hodges et al (1986) suggest that poor soil drainage may stress trees, increasing their susceptibility to borers and root disease.

Stemmermann (1983) documented differences in the distribution of different morphological forms of *ohi'a lehua* on young and old lava flows and suggests that there may be several successional forms of this tree. She considers the occurrence of dieback in these forests as a natural successional process. Mueller-Dombois (1986) regards the dieback of these forests as an example of synchronous cohort senescence possibly triggered by excess rainfall. He has described five dieback types on the windward slopes of Mauna Kea and Mauna Loa (Mueller-Dombois 1983):

A. *Wetland Dieback* - Usually a radical tree-to-tree dieback on poorly drained, shallow, lava outcrop soils (Fig 7.2).

B. *Dryland Dieback* - Usually a salt-and-pepper or patchy dieback on well drained, shallow lava rock outcrop soils (Fig 7.3).

C. *Displacement Dieback* - Found on moderately to well drained deep soils of organically enriched and therefore fertile volcanic ash. Here, tree ferns are so vigourous that they replace the canopy Metrosideros when these undergo stand-level dieback. Metrosideros seedlings may be abundant on the forest floor, but the tree ferns shade out a significant number.

D. *Bog-Formation Dieback* - Occurs also on deep soils of volcanic ash, but here the ash is relatively old, nutritionally poor and permanently soggy or water soaked. This is a salt-and-pepper dieback involving groves of dead trees and non-dieback trees in various patterns.

E. *Gap-Formation Dieback* - Found on the moderately well drained ridges dissecting the bog formation terrain in the northern half of the dieback area. It involves small tree groves or patches as in the dryland dieback. However, this form of dieback occurs on older, nutritionally depleted ash soils, some of which are suspected to show aluminum toxicity.

Figure 7.2 - Wetland dieback of <u>Metrosideros polymorpha</u>. (Photo courtesy of D. Mueller-Dombois, University of Hawaii at Manoa, USA.)

Figure 7.3 - Stand of <u>Metrosideros polymorpha</u> affected by dryland dieback. This photo shows vigorous regrowth, a situation known as replacement dieback. (Photo courtesy of D. Mueller-Dombois, University of Hawaii at Manoa, USA.)

TABLE 7.3

SUMMARY OF FOREST DECLINE EVENTS
BY POSSIBLE CAUSAL FACTORS
PACIFIC ISLANDS *

| DECLINE EVENT | FOREST SITUATION** | PREDISPOSING FACTORS | INCITING FACTORS | CONTRIBUTING FACTORS |
|---|---|---|---|---|
| *Nothofagus* sp. (Papua New Guinea, 7.4.) | N | Cohort senescence | None given | Root fungus, *Phytophthora cinnamomi* Wood borers |
| *Metrosideros polymorpha* (Hawaiian Islands, USA, 7.5.) | N | Cohort senescence | Excess rainfall | Root fungus, *Phytophthora cinnamomi* Wood borer, *Plagithmysus bilineatus* |

* Causal factors are summarized according to the predisposing, inciting and contributing factors concept of Sinclair and Manion (see section 2.3.2).

** N = natural forest, PI = plantation with indigenous species, PE = plantation with exotic species.

# CHAPTER 8

## LATIN AMERICA AND THE CARIBBEAN.

Episodes of forest decline in Latin America and the Caribbean have occurred in both natural forests and plantations. Some have involved chronic exposure to air pollutants. Others have been associated with soil nutrient deficiencies, drought and high winds. Included in the following sections are case histories from Argentina, Brazil, Colombia, Ecuador (Gallapagos Islands), Mexico, Peru and Uruguay (Table 8.1).

### 8.1. FOREST DECLINE IN THE MEXICO CITY BASIN.

In 1981, extensive decline and mortality of pure forests of Abies religiosa was detected in the *Parque Nacional Desierto de los Leones*, southwest of Mexico City. Symptoms include discoloration of needles, loss of older foliage, reduced growth, dead branches and lack of cone crops (Figs 8.1 - 8.3). Tree mortality is the result of a build-up of two species of bark beetles, Pseudohylesinus variegatus and Scolytus mundos (Coleoptera:Scolytidae).

Forests of Pinus hartwegii, which are located at an elevation zone immediately above the A. religiosa forests, have yellow foliar flecking characteristic of elevated levels of ozone. Trees are being attacked and killed by the bark beetle, Dendroctonus adjunctus (Coleoptera:Scolytidae).

It is believed that the decline of both Abies and Pinus forests is due to elevated levels of ozone which is produced when pollutant laden air is trapped in the Mexico City basin and exposed to sunlight. High levels of ozone have been measured in the basin and street trees and vegetable crops in Mexico City have shown classic symptoms of ozone damage (Bauer and Kruper 1990, Cibrion Tovar 1989, Ciesla and Macias Samano 1987).

### 8.2. OAK DECLINE IN COLOMBIA.

The oak, Quercus humboldtii, is a valuable tree in Colombia because of its high wood quality. This tree occurs in homogeneous stands in the northern part of the Department of Antioquia where harvesting is now regulated to protect remaining stands.

A dieback, affecting both young and old trees, has been reported in these forests. Symptoms include a progressive death of individual branches eventually affecting the entire crown, marginal necrosis and chlorosis of foliage and a vascular discoloration of twigs, branches and roots.

Investigations into the causes of this dieback indicated that several fungi, parasitic plants (mistletoes), insects and an unidentified nematode were associated with symptomatic trees. The following fungi were recovered; Phialophora sp. from necrotic foliage, Pestalotia sp. from both chlorotic and necrotic foliage and Dothiorella sp. from dead branches. Several families of insects were found feeding on the foliage and secondary wood borers, ants and termites were found in dead and dying trees.

Figure 8.1 - Foliage of healthy Abies religiosa with three to four years of needle retention. (Photo by W.M. Ciesla)

Figure 8.2 - Foliage of Abies religiosa suffering from photo-oxidant injury in the *Parque Nacional Desierto de los Leones* near Mexico City, Mexico. Note that only the most recent two year's growth of foliage is retained. (Photo by W.M. Ciesla)

Figure 8.3 - Abies religiosa with symptoms of decline, *Parque Nacional Desierto de los Leones, Mexico.* (Photo by W.M. Ciesla)

Ramirez Correa (1988) concludes that the dieback may be due to several factors which could produce similar symptoms. He suggested studies leading toward a better understanding of the structure of these stands as a means of developing strategies to protect them from damaging agents.

## 8.3. DIEBACKS OF EUCALYPTUS SP. IN SOUTH AMERICA.

Eucalypts are widely planted in many South American countries where they are used for fuelwood, charcoal, mine timbers, structural lumber, poles, posts and other wood products. They are also used for windbreak and ornamental plantings. While this group of trees is well adapted to a wide range of climatic, topographic and edaphic conditions, there have been a number of problems associated with plantation establishment in the region. Several of these appear to be the result of a complex of interacting factors which fit under the definition of decline.

8.3.1. BRAZIL - Eucalypts planted in the Rio Doce Valley in the state of Minas Gerais are affected by a disease of unknown aetiology which is locally known as *Mal do Rio Doce* or *Seca de Ponteiros*. Some 30,000 ha. of plantations have been affected since 1974. *Mal do Rio Doce* is presently considered to be the most damaging disease of eucalypts in Brazil.

Symptoms, which appear 8 to 10 months after transplanting to the field following the first dry season, include loss of foliage, shoot dieback followed by secondary branching which results in poor form, girdling branch cankers and reduced increment. A number of species, including most of those of commercial importance, have been affected (Dianese and Moraes 1986).

A number of hypotheses have been postulated as to the causal factors associated with this disease. These include unfavourable soil and water chemistry, air pollution and acid rain. None of these factors have been confirmed as causal agents, however, and the aetiology of this disease is still unknown. In addition, no pathogens have been recovered to date from affected trees which could be firmly implicated as causal factors other than a few foliar and stem fungi, notably Colletotrichum gleosporioides. These are believed to be secondary factors (Dianese et al 1984, 1985).

Certain provenances of E. saligna, E. pellita, E. camaldulensis, E. resinifera, E. punctata, a clone of E. grandis and a provenance of E. saligna appear to be resistant to this condition in the field. E. torelliana appears to be highly resistant to *Mal do Rio Doce*. Utilization of resistant species or varieties appears to be an effective means of managing this disease even though the aetiology remains elusive (Dianese et al 1984).

8.3.2. COLOMBIA - Eucalyptus globulus is one of the principle species used for reforestation in Colombia. This tree has been widely planted in the Departments of Cundinamarca, Boyaca, Tolima and Nariño because it is well adapted to cool climates and provides an important source of fuel wood, posts, structural lumber and other wood products.

In the Department of Nariño, this tree has suffered from a progressive dieback (*secamiento ascendente*) which has affected an estimated 60% of the plantations. The condition is initially characterized by a reddening of the foliage, followed by foliage and branch necrosis and tree mortality.

Investigations into the cause of the dieback, including analysis of soils and foliage, indicate that affected plantations are growing on soils deficient in potassium and, to a lesser degree, phosphorus and boron. Fungi recovered from symptomatic trees include Pestalotia sp., which was recovered from necrotic foliage and branches, and Botrydiplodia, from necrotic root tissue. These fungi were regarded as secondary factors affecting trees stressed by the nutrient deficient soils.

Applications of a 10-20-10 fertilizer with borax (10.5%) resulted in some recovery of the trees. The investigators recommend application to plantations less than three years of age with less than 50% of the trees affected by dieback. Fertilizer applications should be made at the beginning of the winter rainy season (Orozco Jaramillo and Copete Perdomo, no date)

8.3.3. PERU - Eucalyptus globulus has been widely planted in portions of the Andean highlands of Peru for many years. Some 59,000 ha of plantations have been established. These are subject to periodic episodes of foliage yellowing and withering (*La marchitez del eucalypto*).

Toward the end of 1983, some 6,000 ha of eucalypt plantings in the southeastern highlands of Peru were affected by this condition. Initially infection of root systems by Phytophthora or a soil boron deficiency was suspected as a causal factor. However field studies failed to confirm the involvement of either of these factors.

An analysis of the geographic distribution of the condition showed that it was concentrated in the *Valle Sagrado de los Incas*, an area which had suffered from a severe drought during 1983 (18% of normal precipitation). Within the area affected by the drought, plantations which were established on steep slopes with shallow, rocky soils were most severely damaged.

Guidelines for assessment of site conditions prior to planting were developed which could be used to identify sites best suited for establishment. These were presented as a risk rating system which was based on topography, soil condition and precipitation (Cannon 1984).

## 8.4. CANOPY DIEBACK OF SCALESIA PEDUNCULATA IN THE GALAPAGOS ISLANDS, ECUADOR.

A dieback of Scalesia pedunculata, one of the major canopy species of the Galapagos Islands, is described by Itow and Mueller-Dombois (1988), Lawesson (1988) and Mueller-Dombois (1988). This fast growing species, which may complete its life cycle in 20 years and grow to a height of 20 meters, apparently evolved from a forb in the family Compositeae.

Scalesia pedunculata is the dominant canopy tree of the moist forest zone, which is well represented at mid to upper elevations (500 - 700 m) on the windward side of Santa Cruz island. The existence of large, even age stands (cohorts) of this species may be the result of past disturbances including wildfires due to human activities and heavy rains associated with El Niño. This forest goes into periodic episodes of canopy dieback which is usually followed by abundant regeneration. The dieback appears to be related in part to the stand demography resulting in aging cohort stands and in part to environmental triggers, such as heavy rains associated with "El Niño" or other physiological upsets, such as drought.

Two dieback events have occurred during this century. The first occurred between 1935 and 1940 when the forest thinned down to only a few scattered remnants. During the early 1940s, heavy flowering, coincident with a dry period, provided seed to restock the areas which suffered from dieback. A more recent dieback event occurred following the 1982/83 El Niño, which brought unusually heavy rainfall to the Galapagos Islands.

Studies on the ecology of S. pendunculata forests indicate that they are characterized by:

A. A pioneer behaviour.

B. Species-poor constitution.

C. An absence of young trees.

D. The synchronous collapse of canopy tree populations.

E. A self cyclic or build-up and collapse succession.

The dieback of these forests is similar to dieback events in other Pacific Islands (e.g. Hawaii, New Zealand, Papua New Guinea) and is believed to be another example of cohort senescence.

## 8.5 FOREST DECLINE IN PARQUE ANCHORENA, URUGUAY.

A decline of both native and exotic trees has recently been detected and investigated in Parque Anchorena, a 1370 ha national park located some 208 km west of Montevideo. This park is located on a broad, level, exposed coastal plain.

The condition were first detected in December 1990 and intensified between 1991 and 1992. Symptoms include reduced growth, poor vigour, foliage which is smaller than normal and either chlorotic or with a grey cast and stems and roots with cankers and necrotic areas. Species affected include Celtis spinosa, Eucalyptus spp., Quercus spp., Scutia buxifolia, Schinus spp. and other plants.

Ramierez Grez (1992) suggests involvement of Phytophthora and Stereum but was unable to make specific identifications or determine the role of these fungi in the onset of decline. Exposure of trees to episodes of high velocity southwesterly winds, causing bark damage and creating infection courts for fungi, is a probable predisposing factor. A prolonged drought during 1988 and 1989 may have placed an added stress on the trees.

Recommended actions include salvage of dead and dying trees and improved management of the park's flora and fauna including reduction of the park's introduced deer population (Ramierez Grez 1992).

## 8.6. DECLINE AND MORTALITY OF AUSTROCEDRUS CHILENSIS IN ARGENTINA

The conifer, Austrocedrus chilensis, is indigenous to the Andean region of central and southern Argentina and Chile. In Argentina, a decline and mortality of this species (*Mal de cipres*) has been observed since 1948. The condition is restricted to Argentina where it is causing considerable damage to a tree which is important both from an ecological and economic standpoint.

Symptoms are uniform and include discolouration of foliage followed by foliage loss, resinosis and butt and root rot. Foliar symptoms are most prevalent during the summer dry seasons.

Despite a number of investigations, the causal factors have not been identified (Havrylenko et al 1989). An analysis of the spatial distribution of symptomatic trees indicates that they tend to occur in patches as in the case of many root diseases (Rosso et al 1989).

## 8.7. DIEBACK IN FUEGO-PATAGONIAN NOTHOFAGUS FORESTS

In the northern Patagonia region of Argentina, over an west-east distance of approximately 50 km, the vegetation changes from Nothofagus rainforests through woodlands of Austrocedrus chilensis to steppe dominated by bunch grass and shrubs. Pure stands of N. antarctica dominate the forest-steppe margin along the entire length of this vegetation gradient.

Dieback and mortality of N. antarctica has been noted as a characteristic of these stands. Its presence, along with other characteristics of the vegetation along this east-west gradient, has been interpreted as an indicator of regional aridification. However, more recent investigations on the vegetation dynamics of this region shows that cessation of frequent burning of the steppe, first by indigenous hunters and later by European settlers, has permitted tree invasion of areas which were previously occupied by grasses and shrubs. Exclusion of fire from stands of N. antarctica, a short lived species, rarely attaining ages over 120 years, allows them to reach a stage of senescence, setting the stage for episodes of crown dieback and tree mortality (Veblen and Lorenz 1988). N. antarctica is often replaced by N. dombeyi and Austrocedrus chilensis (Veblen and Markgraf 1988).

Rebertus et al (1993) describe several types of gap formation and dieback in Nothofagus forests of Patagonia and Tierra del Fuego in southern Argentina and Chile. These include canopy dieback and mortality in N. pumilio and N. betuloides and persistent partial crown dieback in N. pumilio and N. antarctica. Partial wave mortality is a localized expansion of gaps which superficially resemble the cyclical wave patterns in Abies in the United States and Japan (See sections 4.9. and 6.1.2). Partial crown dieback is believed to represent incomplete recovery from defoliating insects or wood borers although climatic factors and the mistletoe-like Misodendrum sp. may also be involved.

TABLE 8.1

SUMMARY OF FOREST DECLINE EVENTS
BY POSSIBLE CAUSAL FACTORS
LATIN AMERICA AND THE CARIBBEAN *

| DECLINE EVENT | FOREST SITUATION** | PREDISPOSING FACTORS | INCITING FACTORS | CONTRIBUTING FACTORS |
|---|---|---|---|---|
| Mexico City Basin (8.1.) | N | None given | Ozone | Bark beetles |
| *Quercus humboldtii*, (Colombia, 8.2.) | N | Unknown | Insect defoliation? | Fungi<br>Nematodes<br>Wood boring insects |
| Eucalypt declines (8.3.) | | | | |
| *Mal do Rio Doce* (Brazil, 8.3.1.) | PE | Soil and water chemistry? | Air pollution?<br>Acid rain? | Stem fungus *Colletotrichum gleosporiodes* |
| *Secamiento ascendente* (Colombia, 8.3.2.) | PE | Soil nutrient deficiencies | None given | Secondary fungi |
| *La marchitez del eucalypto* (Peru 8.3.3.) | PE | Steep slopes<br>Shallow, rocky soils | Drought | None given |
| *Scalesia pedunculata* (Ecuador 8.4.) | N | Cohort senescence | Heavy rains<br>Drought | None given |
| Parque Anchorena (Uruguay 8.5.) | N<br>PE | High winds | Drought | Secondary fungi |
| *Austrocedrus chilensis* (Argentina 8.6.) | N | Unknown | Unknown | Root disease? |
| *Nothofagus* spp. (Argentina 8.7.) | N | Fire exclusion<br>Senescence | Insect defoliation<br>High winds<br>Mistletoe | None given |

* Causal factors are summarized according to the predisposing, inciting and contributing factors concept of Sinclair and Manion (see section 2.3.2).

** N = natural forest, PI = plantation with indigenous species, PE = plantation with exotic species.

# CHAPTER 9

# DISCUSSION AND CONCLUSIONS

## 9.1. DECLINE AS A GLOBAL PHENOMENON.

The case histories described in the preceding sections clearly establish decline as a condition which can be found throughout the world's forests (Fig. 9.1). Decline events are reported from boreal, temperate and tropical forests. They are found from high elevation montane forests to coastal mangrove forests, in plantations and natural forests. They occur in the forests of developing countries as well as in industrialized countries. Decline has been reported from areas of heavy human influence and from areas which are still relatively untouched.

Undoubtedly decline events have occurred in addition to those described in this paper which have not been intensively studied or well documented. For example, there are reports of dieback in dipterocarp forests in the Philippines[1], dieback of several tree species in Pakistan[2] and dieback and mortality of mangrove forests in Trinidad[3]. Unfortunately the information base for these and other events was insufficient for the development of case histories. There are, no doubt, other cases which have either not been documented or which have escaped the attention of the authors. Therefore this paper cannot be considered a *complete* global record of forest decline.

There is also some evidence to suggest that additional studies could confirm that biotic agents may have a more dominant role in some declines. One example is jarrah dieback in Western Australia (7.3.1) where P. cinnamomi may be acting as the primary causal factor. Another example is the decline and mortality of Austrocedrus chilensis in Argentina (8.6)[4], the pattern of which may suggest infection by a yet undetermined root disease.

## 9.2. CAUSES OF DECLINE AND DIEBACK.

Complexes of interacting factors have been presented as the likely causes for most of the decline events described in the preceding sections. In a number of cases, the aetiology of the decline event is still not well known. For those declines which have been studied intensively the causal factors can, in many cases, be ordered according to the combined concepts of Manion and Sinclair (Manion 1991) and Mueller-Dombois (1992a) (Tables 5.1 - 8.1).

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[1] Personal communication, Emilio Rosario, Director, Ecosystems Research and Development Bureau, Department of Environment and Natural Resources, Republic of the Philippines.

[2] Personal communication, Bashir Ahmed Wani, Deputy Inspector General of Forests, Government of Pakistan.

[3] Personal communication, S. Faizool, Acting Director, Forestry Division, Ministry of Agriculture, Land and Marine Resources, Trinidad.

[4] Numbers in parentheses refer to the section in the text of this paper which describes the decline event.

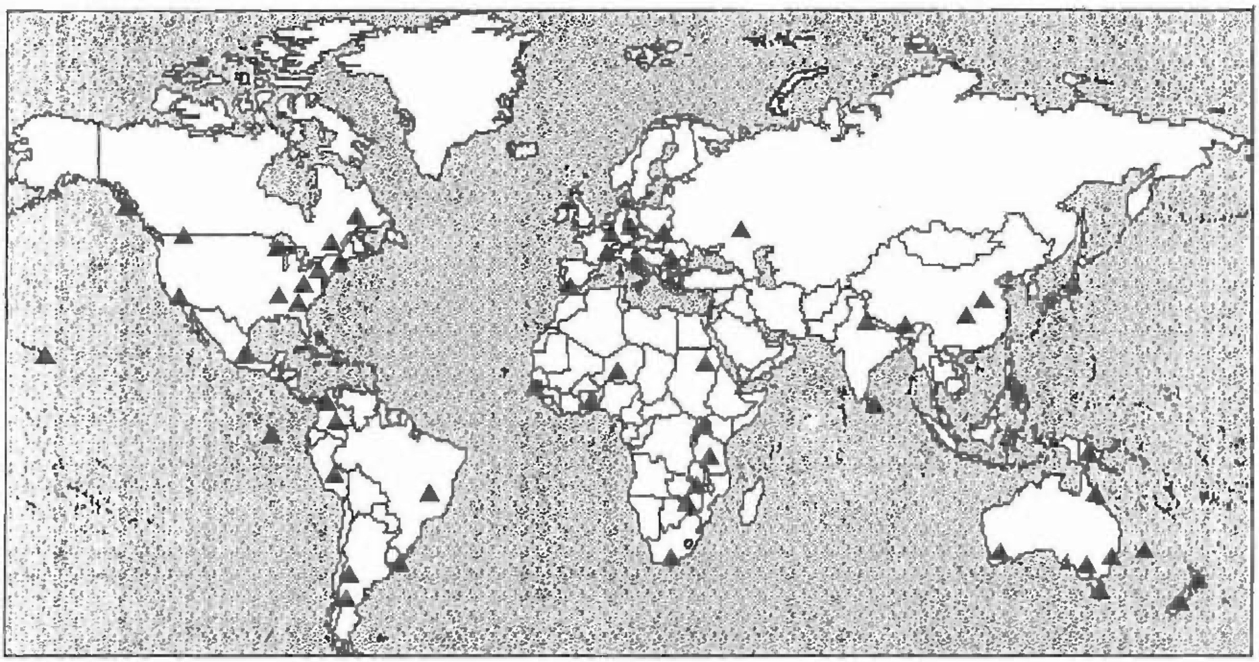

Figure 9.1 - Approximate location of decline events described in this paper.

There has been a tendency to categorize forest decline events into those which have occurred in the relative absence of human influences (non-anthropogenic) and those which can be attributed to human activities (anthropogenic), especially industrial pollution. These will be discussed in the following sections:

9.2.1. NON-ANTHROPOGENIC FACTORS - Many decline events have appeared in remote locations, far removed from sources of pollution, timber harvesting, agricultural operations or other identifiable anthropogenic influences. Despite the fact that they have occurred in areas which are widely separated geographically, they share a number of common characteristics. These include:

A. Low species diversity.

B. Formation of even age stands (cohorts) on marginal sites, usually following a catastrophic event such as a volcanic eruption, wildfire or high winds, which has destroyed the original vegetation.

C. Development of cohort senescence.

D. A perturbation or triggering mechanism such as defoliation, drought, excess rainfall or high winds.

E. Invasion of declining trees by secondary pathogens or insects.

Examples which show some, if not all, of these features include wave generated mortality of Abies spp. in the eastern United States and Japan (4.9., 6.1.2.), canopy dieback in upper montane forests of Sri Lanka (6.6.), stand level dieback of Nothofagus spp. in New Zealand, Papua New Guinea and the Fuego-Patagonia region of South America (7.4.1., 7.5, 8.7), stand level dieback of Meterosideros polymorpha in the Hawaiian Islands (7.6.), and canopy dieback of Scalesia penduculata in the Galapagos Islands (8.4). These examples fit the model of cohort senescence described by Mueller-Dombois (1992a) and can be considered as processes of ecosystem dynamics resulting in either plant succession or re-establishment of new stands of the same species which dominated the forest canopy before the decline event took place. There is evidence that the forest ecosystems affected by this sequence of events have co-evolved with and are adapted to these processes. In many cases, natural regeneration of the species affected is dependent on the periodic occurrence of stand level dieback or the recurrence of the catastrophic event which created conditions for establishment of the original cohort stands. The declines which fit this model are, therefore, natural and essential events within the forest ecosystem. Our attention is drawn to these events because of a diminishing forest area and concerns about adverse effects of human activities on forests.

A notable exception to this sequence of events is the decline of Chamaecyparis nootkatensis in southeastern Alaska, USA (4.10). Stands of this species do not appear to be even aged cohorts. This decline has been a more or less continuous event since the late 1800s and does not appear to be related to episodic inciting or triggering events.

In the case of other forest declines which appear to be primarily related to non-anthropogenic factors, the role of the decline in the dynamics of the affected forest is less clear. Examples include many of the declines which have been documented in the temperate forests of Europe and North America (eg. silver fir decline (3.1.) and oak decline (3.2.) in Europe, birch dieback (4.1.), pole blight (4.2.), ash dieback (4.3.) etc in North America). The one factor that this group of declines seems to have in common with the declines found in clearly definable cohort stands is the occurrence of a perturbation or triggering event. Various workers have related decline occurrences to outbreaks of defoliating insects, drought, excess rainfall and freezing. Auclair et al (1992) present evidence which suggests that the universal initiating mechanisms for forest declines are climatic anomalies (e.g. winter thaw/freeze events or excess rainfall followed by a prolonged period of dry weather). These cause xylem cavitation which results in moisture stress and produces decline symptoms.

Mangroves are dependent on seasonal flushes of fresh water to regulate salinity. Failure of these flushes due to prolonged drought can stress mangroves resulting in decline, dieback and mortality. Examples include decline of mangroves in Gambia (5.8), Bangladesh (6.5), Australia (7.2.) and Papua New Guinea (7.5.).

9.2.2. ANTHROPOGENIC FACTORS - Most of the world's forests have been influenced to one degree or other by human activity. These influences have had far reaching effects on ecosystem stability and dynamics and have been associated with many cases of forest decline.

Atmospheric deposition of pollutants has been widely discussed as a cause of decline. The effects of pollutants such as sulphur dioxide, hydrogen fluoride and ozone on vegetation are well known. Symptoms of exposure to these agents have been described for many types of vegetation including trees (Jacobson and Hill 1970, Malhotra and Blavel 1980). Skelly (1989) regards air pollution as potentially the most important pathogen confronting modern day and future forests. Effects have been demonstrated to include foliar injury, growth responses and tree mortality near point sources (e.g. smelters, power plants, aluminum reduction plants etc.) (Linzon 1988). In addition the detrimental effects of ozone on forest vegetation have been demonstrated on a more regional basis. Examples include the California X-disease (4.11) and the decline of Abies religiosa and Pinus patula in the Mexico City Basin (8.1).

It has been suggested that some forest decline events, including the regional decline of hardwoods and conifers in Europe (3.4), maple decline in eastern Canada (4.4) and decline of Picea rubens in the eastern United States (4.8) are at least in part due to long distance (transboundary) spread of air pollutants. While air pollution may be part of the complex of factors associated with these declines, a conclusive cause and effect relationship has not yet been established. Discussions of these declines, accompanied by photos of forest devastation, have appeared in articles in newspapers and a number of popular and semi-popular magazines. These have often attributed the damage to acid rain. While these articles have incited strong public opinion and concern, a relationship between acid rain and such forest devastation as depicted in these articles does not yet exist (Skelly 1989).

Other anthropogenic factors which have been linked to decline events include:

*Use of Forests and Woodlands for Pastoral Purposes* - Heavy grazing in Acer saccharum forests in the eastern United States is one of many factors associated with maple decline (4.4). The use of woodlands for pastoral purposes, introduction of exotic grasses and fertilization has been suggested as a key factor in the decline of eucalypts in Australia known as rural or New England Dieback (7.3.2., 7.3.3.). Severe competition from introduced grasses and shrubs, overgrazing and nutrient depletion on land originally cleared for agriculture has been implicated in the decline of Araucaria heterophylla on Norfolk Island (7.1.). Site modification associated with grazing also has been suggested as a factor in the sudden decline of Cordyline australis in New Zealand (7.4.3.).

*Harvesting of Forest Products* - Heavy tapping of Acer saccharum in the eastern United States and Canada for maple syrup production has been identified as a factor associated with maple decline (4.4.). Construction of logging roads and resultant changes in local hydrology stresses trees and creates conditions favourable for the development of the fungus Phytophthora cinnamomi which invades the weakened trees. This sequence of events has been associated with declines of Ocotea bullata in South Africa (5.5) and Eucalyptus marginatus in western Australia (7.3.1).

*Plantations* - Single species plantations, especially of exotics which may represent a narrow genetic base, are generally considered to be at high risk to damage by pests and diseases. Large areas of exotic plantings have been established throughout the world. A recent assessment of forest resources by FAO indicates that the total plantation area reported in 90 tropical countries was 43.8 million ha as of the end of 1990 (FAO 1993). In many cases, they have performed remarkably well in their new habitats with faster growth rates than in their natural ranges. The performance of Pinus radiata in the southern hemisphere and eucalypts in many regions of the world serve as good examples.

There are however, examples of plantation failure both due to aggressive insects and diseases and declines. These are often the result of failure to select tree species, varieties or provenances which are best suited to the site being planted. Examples of declines in various types of tree plantations include Azadirachta indica in the Sahel (5.1.), dieback of Terminalia ivorensis (5.3.) plantations established on nutrient poor soils in Cote d'Ivoire and Ghana, decline of Pinus patula in Tanzania (5.9.) and diebacks of eucalypts in South America (8.3.).

Because of increasing demands for forest products due to an increasing world population and concerns about global climate change, the trend toward increased area of forest plantations is expected to continue into the foreseeable future. Consequently the risk of damage due to all pests, including declines, will remain high.

*Accidental Introduction of Pest Species* - The gypsy moth, Lymantria dispar, which was introduced into North America in the latter part of the 19th century and is now a major defoliator of hardwood forests, has been implicated as an inciting factor in some episodes of oak decline (4.5). Occurrence of beech bark disease (4.6) in North America is related to the introduction of beech scale, Cryptococcus fagisuga, from Europe. Scale infestations cause a drying and cracking of the bark surface which creates conditions favourable for the invasion of fungi of the genus Nectria. Browsing by the introduced Australian possum, Tricosurus vulpecula, is a factor in stand level dieback of Metrosideros sp. and Weinmannia racemosa forests in New Zealand (7.4.2.).

Phytophthora cinnamomi, is mentioned in this section because some scientists believe that this fungus may have been introduced into Europe, Australia, New Zealand, Central and South America and portions of the United States from a location somewhere in southeast Asia. This is disputed however and other scientists argue that it is an indigenous component of the soil microflora (Newhook and Podger 1972). There is now a general consensus among Australian phytopathologists that this fungus has been introduced into Australia (Weste and Marks 1987). P. cinnamomi is associated with a number of declines worldwide including decline and mortality of Quercus ilex and Q. suber on the Iberian Peninsula (3.2.), littleleaf disease of shortleaf pine in the United States (4.7.), decline of Ocotea bullata in South Africa (5.5.), jarrah dieback in Australia (7.3.1.) canopy level dieback of Nothofagus spp. in Papua New Guinea (7.5) and stand level dieback of Metrosideros polymorpha in the Hawaiian Islands (7.6). P. cinnamomi was also reported causing a root disease of American chestnut, Castanea dentata, and several species of chinkapins over large areas of the southeastern United States in the early part of this century. This fungus caused extensive tree mortality before the chestnut blight, caused by Endothia parasitica spread into these areas (Bowen et al 1945). In addition, P. cinnamomi has been reported as a root pathogen of Abies alba in Germany (Kühne 1979) and of Castania sativa and Quercus rubra in France (Abgrall and Soutrenou 1991).

Since 1980, the number of introductions of destructive forest insects has increased. These include the European pine shoot moth, Rhyacionia buoliana, into Chile; leucaena psyllid, Heteropsylla cubana, into Asia, Australia, the Pacific Islands and Africa; cypress aphid, Cinara cupressi, into eastern and southern Africa and the Asian form of the gypsy moth, Lymantria dispar, into North America (Ciesla

1993b). While these insects have proven to be aggressive, singular causes affecting the health of trees and forests, some species such as the Asian form of the gypsy moth could be a factor in future forest decline events.

*Fire Exclusion* - The natural role of fire in the dynamics of forest ecosystems has only recently been understood. Changes in fire frequency as a result of forest fire protection or land use change can result in accumulations of vegetative biomass which is in excess of the carrying capacity of the site. This causes stress and increases susceptibility to invasion by pests and disease. The occurrence of the eucalypt decline known as "high altitude dieback" (7.3.4) is related to fire exclusion. The decline of Nothofagus antarctica in the Patagonia region of Argentina (8.7) is also believed to be the result of senescence of stands which have become established in areas which were once frequently burned; initially by indigenous hunters and later by European settlers. These lands have been abandoned and are now relatively free from fire, thus allowing trees to reach senescence.

*Altered Hydrologic Systems* - The sensitivity of mangroves to changes in water salinity has been mentioned in a preceding section (9.2.1). These changes can be the result of upstream diversion or impoundment of water for irrigation or domestic uses. Decline of Heritiera fomes in Bangladesh (6.5) has been attributed to upstream diversion of water. Jimenez et al (1985), in an analysis of 28 worldwide reports of massive mangrove mortality, attribute a number of events to siltation, impoundment and runoff diversion.

Altered drainage patterns which result in excessively wet or waterlogged soils stresses trees and creates conditions favourable for the development of Phytophthora cinnamomi. Altering of natural drainage patterns due to road construction, plantation establishment and timber harvesting has been suggested as factors in the decline of Ocotea bullata in South Africa (5.5) and in the dieback of Eucalyptus marginata in western Australia (7.3.1).

9.2.3. CLIMATE CHANGE - The earth's climate has fluctuated throughout geologic history. These changes have influenced the existence, abundance and distribution of plants and animals. Today, there is much concern that increases in the levels of carbon dioxide ($CO_2$) and other greenhouse gases in the earth's atmosphere, largely the result of human activities, may be changing global climate at an accelerated rate. Increases in atmospheric $CO_2$ and methane ($CH_4$) have been measured since about 1850. This has been accompanied by a 0.5°C rise in temperature. These increases are due to a number of natural and anthropogenic causes. The leading anthropogenic factors are burning of fossil fuels and biomass burning associated with deforestation and land use change (IPCC 1990).

There are predictions that if present trends continue, the atmospheric concentration of $CO_2$ will double from the pre-industrial revolution level of around 260 parts per million by the year 2065 (Pollard 1985). This is expected to influence global and regional climates. An increase of from 2 to 5°C is predicted. Temperature increases are expected to increase with latitude and therefore exert a major effect on northern ecosystems. Precipitation is also expected to change, generally increasing because of increased energy available for evaporation. According to several studies, increased frequency and intensity of tropical storms may be associated with trends toward a warmer, wetter climate. These changes could have significant effects on forests including shifts in the distribution of tree species and forest communities, changes in forest productivity, tree physiology and growth. Increased occurrence of wildfires, pest outbreaks and decline events have also been predicted (Andrasko 1990).

The effects of global climate change on the frequency and severity of forest decline events are presently not known. However, since climatic perturbations such as warming trends and thaw/freeze events have been implicated as causal factors in some of the events described in this paper, an interaction between the two would seem to be a reasonable assumption. Auclair et al (1992) hypothesize that episodic, region-wide forest dieback or decline may be driven by global climate change. With global warming, there is a tendency for winter and spring temperatures to increase more than summer and fall temperatures and for variability to be highest during warm, dry periods. This increases the probability of climatic conditions which cause xylem cavitation which is believed to result in moisture stress resulting in the onset of decline.

Mueller-Dombois (1992b) suggests that climate change adds a new dimension to his concept of cohort senescence because it touches on all of the events which lead up to decline. Elevated levels of atmospheric $CO_2$, may increase net primary production in trees. However many sites may be unable to support the increased rates of plant metabolism. This could shorten the overall life span of trees and hasten the advent of senescence. On edaphically poor sites, the site may be unable to support increased rates of plant metabolism which could bring about premature senescence even earlier. Climatic disturbances which trigger decline events could increase in frequency and intensity. The activity of biotic agents which function as contributing factors could also increase with the advent of warmer temperatures.

## 9.3. MANAGING FOREST DECLINE

9.3.1. DIAGNOSIS OF DECLINES AND DIEBACKS - The obvious first step in the management of a forest disease is its diagnosis and identification of causal factor(s) Diebacks and declines are the result of a complex of interacting factors, therefore it is impossible to establish pathogenicity of causal factors using the classical approach of Koch's postulates. Manion (1991) points out that diagnosis of decline is much more complex than diagnosis of other diseases. In the past, it was acceptable to describe declines based on subjective evaluation of obvious factors. This has led to disagreements and lack of progress. Declines have also been defined on the basis of a few symptoms or on selected hypothesis of poorly defined interactions among factors. This has led to misconceptions and has masked the true identity of the associated factors. It is appropriate to recognize that the causes of declines are best identified only after well executed field surveys and statistical analysis. Simple correlation or multiple regression analyses are suggested as means of identifying causal factors. In the case of a simple correlation analysis, correlation of symptoms in relation to signs, weather or site variables will often show weak relationships. A strong correlation would suggest that the problem is not a decline but the result of a single factor.

9.3.2 MONITORING AND ASSESSMENT - Many European countries, Canada and the United States have either established or are in the process of establishing systematic surveys to monitor overall forest condition. Where these already exist, they are annual surveys where permanent sample trees are rated for crown condition, foliage colour, dieback or other symptoms. They are designed to provide an overall indication of forest condition or health over time in relation to changing environmental or climatic conditions. While the need exists, there are no such surveys being conducted in developing countries. A similar monitoring program has been recommended for assessment of neem, Azadirachta indica, decline in the Sahel (Boa 1992, Ciesla 1993a). Forest health monitoring programs are also needed in developing countries where industrial development is underway and associated environmental pollution may increase (eg. China and Mexico). Surveys can provide information on trends of overall forest condition over time, provided they are carried out in the same manner during each survey cycle. They will *not* provide data on the causes of any deterioration in forest condition.

9.3.3. MANAGEMENT TACTICS - Management of a condition brought about by a complex interaction of factors presents many challenges. This is especially true in cases where declines occur in unmanaged forests and are triggered by climatic or other events which cannot be predicted with any degree of reliability. One of the few published recommendations available to address this class of decline is by Hosking (1989) who recommends care in the planning and development of recreational sites in New Zealand Nothofagus forests to minimize disturbances which could increase susceptibility of stands to high winds or other events which could trigger decline.

In cases of declines where anthropogenic factors are part of the causal complex management practices have been suggested to reduce losses to the forest resource where the specific cause(s) of decline are known. They include:

A. Avoid overgrazing and associated soil compaction in forests and woodlands which are prone to decline events.

B. When establishing plantations, select species, varieties and provenances which are adapted to the sites being planted. Identify exposed, severe sites with poor soils using risk rating criteria similar to those developed by Cannon (1984, 1985a,b). Select species which have a known tolerance to atmospheric pollution in areas known to have elevated levels of deposition of anthropogenic pollutants. Pay attention to genetic base. In cases where the genetic base of a plantation species is narrow (eg. clonal plantations), plan for conservation of a wider genetic base elsewhere as a backup.

C. Institute surveillance at ports of entry to intercept potentially damaging insects, fungi and other agents which could serve as either incitants or contributing factors in decline events. If pest species should be accidentally introduced, establish appropriate quarantine and integrated pest management tactics to limit their spread.

D. In cases of decline which may be related to fire exclusion, consider the use of prescribed fire to help keep the desired vegetation in a healthy condition (eg. High Altitude Dieback in Tasmania (7.3.4)).

E. Experiments have shown that, in some cases, a fast and sustained revitalization of declining forest ecosystems can be achieved through liming and fertilization provided that the decline is associated with a soil nutrient deficiency (e.g. acute yellowing of spruce (3.3). This has been demonstrated by chemical and histological analysis of foliage and by visible improvement in condition of trees and stands. Soil analysis have also indicated a positive change when stand and site specific fertilization has been done (Evers and Hüttl 1990). Fertilizer applications in forests is expensive however and is generally cost-effective only in fast growing, intensively managed stands.

F. Comprehensive environmental analysis prior to implementation of development projects should be conducted where changes in the pattern or volume of water flow in rivers and estuaries are anticipated. These analyses should identify potential downstream effects such as changes in the salinity of mangrove forests and identify mitigation measures to prevent undesirable effects such as occurrence of widespread dieback and mortality.

Vegetation damage attributable to a single pollution source, such as a smelter or power generating plant, can be reduced through installation of effective emission control systems. Environmental analyses can identify potential pollution hazards and strategies for their mitigation *prior* to site construction. The management of decline events believed to be at least in part the result of long distance spread of air pollutants are infinitely more complex, however, especially if the suspected pollutants are originate from multiple sources and cross international boundaries. Actions to address these events must be taken at the country or regional level and will involve establishment of national or regional policies to control emissions. These can have widespread effects on national economies and people's life styles. Therefore sound data which firmly establish a cause and effect relation between the suspected pollutant and decline is essential to support such decisions (See section 9.3.1). Because declines are complex conditions with anthropogenic factor(s) being only a part of the causal complex, if they are involved at all, these data are difficult to acquire. In addition, the issues are often clouded by emotions.

Mueller-Dombois (1992a) states: "For evaluating the impact of new anthropogenic stresses such as air pollution, climate change and biotic impoverishment on forests, it is important to understand the natural processes of forest dynamics. Only then will it be possible to untangle the real impact of human influences on forest decline and dieback". This statement points out the need for continuing research to help identify those factors responsible for individual decline events, their ecological, economic and social impacts, and their role in the dynamics of forest ecosystems. This is especially true for tropical forests and developing countries where relatively little is known about decline and may experience more decline events as they become more industrialized and as foresters and forest workers become more aware of forest health and forest decline. Knowledge obtained from these studies should be the basis for development of policy and action options. These studies should also identify those cases where management of decline events is desirable to ensure sustainable flows of goods and services from forests and those where the event is clearly a part of the dynamics and regeneration of natural forests and human intervention to prevent or manage the event may not be appropriate.

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