AN INVESTIGATION OF TREE DECLINE ON TASMANIAN FARMS

by

Stephen K. McMurray, B.Sc.

Being a thesis submitted in part fulfilment
of the requirements for the degree of
Master of Environmental Studies

Centre for Environmental Studies
University of Tasmania
Hobart

August 1983

ACKNOWLEDGEMENTS

A debt of gratitude is owed to many people who assisted me in the course of this study. I am especially grateful for the patient assistance and advice of my supervisors, Dr. Les Wood and Dr. Richard Jones, and for invaluable discussion with my external supervisor Neil Parker of the Private Forestry Division, Forestry Commission. Thanks are also due to Craig Midgely and Mike Tandy of the Department of Agriculture; to Nigel Ricketts and the staff of the Lands Department State Publication Centre; to Adrian Jessup and Bill Killalea of the Lands Department Valuation Division; to the staff of the Lands Department Cartographic Division; and to those farmers who gave freely of their time to participate in the study. Last, but not least, my thanks to Lyn Wilson for her typing of this thesis.

ABSTRACT

Little attention has been given to the death and decline of remaining native trees on Tasmanian farms. This phenomenon is prevalent in the pastoral Midland region of the state and, so far, is unstudied. The present study, as an exploratory investigation, seeks to ascertain certain characteristics of this loss of farm trees.

The rate of loss of scattered, native trees on 14 grazing properties was estimated from tree counts of aerial photographs, separated by a period of 32 years. A mean rate of 54 per cent was found for this period. This considerably exceeds estimated rates of tree decline found in similar studies in mainland states.

Factors associated with tree decline were also investigated. Photographic interpretation and landholder interviews enabled areas within properties to be classified according to pasture type and associated management practices. Tree count data from these areas showed an increasing rate of tree decline appeared to be associated with increasing intensity of land management.

Biological and physico-chemical factors potentially associated with tree decline were assessed through landholder interviews. Drought emerged as an important non-lethal incitant in farm tree decline, although other biophysical factors were not widely implicated in causal or predisposing capacities. In this respect, neither severe insect defoliation nor excessive soil salinity, important in tree decline elsewhere, is apparent in the Midlands. Tree decline in the region appears largely to be a land-use related phenomenon.

The finding that there has been a high rate of loss of remaining farm trees in the region is seen as timely. It coincides with initial efforts by government to encourage replacement of trees on farms. These efforts are in need of considerable expansion. Landholders, generally, did not recognize tree decline and efforts are also required to raise awareness to the existence of, and problems associated with, such a high rate of tree loss.

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CHAPTER 1: THE NEED FOR THE STUDY

The presence of scattered *Eucalyptus* trees in rural areas is widely regarded as the norm in terms of Australian landscape. To some, such trees are valued for their amenity but, increasingly, it has become realized that isolated trees in paddocks serve important functions both ecologically and in terms of agricultural productivity. Despite their value, recent research suggests that this considerable and diverse resource is constantly diminishing, and concern has been expressed for the survival of adequate numbers of trees on farmland in the future (Kile 1981a).

Rural tree decline refers to this continued loss of the remaining eucalypts from agricultural land. It involves both deliberate removal and clearing of trees, as well as the premature decline and death of trees from biological, physical and chemical environmental stresses. Further, it extends to other tree species and the loss of associated vegetation, and is an integral part of the disappearance of a once widespread ecosystem.

In essence, the problem can be viewed as a manifestation of the cumulative effects of land settlement and past and present land use. Trees in most parts of agricultural Australia are now part of an environment that has been changed markedly to accommodate techniques of animal and crop production, introduced with European settlement. This has included the initial clearing of forests and woodlands and, over time, an increasing and more widespread use of inorganic fertilizers, exotic pasture species and heavy machinery.

Such innovations have permitted a general increase in stock carrying capacities.

In many cases, the trees now succumbing to the effects of these changes are those that, as more mature trees, were retained during clearing for reasons of shade, shelter, aesthetics, or because they were too difficult to remove. The natural senescence expected in this population has been accelerated by numerous stresses caused through changes to the environment. A broad assessment of the situation was expressed in the final conclusions and recommendations of the conference on "Eucalypt Dieback in Forests and Woodlands" (Old *et al.* 1981), held in Canberra in 1980, where it was stated:

> *Nationally, rural areas which seem to be particularly prone to eucalypt dieback are those with an ageing tree population where pastoral management reduces or prevents the regeneration of native eucalypts and where trees are subject to periodic stresses (such as salt, drought or insect defoliation). The condition is exacerbated by widespread tree clearances and intensive pasture management.*

Despite the many factors that have been implicated in the death of trees on farmland, none has been adequately studied and there is no widely accepted explanation of the specific causes of tree decline (Day 1980). While dieback in commercial forests has a relatively small number of causes, the number of variables potentially influencing farm trees is greatly increased. Obviously, the changed environment consequent upon agricultural exploitation overlaps both natural and agricultural ecosystems.

Eucalypt dieback, a non-specific deterioration in crown health, is part of the rural decline phenomenon. Dieback occurs naturally in forests and woodlands from causes such as fire, drought, insect defoliation or disease and is usually followed by rapid recovery (Richards 1981).

Recovery may not occur, however, when stresses are imposed from an agricultural system. These may stem from clearing with subsequent isolation and exposure of trees, changes to microclimate and water balance, increased evaporation and increased susceptibility to damage by wind, frost and farm machinery. The establishment and maintenance of pasture may induce stress through mechanical disturbance, application of fertilizers and other chemicals while introduced pasture species may compete with trees for moisture and nutrients. Stresses also result from grazing of livestock via trampling and soil compaction, with associated effects on soil structure and soil-water relations, and by altering nutrient balance through excess dung and urine deposits.

In addition there are two important factors exacerbating the situation caused by stress-induced decline. Firstly, in most cases, natural regeneration is inhibited by both grazing and cultivation and, secondly, tree numbers are further reduced due to clearing for pasture and farm timber. While not an exhaustive list of the factors involved in farm tree decline, the above gives some indication of the nature and scope of the problem.

Generally, the attrition of the rural tree population has been a gradual process, except for some more dramatic cases such as on the New England Tablelands of New South Wales (Mackay 1978; Anon 1979). Only recently, with extensive areas afflicted by severe land degradation problems, has wider attention been focussed on the disappearance of trees on farms. It may be because the value of trees in providing farm, as well as community, benefits is difficult to quantify that research into rural dieback and decline has lagged behind that affecting commercial forests. In addition, the apparent ubiquity of eucalypts in the rural landscape has probably helped delay real interest in the numbers and health of farm trees. However, it has become increasingly realized that farm tree decline has significant ecological and economic implications. Ecologically, the phenomenon has been linked with increased rates of soil erosion and salinization. Such trends may well be matched by declines in land value and productivity. More directly, the economic benefits of shade and shelter on crops, pastures and animals have also been realized.

These trends have all contributed to an increased awareness of the tree decline problem but, as in most newly developing research areas, there is in Australia a serious lack of information regarding the causes of death of native trees, its occurrence and extent. The urgent need for such information can be appreciated in the light of the economic, ecological, cultural and aesthetic effects of tree decline, and is necessary also for the remedial and preventative action that must take place.

From recent papers (Old *et al.* 1981), it is apparent that all mainland states have investigated, to some extent, the state of tree decline in rural areas. Data presented then, and subsequently, related to biophysical and land management parameters associated with tree decline and, to a lesser extent, rates of tree decline (see, for example, Kile *et al.* 1980; Devonshire and Greig 1981; Sullivan and Venning 1982; Wylie and Bevege 1981; Clark *et al.* 1981; Anon 1979).

In contrast, the position outlined applying in Tasmania concentrated mainly on dieback in commercial forests. It included the following statement (Felton 1981) regarding rural tree decline, the implications of which are fundamental to the present study:

> *Neither the extent nor the causes of rural dieback (premature and relatively rapid decline and death of trees in pastoral areas) in Tasmania have been surveyed. It is known to be extensive and it appears to have increased in intensity in the last few years. The drought of 1979-80 in the southeastern parts of Tasmania has also had significant effects.*

To this writer's knowledge, no investigation of rural tree decline in Tasmania had then, or since, been undertaken. Neither was concern expressed by relevant Government authorities such as the Forestry Commission or Department of Agriculture.

There was found to be a general lack of active interest which, in some ways, is explicable. Tasmanian agricultural environments are different in many ways from those of the mainland. Mountains and wooded hills are widespread throughout Tasmania and agriculture exists within a relatively more treed environment. By comparison with the mainland, farms are typically far smaller and more diversified in their enterprise structure. Large expanses of monoculture are limited and the severe and extensive signs of land degradation, commonly associated with tree decline in other states, are not readily apparent. It may also be significant that major environmental debate has, for some time, been dominated by the two more obvious issues of hydro-electric power development and the use of Tasmania's forests for woodchip production. More insidious change is less obvious to the public.

Conversely, Tasmania differs little from other states in regard to the development and use of land management practices for pastoral activities. Clearing of trees from original forests and woodlands for increased grazing area, top dressing with fertilizers and establishment of improved pastures with constant grazing are examples of important similarities. It can be said that the same potential for a treeless pastoral landscape exists in Tasmania as it does in relatively similar grazing regions of other states. Given the hilly, broken nature of the land in Tasmania, and the utilization of this type of country, there is also the potential for accompanying forms of land degradation. The occurrence of salinization, although not widespread, is symptomatic also of possible problems in the future (Colclough 1978).

The foregoing has broadly laid out the context in which the present study will be undertaken. In the absence of previous work in this field in Tasmania, an exploratory approach will be adopted, with the basic objective of gaining a clearer picture of rural tree decline in a pastoral region of the state. This should allow further research needs to be more accurately assessed.

Two investigative approaches will be employed toward this end. Firstly, the change in tree cover on a number of individual properties will be assessed using aerial photographs separated by a known period of time. Secondly, land management practices and biophysical factors, which may be associated with a change in tree cover, will be assessed by means of personal interviews of landholders. Both these techniques comprise a number of procedures and, in the following chapter, a more detailed discussion of the methodology involved will be presented.

CHAPTER 2: METHODOLOGICAL BACKGROUND

2.1 Objectives in Data Collection: An Approach to Investigate Tree Decline

Before discussing the reason for the two-level approach used in the investigation, as indicated at the end of the previous chapter, the concept of tree decline requires some elaboration.

Rural tree decline involves a loss of trees from agricultural land and comprises three elements: loss due to rural dieback, loss due to deliberate clearing and loss due to natural senescence. Podger (1981a) states that dieback can be studied at three levels, that of the individual symptom, the affected tree, and the affected forest or stand. The concept common to all is that "diebacks are the result of protracted malfunction in vital physiological processes due to the persistant action of some damaging factor or factors".

For a dieback-affected forest the proportion of dieback-affected trees is seen as the fundamental criterion. It has been defined as "...an incidence of unhealthy, dead and dying trees ... greater than that which can be expected from normal tree growth and senescence", and involves the loss of some expected benefit (Podger 1981a). The nature of the cause however is not a determinant, as is indicated in the description of eucalypt dieback as "a general term used in Australia to refer to a whole range of diseases which produce a common, non-specific symptom of deterioration of crown health and vigour" (Duggin 1981).

For the purpose of the present study the reduction in tree number due to rural dieback will refer to those trees in an agricultural ecosystem that have succumbed to biophysical and land-use related environmental stress.

Deliberate clearing of trees covers broadscale clearing of bushland, and selective or "secondary" clearing of remnant trees to provide an increased grazing area and, in cases, timber or firewood. As this study focusses only on the remnant tree population, initial broadscale clearing is excluded from the final assessment of tree decline.

Finally, as the old age of many farm trees can be regarded as normal, death through natural senescence cannot be excluded from contributing to the overall reduction in tree numbers. The issue is somewhat complicated, however, by the reduced ability of old trees to resist stress making it difficult to distinguish between senescence and dieback.

This study, therefore, focusses on changes over time in the population of isolated trees in farmed areas. Change in tree numbers is estimated by counting individual trees on selected properties, using aerial photographs of the same area separated by the greatest available time span. Such an approach has been used elsewhere to estimate rates of tree decline in Victoria (Kile *et al.* 1980; Devonshire and Greig 1981) and more recently in South Australia (Sullivan and Venning 1982).

Tree counts of the same area at different points in time permit estimates of rates of tree loss or gain and, similarly, provide an objective data base from which to explain such changes. Causes of change in tree populations cannot be ascertained from aerial photographs, hence the second stage of the analysis involved interviews with the individuals responsible for land management in each selected area. The full scope of the interviews is discussed below but, basically, the aim was to obtain an impression of those factors which land managers associate with change in farm tree populations. Such information should aid interpretation and explanation of the data obtained from the analysis of aerial photographs.

2.2 Selection of Sample Areas

2.2.1 Choice of Study Region

Most studies of rural tree decline and, indeed, most concern for the adequacy of tree cover relate to regions where land use is dominated by pastoral activities. Certainly it is in such areas that the greatest potential for the problem exists (Boyd 1965; Mackay 1978; Anon 1979; Kile *et al*. 1980; Boardman 1981). On farmland that is regularly cultivated, isolated trees tend to provide an obvious obstacle to efficient tillage practices. In these areas, relatively complete clearance of trees tends to be the norm. But where extensive systems of arable agriculture are used in combination with the grazing of pasture or on country dominated by pastoral activities, the removal of trees may be disadvantageous to both agricultural productivity and the ecosystem. Primarily, for these reasons, the current study focusses on an area in Tasmania dominated by grazing.

Within the state, the Midlands is a long-settled belt of plains along the line of the Midland Highway between Bridgewater and Perth, bounded on the west by the Central Plateau and on the east by the Eastern Highlands (Macphail and Jackson 1978). Falling in the rain shadow of the Central Plateau, it is, by Tasmanian standards, a relatively low rainfall area with dry summers and cold winters. Types of farming involve an emphasis on sheep farming, although this is often mixed with proportionately less cattle grazing and cropping (Scott 1965).

The observant visitor, travelling through the Central Midlands from south of Oatlands to north of Campbell Town, is struck by the preponderance of scattered, ailing eucalypts. The lack of younger trees or, indeed, any sign of regeneration and the general absence of associated vegetation are similarly notable. To the east and west distant wooded hills are almost constantly in sight. In many respects the situation is representative of the rural tree decline syndrome that exists on the mainland and, as such, was felt suitable for the purposes of the present study.

A decision to focus on the Midlands was supported by discussion with extension officers of the Department of Agriculture responsible for the two regions covering the Central Midlands, and with the Project Officer for the Private Forestry Division of the Forestry Commission, all of whom indicated an awareness of a tree decline problem and all of whom suggested that investigation in the Midland region would be particularly appropriate.

2.2.2 Choice of Study Unit

After initial consideration, it was decided that properties, as land management entities, would form the basic units for analysis. One alternative of randomly selecting samples of quadrats distributed throughout the study region was rejected on several grounds. It would, for example, complicate the integration of tree counts with land management information as quadrats could overlap property boundaries. For the same reason this would present logistic difficulties by requiring a larger sample size for the questionnaire. As a corollary, each farmer would only be queried about part of his property under this approach.

It can also be argued that areas under single management represent perhaps the most meaningful units for examining questions related to tree decline. Certainly some of the suggested causes of tree decline relate strongly to land management practices and procedures.

An initial group of 23 properties was obtained by discussion with the above-mentioned agricultural extension and private forestry officers, based on their experience of properties in the region. A deliberate attempt was made to select properties on which tree decline was known to exist. In some cases these officers were personally aware of the existence of tree decline; in others, tree decline could be inferred from the enquiries made by landholders regarding assistance in tree re-establishment.

The bias inherent in this approach is readily acknowledged. It was considered suitable given the absence of any previous examination of tree decline in Tasmania. By focussing on areas in which a problem was thought to exist, the approach should enable specification of the rate of tree decline and a preliminary assessment of the factors potentially associated with it.

2.2.3 Choice of Property Sample

Selection of the final group of properties to be used in the analysis was based on the criteria of property size, length of tenure of the current landholder and his willingness to participate in the study. The cooperation of the Lands Department was sought and information regarding property size and length of tenure made available through the Valuation Division. A specific decision was made to include some large (by Tasmanian standards) properties, on the grounds that such properties would be likely to include land of different capabilities which may have been subject to different land management practices. For example, the juxtaposition of bush runs, top-dressed native pasture and more intensively managed pastures was more likely to be found on the larger properties. Similarly, inclusion of less intensively managed areas *per se* would be of value when comparing land management parameters with decline status. This approach did, in fact, prove useful.

Length of tenure was used to enable selection of properties that had been associated with the current landholder for the greatest length of time. Properties where landholders had a knowledge of changes in land uses and management techniques for a greater part of the study period were selected in preference to those of shorter tenure. The reason for such a decision is obvious, in that long-tenure landholders would probably have a greater knowledge of the sequence of management practices used on individual parts of each property.

All landholders approached were willing to participate in the study. A final sample of fourteen properties was used for analysis by tree counts of early and recent aerial photographs and for the questionnaire interview of landholders.

An indication of property locations in the region is found on Figure 2.1.

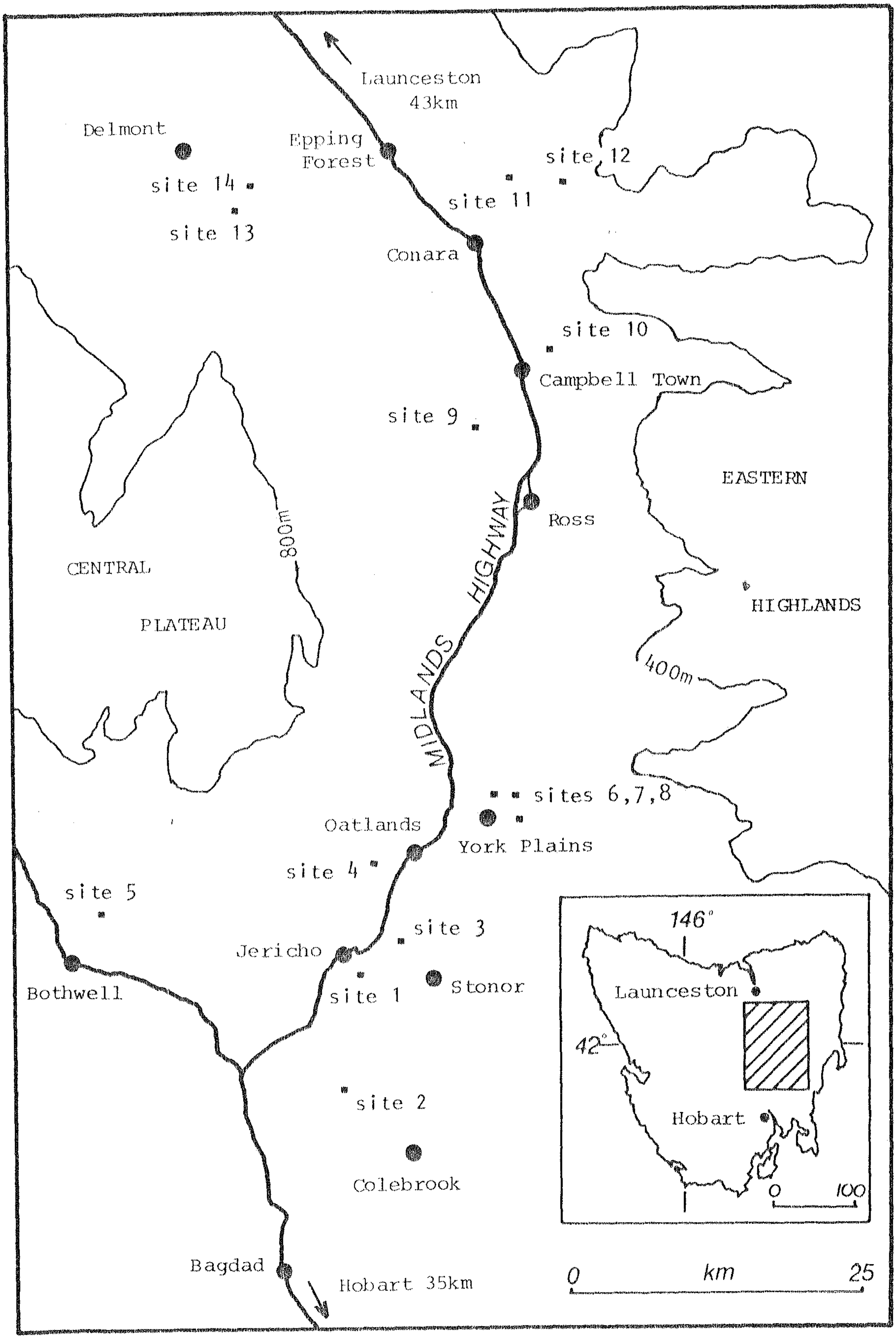
2.3 The Procedure for Data Collection

2.3.1 Analysis of Aerial Photographs

Before the following method for data collection could be considered for use, it was necessary to ascertain the accessibility of aerial photographs and the greatest period of time separation for

FIGURE 2.1

The Tasmanian Midlands Showing Survey Site Locations



each property. The Tasmanian Lands Department was approached for its cooperation, and access was granted to the collection of aerial photographs housed in the Hobart offices of the State Publication Centre. The most recent set covering the Midlands, from 1979, was made available for loan. The earliest set, from 1947, could not be borrowed but was available for use, and it was arranged that space in the Lands Department offices would be provided for this purpose.

The first stage involved marking property boundaries on the unmarked aerial photographs. For this information the Valuation Division of the Lands Department was approached and access sought to sets of aerial photograph enlargements showing property boundaries. Because the properties chosen for the survey were covered by the southern (Hobart) and northern (Launceston) regional offices of the Valuation Division, two procedures were necessary. For the southern set, photocopies of the aerial photograph enlargements were made. These were of sufficient quality to enable identification of property boundaries. The boundaries were transposed onto the library sets of aerial photographs that were to be analysed.

A rather more protracted procedure was necessary for the northern set. As aerial photograph enlargements showing property boundaries could not be removed from the Launceston office, and because the quality of photocopying in this case was insufficient to consistently distinguish property boundaries, it was necessary to use copies of land title plans. From these, it was possible to at least identify the corresponding 1979 sets of aerial photographs required, which were subsequently borrowed and transported to Launceston where property boundaries were transposed from the originals.

The further step of transferring property boundaries onto 1947 aerial photographs was relatively straightforward. In no case did the boundaries of the selected properties differ between the two dates.

The first stage of counting involved all properties using the most recent (1979) sets of aerial photographs. Stereo pairs of aerial photographs for the 14 properties were borrowed separately from the State Publications Centre of the Lands Department and property boundaries marked in wax pencil. Each property was then divided into "blocks" for simplified counting and subsequent analysis. Blocks were based on discrete paddock boundaries or groups of adjacent paddocks of the same land use as identified from the aerial photographs. To facilitate counting of tree crowns a transparent overlay marked with a faint 1 cm^2 grid was, after some discussion of the function required, manufactured by the Cartographic Division of the Lands Department. This was placed over one photo of each stereo pair to ensure counting accuracy. A WILD HEERBRUGG ST4 mirror stereoscope with 3 x magnifying lenses was used at the Centre for Environmental Studies. Aerial photographs were standard 20 cm by 20 cm size at a scale of 1:42 000.

The stereoscopic viewer enabled tree crowns to be easily identified, making the distinction between trees and understorey vegetation quite obvious. It was also possible to distinguish between healthy and deteriorating or dieback-affected crowns, both of which were counted, and dead trees which were not. An electronic counter was used, and all tree crowns that could be individually identified were counted. Where dense clumps of trees or bushland prevented this, the area was clearly identified and the corresponding area on the 1947 photograph excluded from the count.

The area of each block counted, and of dense clumps and bushland excluded from the count, was measured for all properties. This enabled the calculation of the rate of change not only by number but also by density. Measuring these areas involved tracing boundaries onto acetate sheets with a fine nylon-tipped pen, calculating this area with 1 mm^2 graph paper, and using the known scale of the aerial photographs for conversion. The use of a planimeter had been originally proposed for measuring area, but was abandoned due to inaccuracy over small areas and the relative ease of operation of the above method.

For the second stage, analysis of all 1947 aerial photographs was carried out at the State Publication Centre of the Lands Department. The procedure applying to tree counts of 1979 sets, outlined above, was used for this stage but with slight modification. Because of the larger scale of the 1947 aerial photographs (1: 15 840) the use of the same stereoscope was considered inappropriate as no lenses other than those fitted were available. It was considered that the use of a smaller stereoscope of reduced magnification would provide approximately the same resolution of tree crowns and so provide continuity in defining a "clump" of trees. Dense clumps of trees and bushland so identified were, as with the 1979 set, excluded from the 1979 count.

By pursuing the procedure of excluding clumps, a potential source of tree-loss or tree-gain is obviously being omitted from the final reckoning. This was noticed in both cases, in that clumps present in 1947 had thinned by 1979 and clumps present in 1979 had evolved from thinner stands since 1947. Ideally, full assessment of changes in farm tree populations should include consideration of trends evident in bush areas, clumps and isolated trees. However, in order to define a problem of manageable proportions and, given the technological difficulties of counting tree numbers in areas of continuous crown cover, the analysis focusses mainly on isolated trees.

During the course of the analysis, checks were made for accuracy. For tree counts, this involved comparing several counts of one property from a standard 1:42 000 aerial photograph, using the method outlined, with counts of the same property using a 3 x enlargement of the same photograph. As totals showed little difference it was assumed that error inherent in this part of the procedure would be minimal. As well, early property counts of both 1947 and 1979 aerial photographs were repeated several times, totals again showing little variation.

Error in calculating the area of counting blocks was ascertained by comparing the area of a property, as calculated by the method described, with that recorded by the Valuation Division of the Lands Department. For the set of 14 properties average error for this procedure was less than 5 per cent.

2.3.2 Questionnaire Structure and Implementation

The questionnaire, which involved personal interviews of landholders, was designed to explore the possible effect of various land-use related parameters on tree decline. Information was sought on the physical operation and attributes of each property, and on the landholder's perception of tree decline and factors associated with tree decline. In one sense, therefore, the method was used as a substitute for a ground survey in assessing the significance of bio-physical factors associated with tree decline.

Obviously, a degree of subjectivity is involved in any data collection based on interviews, particularly when the sample is small. The approach was, nevertheless, seen as worthwhile in gaining a broad picture of tree decline in the region, information that could not have been gathered otherwise within the constraints of the study. As well, depending on the outcome of the tree count analysis prior to the questionnaire investigation, the personal interview enabled some assessment of landholders' awareness of tree decline *per se* both on the property and in the region.

Investigations of tree decline on the mainland have suggested some useful lines of enquiry (Wylie and Bevege 1980). In addition, the broad literature suggests a range of factors that may be associated with tree decline (Boyd 1965; Anon 1979; Day 1980). Drawing on these leads, the questionnaire was structured to gather information on biophysical parameters such as vertebrate and invertebrate pests, drought, flooding, waterlogging and impaired drainage, fire, frost, and salinization, and on land-use related parameters including land-use type and change, pasture management techniques (clearing, cultivation, fertilizer regimes, pasture type) and tree management practices.

In its final form, the questionnaire sought information in four broad areas:

Section A: Property establishment and tenure.

Section B: Land-use type and change; pasture types; carrying capacity; fertilizer use.

Section C: Vegetation and tree species; clearing and associated tree deaths; tree husbandry.

Section D: Biophysical factors associated with tree death.

In practice, the questionnaire was used as an *aide mémoire* around which the interview was structured. A pilot version was used in interviews with 3 landholders after which, despite the adequacy of the content, some modifications regarding format and question detail were made for ease of use. The questionnaire is included in the Appendix. The approach was found to be successful in the field. It provided flexibility enabling unproductive lines of inquiry to be summarily dealt with and for deeper discussion and clarification of the more interesting and useful responses. In this regard, information was often gained relating to areas not specifically referred to in the questionnaire and, in conjunction with some closer inspections of areas of tree decline on the properties, provided a better perspective of the nature of the problem than could have been obtained with a more structured set of questions.

CHAPTER 3: QUANTITATIVE ESTIMATION OF TREE DECLINE

In this chapter information obtained from the aerial photograph analysis, and from questionnaire interviews, is used to produce a comprehensive picture of the dimensions of tree decline in the study region.

Estimating rates of tree decline proved to be a complex procedure. It was obvious that simple tree counts of whole properties would be insufficient to give an accurate indication of tree decline, as defined in Section 2.1, due to the influence of factors such as deliberate clearing and planting of trees. As mentioned earlier this was partly circumvented by excluding clumps of trees and areas of bush from the count. In addition, it was decided to exclude windbreaks, shelterbelts and other plantations, as well as trees along paddock edges.

The approach taken in estimating changes in numbers of isolated trees then involved a progressive narrowing of focus onto certain areas of a property. A filtering process of several stages was employed. Beginning with tree counts for whole properties (Table 3.1), areas treeless at the start of the study period were first eliminated from the analysis (Table 3.2), followed by areas that had undergone extensive, deliberate, broadscale clearing during this period (Table 3.3). The resultant information was then integrated with data (obtained by interview) relating to the specific land use and management histories of each area (Table 3.4). This information, it was hoped, would provide some understanding of the major factors responsible for tree decline.

Table 3.1 presents empirical data obtained from analyses of aerial photographs, indicating overall tree counts for whole properties and associated parameters of percentage change and relative densities.

TABLE 3.1

Isolated Tree Numbers and Densities on 14 Properties, 1947 and 1979.

Site	Region[1]	Area Counted[2] (hectares)	Tree Count 1947	Tree Count 1979	Change %	Density (tree·ha^{-1}) 1947	Density (tree·ha^{-1}) 1979
1	Jericho	1122	3161	1263	-60	2.8	1.1
2	Colebrook	521	1144	494	-57	2.2	0.95
3	Stonor	1327	4365	1553	-63	3.3	1.2
4	Oatlands	682	1137	247	-78	1.7	0.36
5	Bothwell	2426	2903	1360	-53	1.2	0.56
6	York Plains	436	371	163	-56	0.85	0.37
7	York Plains	267	373	268	-28	1.4	1.0
8	York Plains	425	1545	569	-63	3.6	1.3
9	Ross	1058	1492	1691	+13	1.4	1.6
10	Campbell Town	793	1186	140	-88	1.5	0.2
11	Conara	1034	1440	580	-60	1.4	0.6
12	Conara	1231	4180	1954	-53	3.4	1.6
13	Delmont	404	657	76	-88	1.6	0.2
14	Delmont	649	889	276	-69	1.4	0.4
TOTAL		12375	24843	10634	-57	2.0	0.86

1. See Figure 2.1
2. Excluding bushland and deliberate plantings. See text.

Essentially these data represent the overall change in numbers of isolated trees at the whole property level. No allowance is made for different land uses or management regimes existing within properties, or those existing between properties. As such, there is little scope for informed comparison between sites or regions. Objective comment on the data as it exists is limited to the observation that, in most cases, tree numbers have declined substantially. At this level of analysis it may be compared with rates of tree decline calculated for *Eucalyptus camaldulensis* (river red gum) grazing country in western Victoria (Kile *et al.* 1980). Here, a similar method of analysis estimated a 25 per cent loss of trees (from 1600 to 1200) over 20 years and a change in average density from 1.0 tree per hectare to 0.75 trees per hectare.

Although of little significance at this stage, total values from Table 3.1 suggest that the situation in the study region is considerably worse. This is also indicated by individual sites, with only one site (9) showing an overall gain while the loss of trees from other sites ranged from 28 to 88 per cent.

During the course of obtaining the above counts it became apparent that there were substantial areas on many properties that, in 1947, had little or no native tree cover. On these areas it was common for very small numbers of isolated trees to occur but, for the purpose of the estimation, such essentially treeless areas were excluded.

As a rough rule of thumb, it was decided to exclude blocks where tree density was below one tree per hectare. By applying this restriction, the analysis focuses on paddocks exhibiting at least moderate tree cover at the start of the period. For convenience such areas are referred to as "treed paddocks".

TABLE 3.2

Isolated Tree Numbers and Densities on all "Treed Paddocks", 1947 and 1979.

Site	Region	Area Counted (hectares)	Tree Count 1947	Tree Count 1979	Change %	Density $(tree.ha^{-1})$ 1947	Density $(tree.ha^{-1})$ 1979
1	Jericho	965	3053	1215	-60	3.2	1.3
2	Colebrook	285	1064	466	-57	3.7	1.6
3	Stonor	1327	4365	1553	-63	3.3	1.2
4	Oatlands	577	1133	247	-78	2.0	0.43
5	Bothwell	2426	2903	1360	-53	1.2	0.56
6	York Plains	305	367	163	-56	1.2	0.53
7	York Plains	117	370	265	-28	3.2	2.3
8	York Plains	366	1526	564	-63	4.2	1.5
9	Ross	523	1487	1688	+14	2.8	3.2
10	Campbell Town	567	1182	387	-67	2.1	0.7
11	Conara	746	1437	578	-60	1.9	0.8
12	Conara	886	4058	1919	-53	4.6	2.2
13	Delmont	219	657	76	-88	3.0	0.35
14	Delmont	537	835	267	-60	1.7	0.7
TOTAL		9846	24437	10748	-56	2.5	1.1

Comparison of Tables 3.1 and 3.2 shows that eliminating virtually treeless areas reduced the area counted by almost 22 per cent, while the total number of trees recorded fell by only 2.5 per cent. Eliminating treeless paddocks does, however, yield a more realistic picture of density changes of scattered trees on areas with at least one tree per hectare in 1947.

At this stage these results can be compared with estimated rates of tree decline obtained in Wannon Shire in western Victoria (Devonshire and Greig 1981). In that study, clumps of trees or forest and exotic trees were excluded from tree counts of randomly located plots in *Eucalyptus camaldulensis* savannah woodland. Over a period of 28 years, tree density declined from 1.7 trees per hectare to 1.23 trees per hectare. This estimated rate of tree loss of 1 per cent per year was similar to that, noted earlier, by Kile *et al.* (1980). In comparison, tree loss in the study region again appears considerably greater, with the average density on "treed paddocks" falling from 2.5 trees per hectare to 1.1 trees per hectare over 32 years, or an estimated rate of loss of 1.75 per cent per year.

The areas accounted for in Table 3.2 cover all parts of a property where, in 1947, isolated trees occurred at a density of 1 per hectare or greater. Within a single property such areas may have been under different land uses or management techniques, including clearing regimes. Thus it is possible that tree decline estimates indicated in Table 3.2 may have been influenced to some extent by clearing operations.

In order to focus on tree decline as earlier defined, landholders were questioned about clearing that occurred on the property between 1947 and 1979. Two basic types of clearing could be defined. *Broadscale clearing* covered extensive clearing of the greater proportion of eucalypts from virgin bushland, or from areas where bushland had been previously cleared of only understorey species and the smaller trees, such as *Acacias* or *Banksias*, associated with scrub. This category also included clearing by woodchipping contractors. *Secondary* or *selective clearing* usually involved removing a minor proportion of eucalypts for increased grazing area, occasionally for timber or firewood, as well as removing dead or ailing trees in "cleaning up" operations.

The distinction between these two types, while essentially subjective on the part of the landholder, was established during the interview. Areas where broadscale clearing had occurred on the property were relatively simple to identify with the aid of aerial photographs. In comparison, areas that had undergone secondary clearing, while not appropriate to every property, were often outlined by the landholder more generally.

Thus, by excluding areas that had been extensively cleared, tree losses emerging from this stage of the analysis encompass both deliberate loss through secondary clearing and non-deliberate loss through rural dieback and natural senescence. These estimates will be used hereafter as representative of real rates of tree decline, and are presented in Table 3.3.

A comparison of Tables 3.3 and 3.2 shows that on most properties some extensive clearing had occurred, with extents varying from approximately 10 per cent to 70 per cent of the area treed in 1947. On some sites, however, the point was emphasized by landholders that no extensive clearing had taken place, although some secondary clearing could not always be ruled out.

While areas counted in Table 3.3 do not relate to whole properties, the significance of this data lies in the essential similarity of these areas with each other. By reducing the variability between sites, direct comparisons can now be made and some validity attached to the calculated mean rate of tree decline.

What emerges from this data is that most properties have experienced a marked decline in numbers of scattered eucalypts, in many cases losing about 60 per cent of this population in the 32 year post-war period. Only one property recorded an overall increase in tree numbers, and the peculiarities of this case will be outlined

TABLE 3.3

Isolated Tree Numbers and Densities on "Treed Paddocks" Exclusive of Extensive Clearing, 1947 and 1979.

Site	Region	Area Counted (hectares)	Tree Count 1947	Tree Count 1979	Change %	Density (tree.ha^{-1}) 1947	Density (tree.ha^{-1}) 1979
1	Jericho	869	2988	1195	-60	3.4	1.4
2	Colebrook	285	1064	466	-57	3.7	1.6
3	Stonor	935	2186	609	-72	2.3	0.7
4	Oatlands	577	1133	247	-78	2.0	0.4
5	Bothwell	860	985	538	-45	1.1	0.6
6	York Plains	71	215	129	-24	3.0	1.8
7	York Plains	81	324	250	-23	4.0	3.0
8	York Plains	306	697	189	-73	2.3	0.6
9	Ross	523	1487	1688	+14	2.8	3.2
10	Campbell Town	517	1101	387	-65	2.1	0.75
11	Conara	547	1313	563	-57	2.4	1.0
12	Conara	886	4058	1919	-53	4.6	2.2
13	Delmont	138	192	39	-80	1.4	0.3
14	Delmont	361	605	242	-60	1.7	0.7
TOTAL		6956	18348	8461	-54	2.6	1.2

shortly. Other properties recorded lesser rates of decline but, by and large, no correlation is readily apparent with either property size or initial tree density. Tree density at the close of the period is, as might be expected, generally lower for sites where rates of tree decline are higher.

It should also be indicated at this stage that the overall loss, estimated at 54 per cent for the 32 year period, does not necessarily mean there was an (average) annual loss since 1947 of 1.8 per cent.

Until further information is available for changes over smaller periods of time, the data can only be interpreted in the broader context of total change over the one time period. Nevertheless, rates of loss estimated here do appear significant, not least when compared with findings interstate where concern has been expressed for the steady (though less rapid) loss of eucalypts on farmland.

So far, comparative counts from aerial photographs have been used to give a broad picture of trends in tree populations for individual properties. Obviously, however, different land uses and management regimes may well be reflected in different rates of tree decline between paddocks. Further analysis was therefore undertaken to estimate intra-site variation in tree decline as a function of land management, and to this end areas under different management within a property were identified from the most recent aerial photographs and from landholder interviews.

To establish continuity regarding these areas landholders were questioned about changes in land use and management practices over time. Generally land use had remained predominantly pastoral for all properties in the region during, and for a considerable time prior to, the period under review. On the other hand, associated management practices were seen to have gradually changed with the sowing of improved pasture species, aerial top-dressing (particularly since the early 1950s) and consequent increases in stocking rates. In this respect, the introduction of a cropping rotation into permanent pasture was the only notable change to the system of management, and has been taken into account hereafter in the analysis.

From interpretations of aerial photographs and discussions with landholders, it appeared that basic pasture types provided a good representative classification of different management regimes. In most cases individual paddocks, as counting blocks, fell into one of the following categories: bush runs; permanent pastures of native grass species; improved permanent pastures of introduced grasses and clovers; and improved pastures rotated with feed (or other) crops. Classification of paddocks on this basis enabled intra-site rates of tree decline to be associated with a particular type of management. The classification clearly reflects a progressive increase in land use.

The effect of this procedure can be illustrated by reference to site 9. Change in tree numbers on this property, excluding treeless and extensively cleared areas, shows an overall gain of 14 per cent (Table 3.3). Correlating this with the breakdown into management types indicates that this change comprised a 71 per cent decrease in tree numbers on improved pasture-rotation paddocks, and an increase of 54 per cent on a more extensive area of native pasture and contiguous bush run.

Not all properties contained extensive multiple land management systems, most of those surveyed being based solely or to a greater extent on improved pasture-cropping rotation paddocks. The range of management types applying to the sample and the estimated changes in tree number pertaining to each are described in Table 3.4. Properties exhibiting more than one pasture type are given multiple entries. As with Table 3.3, tree counts in Table 3.4 refer to "treed" areas that have not been extensively cleared since 1947, although some selective clearing may have occurred.

Casual inspection of Table 3.4 suggests some direct association between intensity of management and rate of tree decline. This becomes much more noticeable when the areas are ranked in order of ascending rate of tree loss and the corresponding pasture types are also shown (Table 3.5).

TABLE 3.4

Association of Tree Decline with Pasture Type

Site	Region	Tree Decline (%)	Pasture Type
1	Jericho	60	Improved permanent pasture
2	Colebrook	70	Native permanent pasture
		31	Improved pasture-rotation
3	Stonor	72	Improved pasture-rotation
4	Oatlands	78	Improved pasture-rotation
5	Bothwell	0	Bush run
		45	Improved permanent pasture
6	York Plains	45	Improved permanent pasture
		24	Native permanent pasture
7	York Plains	23	Native permanent pasture
8	York Plains	73	Improved pasture-rotation
9	Ross	(-) 54	Native permanent pasture
		71	Improved pasture-rotation
10	Campbell Town	65	Improved pasture-rotation
11	Conara	57	Improved pasture-rotation
12	Conara	50	Native permanent pasture
		62	Improved pasture-rotation
13	Delmont	80	Improved pasture-rotation
14	Delmont	48	Native permanent pasture
		75	Improved pasture-rotation

Clearly the classification of "pasture type" is broad, and within any one type there would be wide variations in management regimes of areas concerned. This variation involves such factors as the past sequence of usages and treatments of individual paddocks

TABLE 3.5

Ranking of Tree Decline with Pasture Type

Site	Tree Decline (%)	Pasture Type
9	(-)54	Native permanent pasture
5	0	Bush run
7	23	Native permanent pasture
6	24	Native permanent pasture
2	31	Improved pasture-rotation
6	45	Improved permanent pasture
5	45	Improved permanent pasture
14	48	Native permanent pasture
12	50	Native permanent pasture
11	57	Improved pasture-rotation
1	60	Improved permanent pasture
12	62	Improved pasture-rotation
10	65	Improved pasture-rotation
2	70	Native permanent pasture
9	71	Improved permanent pasture
3	72	Improved pasture-rotation
8	73	Improved pasture-rotation
14	75	Improved pasture-rotation
4	78	Improved pasture-rotation
13	80	Improved pasture-rotation

and the system of practices in force at the end of the period under consideration. Despite these differences, it appears from Table 3.5 that pasture type is potentially a good differentiating characteristic. As such, it is comprised of a number of accessory characteristics that co-vary with rates of tree decline including, in the present case, particular management techniques employed in animal production. A number of these techniques, such as clearing practices, cultivation, the use of fertilizers, the use of pastures of exotic grasses and clovers and higher stocking rates have been implicated in either a causal or predisposing capacity in tree decline syndromes elsewhere, and are examined in detail in Chapter 4.

In view of these implications, some description is appropriate here of systems of management practices which characterize pasture types, and trends in the application and degree of use of several such practices were obtained from the questionnaire (see Appendix). The pasture types identified fall naturally into two categories: more intensively managed areas sown with introduced grasses and clovers, and areas dominated by native grasses.

In the former category, improved permanent pastures and improved pasture-rotation paddocks are perhaps most distinguished by a past history of clearing. Many properties in the sample were established between the early and mid-1800s, and several of the smaller properties were formed by the more recent break-up of such old and extensive holdings. A long history of mainly pastoral land use has seen much of the region cleared of native vegetation, with only larger scattered trees retained. Since the 1930s, these areas were subject to more intensive management in the form of pasture improvement with exotic pasture species and, on all but three properties surveyed, the area sown to pasture varied from approximately 70 per cent to 100 per cent of the property, with most around 85 per cent.

Establishment of improved pasture on sufficiently cleared land required cultivation, but may also have needed selective clearing for use of heavy machinery or extensive clearing for new pasture. On the more intensively managed properties all relatively flat areas were cultivated, as well as some of considerable slope on ridges and hilltops. Gullies, rocky banks and excessively steep areas were generally excluded from cultivation.

Sown pasture species consisted predominantly of a mixture of perennial ryegrass and subterranean clover and, less commonly, white clover, Tasdale ryegrass and porto cocksfoot. Generally seed was sown in conjunction with aerial top-dressing of superphosphate. All sown pastures were fertilized, with this method used by most since the 1950s when rates of 120 to 240 kilograms per hectare annually were common. In recent years, fertilizer use has declined in view of its expense and reduced responses in pasture growth, with applications usually rotated on different parts of a property over a period of years. Most landholders estimated aggregate quantities of superphosphate at 3.8 to 5 tonnes per hectare.

Carrying capacity on properties surveyed ranged from 3.75 to 11.25 head per hectare, with most around 7.5 head per hectare. In many cases this had increased substantially (by 50 to 200 per cent) since the late 1940s, and was attributed to improved pasture techniques and control of the rabbit population's effect on pasture by the use of myxomatosis.

The above gives a brief outline of the type of management involved in the establishment and maintenance of improved pastures. A common adjunct was the use of certain paddocks for cropping and the periodical rotation of this with sown pasture. Hence, an area under improved pasture with a cropping rotation would, over several rotations, experience intensive management for crop and pasture establishment, maintenance, harvesting, and the grazing of stock. Stubble burning, while not widespread, was another technique used in conjunction with the cropping rotation.

Native pastures and more heavily wooded areas used as bush runs occurred to a small extent on most properties but, on the three larger properties of the survey, were the dominant pasture type. Such areas naturally experience different management to sown pasture, although some techniques are common to both. For present purposes bush runs can be considered as "unmanaged", being more densely treed woodland or dry sclerophyll forest with sparse native grasses and stocked at comparatively low rates.

While native pastures are similarly based on the use of native grasses for stock feed, they may be under some forms of management to allow higher stocking rates. In one case, native pasture had been grazed as heavily as adjoining sown pasture, but only over the past two unusually dry years. Clearing in native pastures was found to a small extent on a single property and, in general, is not the case as all forms of vegetation are made use of including feed grasses, saggs and tussock grasses for low shelter, and smaller trees of *Acacia* spp. also for shelter. On the three larger properties and several others, where this type of vegetation existed, it was commonly used for lambing.

Some areas within native pastures were cultivated, usually involving only small patches of open ground where clovers were seeded in with native grasses. Clover also volunteered from stock droppings and was encouraged by the use of phosphatic fertilizer. Top-dressing with superphosphate was used on all native pastures, although some qualification of this is needed. On the larger properties, extensive native pastures were top-dressed at the same rate as applied to smaller contiguous sown pastures and, while this rate was comparable with the rest of the sample, the period in use was relatively shorter, averaging 17 years as compared to 32 years. Conversely, on smaller properties, native pasture was top-dressed at a lower rate than that under the predominating sown pastures. The effect in both cases was that native pastures received generally less fertilizer than most sown pastures, with aggregate amounts for the former estimated at 1.9 to 2.5 tonnes per hectare.

Questionnaire responses indicated that fire as a management practice was common on native pastures. Regular "cool burning" of small patches was used to control the spread of saggs and cutter grasses, and to promote the growth of native feed grasses. With the exception of stubble burning, deliberate firing on more improved properties was found to be used only at the time of initial clearing or other small "clearing up" operations, neither affecting sown pastures.

Herbicide and pesticide use was not found to be widespread on either improved or native pastures. It was restricted to some localized applications to control gorse and, although limited to a few properties within the sample, more extensive use on improved properties for control of thistles.

The above has indicated the variability that exists between several management parameters that characterize pasture type. This variation, however, does not by itself explain the differences seen in rates of tree decline between and within sites. Many physical and biological parameters also differentiate sites, such as aspects of climate, topography, geology, soil, flora and fauna. On any one site, the environment of the isolated farm tree will be influenced by a complex interaction between all of these biophysical factors, as well as the interaction with the human factor reflected in patterns of settlement, land use and management.

Biological and physical factors have also been implicated as predisposing or causing trees to premature decline, and several were selected for investigation. These included vertebrate and invertebrate pests, prolonged excessively wet or dry periods, impaired drainage, exposure following clearing, excessive soil salinity and erosion. It was proposed to assess the significance of these factors regarding both their occurrence and association with tree decline in the study region. Given the aims and constraints of the study, this assessment would be based on landholders' perceptions as obtained through the questionnaire.

In the following chapter, survey findings regarding individual biophysical and land management parameters will be discussed in the contexts of their role in the aetiology of tree decline, and of related experience from elsewhere in Australia.

CHAPTER 4: ASSESSMENT OF ENVIRONMENTAL STRESSES IN TREE DECLINE

The previous chapter identified a number of factors that have been associated with tree decline. These were of two fundamentally different types: those of natural systems, and those of systems manipulated by man. All possess the common faculty of an environmental stress acting directly, or indirectly, to cause or predispose trees to premature decline and death.

In examining this association, the present chapter will adopt a standard format for each parameter. Information will be presented from the literature regarding the mechanisms involved which induce decline or death, and this will be complemented by examples of tree decline elsewhere in Australia appropriate to that factor. Within this context of an established body of knowledge and experience relevant findings from both the aerial photograph analyses and landholder interviews will be presented to illustrate the situation in the study region.

The system of environmental stresses affecting farm trees is a complex one and, in the concluding section of this chapter, some attempt will be made to indicate the interrelatedness that exists between many of the factors involved. Initially, however, each will be considered in terms of its action as an individual stress.

4.1 The Nature of Environmental Stress

Levitt (1972) defines a biological stress as any environmental factor capable of inducing a potentially injurious strain (irreversible or plastic strain) in living organisms. Such a stress may not, however, be directly injurious if it produces a reversible or elastic strain. Resultant injury is dependent on the phenological stage and physiological status of the tree at the time, as well as the type of stress and period of exposure, and can be induced in several ways:

(1) Rapid injury caused by brief exposure to a stress, such as sudden freezing. This is a *primary direct injury* or *direct plastic strain.*

(2) Stress producing a non-injurious elastic strain may result in an injurious plastic strain if it persists for a long enough period. Chilling stress for instance may slow a plant's chemical processes which, while not directly injurious, may cause a metabolic deficiency if it persists. This is a *primary indirect injury* or *indirect plastic strain.*

(3) A stress may cause injury not via the strain it produces but by inducing a second stress over time. For instance, high temperature may not be directly injurious but may cause injury by inducing a water deficit in the plant. This is a *secondary stress injury* and itself may act directly or indirectly (Levitt 1972; Kozlowski 1979).

Environmental stresses are of two main types: biotic and physico-chemical. Biotic stresses are those involving infection or competition with other organisms while physico-chemical stresses include those involving temperature extremes, water excesses or deficits and chemical factors such as salt, ions or biocides (Levitt 1972; Kozlowski 1979). Any organism or other agent which may cause a plant to malfunction including components of the physical environment such as climatic or soil conditions, has been termed a "physiopath" (Treshow 1970). Although this term will not be employed in the following discussion, the concept of the physiopath does indicate the scope of potential environmental stresses to which trees are subject.

4.2 Land Management Practices as Environmental Stresses

Pasture improvement refers to a number of land management practices involved in increasing pasture productivity in order to maintain higher stocking rates and thus increase animal production. It includes the killing of trees by ringbarking or felling, burning of felled timber and associated vegetation, cultivation and sowing of exotic pasture grasses and clovers, the application of chemical fertilizers and an overall increase in carrying capacity of the holding.

These techniques induce in remnant native vegetation stresses that can be classified either as biotic, such as competition with improved pasture grasses, or physico-chemical, such as those induced by clearing, cultivation, fertilizers and the effects of grazing stock. They may affect tree health directly, as with the impact of cultivation on surface roots, but more often act indirectly through secondary effects such as the altered air drainage patterns and evaporative effects of clearing, or changes to soil nutrient status by fertilizer and stock manure.

Many such effects have been proposed in the literature as adversely affecting tree health and contributing to tree decline. These statements, however, have tended towards the doctrinaire, largely ignoring the means by which land management practices impose their effects on trees. This applies also to the role of biophysical factors in tree decline (see Section 4.3) although to a lesser extent in the case of some, such as insect defoliation in the New England dieback syndrome.

In the following discussion, the land management practices identified above will be examined regarding their possible function as a stress affecting farm trees. Emphasis will be on each factor as an individual stress and, although predisposing effects will be included, a more detailed consideration of interactions with other land-use related or biophysical factors will be the subject of Section 4.4.

4.2.1 Clearing

The process of initial clearing of trees and woody shrubs for agricultural activity introduces a number of stresses affecting, both directly and indirectly, trees which are retained.

In general terms, the reduction of surrounding tree cover and consequent exposure has been seen as imposing an increasingly hostile environment on remnant vegetation via physical damage, salinity and enhanced evaporation (Neumann *et al.* 1981). Adverse responses to this new environment may, in part, be due to morphological and physiological differences between open-grown and forest-grown trees, with the crowns of trees retained after clearing unable to tolerate the new conditions (Grose 1980).

The immediate effect of opening up canopies and isolating remaining trees is to enhance the likelihood of damage by frost, wind and desiccation. The most direct stress will be of a mechanical nature and results from an increased impact of wind on branches and root systems that have been adapted to more sheltered conditions (Levitt 1972).

Wind is the most effective factor that removes the sheath of water-saturated air from around the leaf and, together with the pumping action of leaf flexing, increases water loss and transpiration. When this loss exceeds the rate at which leaf moisture is replaced, stress is induced through atmospheric drought and may result in leaf death (Peace 1962; Simpfendorfer 1978). Richards (1981) lists "change in soilwater balance" as one of the more probable means by which clearing affects tree vigour.

The exposure of trees consequent on clearing greatly enhances the incidence of frost damage due to altered cold air drainage patterns and increased heat loss through radiation (Cross 1979; Treshow 1970). Such microclimatic changes may also be partly responsible for the death of some forest trees after logging operations (Ellis 1964).

Clearing thus induces stress by various means and, if not adapted to, may predispose trees to attack by insects or infection by secondary pathogens (Wylie and Yule 1979). The light-loving behaviour of many of the eucalypt feeding insects also becomes significant in increasing the susceptibility of isolated trees to attack (Anon 1981). In this regard, an important factor associated with clearing is the accompanying loss of habitat for predators and parasites of many types of phytophagous insects. The resultant decrease in numbers of many such bird and insect species following clearing of forest and woodland has been suggested as one of the factors underlying the increasing severity of insect grazing on eucalypts, especially on the New England tablelands of New South Wales (Anon 1979; Davidson 1981; Ford 1981). Serious damage by insects here was rare in undisturbed forest and woodland, more common where trees had been thinned for grazing and most extreme where odd trees were scattered in pasture. Similarly, greater numbers of chrysomelid leaf beetles were found in former forest and woodland that had been extensively cleared than in undisturbed areas (Anon 1979). Duggin (1981) also found that the incidence of eucalypt dieback on the New England tablelands declined with increasing canopy closure.

The exposure or isolation of trees originally in a woodland formation has been implicated in the increased damage seen by arboreal mammals (in particular brush-tailed possums), foliage feeding insects and secondary leaf pathogens in Victoria (Neumann *et al.* 1981). Exposure has also been stated as the cause, either wholly or in part, of the death of trees left after clearing in the Mt. Lofty Ranges and south-eastern region of South Australia (Sullivan and Venning 1982).

An assessment of a causal link between clearing *per se* and tree decline in the study region could not readily be achieved, due mainly to the lack of control sites. On most properties, clearing had been undertaken to a greater extent in the nineteenth century or, if closer to the commencement of the study period, was in association with other developments for pasture improvement. Further, areas that had been cleared extensively and left with scattered trees were excluded from the quantitative analysis as they would not have contributed to estimating the rate of tree decline.

Although frost was mentioned by some landholders as having killed trees, no indications were available regarding proximity to clearing. Effectively all that can be said regarding the relation between clearing and tree decline in the study region is that, on those areas showing the highest rates of tree loss, namely improved pasture-rotation paddocks, most extensive clearing had occurred well before the period under review. Conversely, on native permanent pasture, where the rate of tree decline was least, little or no clearing occurred before or during this period.

4.2.2 Cultivation

Cultivation for the establishment of sown pastures or a cropping rotation induces stress in a number of ways, the most direct being physical damage to surface roots. Lateral roots of eucalypts branching from the primary root are frequently horizontal and close to the surface, and absorb both nutrients and water from the topsoil (Simpfendorfer 1978). It is in the top few inches of the soil profile that the majority of the tree's fine feeder roots are found (Day 1980; Jacobs 1955), and these may extend far beyond the crown of the tree and even past adjoining trees (Simpfendorfer 1978).

Damage to feeder roots may potentiate the effects of water stress in times of water shortage and predispose trees to infection by root rot pathogens (Anderson 1978; Wylie and Yule 1979). Impaired root function due to a range of factors has been suggested as one of the fundamental components underlying dieback of eucalypts on the New England tablelands, and would consequently be exacerbated by damage to existing feeder roots (Richards 1981).

Destruction of surface roots by cultivation allows for the establishment of crops or pasture by reducing competition from tree roots for water and nutrients (Borough 1978). In this regard, Day (1980) sees competition from established shrubs, grasses and herbs as a vital factor in a number of dieback situations. Grasses are often very much more efficient than trees in utilizing water and nutrients from the top few centimetres of soil, and management to increase grass yields may have removed the "competitive advantage" of trees on grazing land (Peace 1962; Day 1980).

Reduced productivity of pastures or crops near eucalypts has been attributed to competition for water or nutrients or both, but may also be the product of allelopathic effects (Anderson 1978; Story

1967; Van Der Sommen 1983). Similarly, allelopathic effects have been suggested as one of the more probable factors impairing tree root function (Richards 1981).

Allelopathy involves the secretion of metabolic substances from roots and aerial tissues by one population of plants that may be harmful to a competing population; strong effects are most likely to be observed in population interactions of recent origin or after sudden changes to an ecosystem, especially through the action of man. Allelopathic compounds occur widely in herbaceous and woody species and in crop and pasture residues, and are known to inhibit the establishment and growth of forest trees. Such toxicity is not only significant for its own sake but for its potential in predisposing plants to infection by root parasites (Kozlowski 1979; Odum 1971; Treshow 1970).

Carter *et al.* (1981) have suggested that allelopathic substances of exotic grasses may have contributed to some cases of eucalypt dieback in New South Wales, particularly in trees already stressed by insect attack.

In the study region, the effects of cultivation were found to be intrinsically tied to pasture establishment and, to a lesser extent, associated cropping rotations. Areas where both practices were found to have been in association for considerable time exhibited high rates of tree decline compared with those where cultivation for sown pasture was not the dominant practice.

On paddocks with rates of tree loss of - 54, 0, 23, 24, 48, 50 and 70 per cent, cultivation was minimal or absent, with pastures either wholly of native grasses or predominantly native pastures with some seeded clover. Another group was identified where pastures had been cultivated and sown with introduced species of grasses and clovers, but were not used for cropping. On these areas, tree loss estimates were 45, 45, 60, and 71 per cent. Where cultivation for pasture establishment was associated with cultivation for cropping, on a rotational basis, estimated rates of loss were seen to be greatest, showing values of 31, 57, 62, 65, 72, 73, 75, 78, and 80 per cent.

Several sites do, to some extent, possess control areas that illustrate the impact of cultivation in tree decline. On site 6, for example, superphosphate has been applied to the entire property to an aggregate amount estimated at 2.5 tonnes per hectare. This property was cleared well before 1947, with no secondary clearing during the study period and was, at an early stage in its development, mainly used for cropping. Most of the property is now improved pasture and rates of tree decline on this area indicated a loss of 45 per cent whereas, on the remaining area of uncultivated native permanent pasture, the estimated rate of loss was 24 per cent. This, however, does not represent a perfect control situation as, besides the absence of cultivation and sown pasture, native pasture would have been under a lower stocking rate.

A similar situation was found on site 9. Here, sown permanent pasture was established on an area originally used for cropping, and had been cultivated for pasture establishment since the 1930s. This area was adjacent to native permanent pasture which had been drill-seeded on the more open parts with clover, with both areas under the same fertilizer regime. The area under sown pasture had not been cleared since the mid-1800s while that under native pasture was effectively uncleared. Estimated rates of decline showed a 71 per cent loss on sown permanent pasture, and a gain of 54 per cent in tree number on native permanent pasture. Again, this difference in rate appears mostly attributable to cultivation and associated pasture establishment, although the early clearing and relatively higher stocking rates may also have contributed to the higher rate of loss on sown pasture, with the lower stocking rates on native pasture possibly allowing for increased tree numbers through natural regeneration.

With respect to this general trend between cultivation and tree decline, site 2 represents something of an anomaly. On this property, the rate of decline on native pasture was estimated at 70 per cent over the 32 year period, compared with 31 per cent for an adjacent area under an improved pasture-cropping rotation. This effect was not readily explicable from survey data. It suggests that land management practices are not by themselves wholly responsible for tree decline, but that other site factors are likely to be significant also.

Observations recounted by landholders, while anecdotal in nature, also involve cultivation in specific instances of tree decline. On one site, decline in the health of mature *Eucalyptus viminalis*, retained during clearing in 1968, was noted following subsequent cultivation for pasture establishment. Similarly, another landholder attributed the gradual deterioration of all paddock trees to cultivation as some paddocks which were cultivated but had never been cleared of standing trees displayed marked decline.

Comment from several landholders associated the loss of particular eucalypt species with cultivation. In four separate cases *E. viminalis* was described as being "shallow rooted" and very susceptible to damage by ploughing, while the associated *E. ovata*, in three of these cases, was mentioned in comparison as being unharmed by close cultivation. The observation of one landholder, that cultivation enables pasture grasses to grow up to the trunk of *E. ovata* but not in the case of *E. viminalis* or *E. pauciflora*, suggests a difference in root system characteristic that has proven significant in the response of trees to cultivation.

4.2.3 Fertilizers

The use of phosphatic fertilizer in many grazing and cropping situations has often been linked with eucalypt death and decline. The basis for this connection is the belief that the evolutionary adaptation of many eucalypts to the nutrient-poor status of most Australian soils has rendered them susceptible to damage by additional nutrients, or that the soil is now "too rich" (Anon 1979). Despite this adaptation, and their conservative use of mineral elements, native trees will respond to phosphatic and nitrogenous fertilizers in controlled amounts (Pryor 1976; Simpfendorfer 1978). However, it is known that excessive quantities of fertilizer will damage plants, more readily if it comes in contact with foliage (Peace 1962).

In adversely affecting tree growth, fertilizers may themselves act as the stress factor or they may induce secondary stresses. Mineral elements present in amounts surplus to optimum requirements (for instance, as a result of continued phosphate application) may be absorbed and accumulated to levels toxic to the plant. The tolerance exhibited to such levels will be influenced by soil factors, and on species characteristics such as nutrient requirement, inherent tolerance, the ability to absorb and accumulate different ions, as well as the relative abundance of elements in the soil. Toxicity is also affected by the relative amounts absorbed - excess phosphorus, for instance, accentuates symptoms of iron and potassium deficiencies, and excess nitrogen leads to magnesium or calcium deficiency (Treshow 1970).

In this vein, Cross (1979) has suggested that large amounts of phosphorus, nitrogen or sulphur may indirectly weaken trees by saturating available ion exchange sites on roots, thus preventing uptake of other essential elements and inducing artificial nutrient deficiencies. Such a nutrient imbalance may contribute towards impaired root function, proposed as an important factor in eucalypt dieback on the New England tablelands (Richards 1981). Accordingly, Kozlowski (1979) indicates that excesses of mineral nutrients may lower the soil water potential and decrease water absorption by osmotic effects, so injuring root cells by plasmolysis.

Superphosphate reverts in the soil to a less soluble form that is not readily leached but is retained in the surface 3 to 5 cm of the soil, where its effect on pH is toward alkalinity (Simpfendorfer 1978). Parsons and Specht (1967) have shown that high soil alkalinity will lower the solubility and availability of some trace elements and, given the large amounts of superphosphate applied to pasture (up to 5 tonnes per hectare aggregate for properties surveyed), this may provide a further route for adverse effects on tree health.

Fertilizing with superphosphate has also been implicated in tree decline by increasing the incidence of insect attack on eucalypts. This occurs through the improved nutrient status of the soil, particularly raised nitrogen levels from enhanced clover growth increasing the attraction of leaves to phytophagous insects (Anon 1979; White 1969, 1978). This action has been suggested as one of the effects of fertilizer in the New England dieback syndrome, where it is also seen as improving the topsoil as a habitat for larvae of leaf-eating beetles (Trenbath and Smith 1981). In New South Wales, "phosphatic poisoning" has been suggested as contributing to the death of eucalypts (Carter *et al.* 1981), and fertilizers were noted as having adverse effects on the health of eucalypts in some instances in Victoria (Neumann *et al.* 1981).

Several situations were found in the survey which, despite their circumstantial nature, highlight the effect of fertilizers in tree decline. On site 12, the equivalent of a control was found with respect to other land management practices in an area of native pasture which had not been cleared or cultivated, but had been top-dressed by aerial application of superphosphate since 1967 to an aggregate of 1.9 tonnes per hectare. According to the landholder, tree death and decline here has only been noticeable since that time. Although the effect of deliberate clearing and cultivation can be excluded in this case, the presence of stock may have contributed to the expression of visible symptoms. Site factors such as edaphic or climatic conditions may also have been important, with the 1967 drought in particular possibly acting in concert with, or predisposing trees to, fertilizer-induced stress.

The implication of fertilizer in tree decline may be seen in another example where native pasture is found adjacent to an improved pasture-rotation paddock on site 14. In addition to other differences in management, this native pasture had not been top-dressed, whereas the rotation paddock had received superphosphate to an aggregate of over 5 tonnes per hectare. Rates of tree decline were estimated at 48 per cent and 75 per cent respectively.

The above example merely indicates that, in this case, fertilizer application should be viewed as an important inducer of stress among the many that can affect trees. Qualification of the various fertilizer regimes as they pertain to "pasture type" was included in Chapter 3.

4.2.4 Stock Effects

The aim of the management practices outlined so far is generally toward greater animal production by increasing the overall carrying capacity of the property. If this is considered with the dwindling tree population, the impact of stock on remaining trees must therefore progressively worsen.

This impact is transmitted in two ways - through dung and urine deposits affecting nutrient cycling and distribution, and through trampling leading to changes in physical properties of soil. Observations have shown that the greatest build-up of nutrients through stock manure occurs at sites where stock regularly rest or camp such as on hilltops, under trees, and near troughs and dams. Similarly, the trampling of soil and incidence of bare ground is also more pronounced on these areas (Hilder and Mottershead 1963; Arnold and Dudzinski 1978).

Tree injuries are known to have been caused by high concentrations of animal excreta, especially at camp sites which act as a sink for pasture nutrients (Boyd 1965). The reaction of trees, however, will be dependent on the presence of other stresses and on individual species' tolerance. Logan (1971) has shown that, of eight eucalypt species from southern New South Wales, six showed signs of deterioration and eventually died after 3-5 years of heavy stock manure deposits around the tree, while 2 species did not succumb and showed signs of vigorous growth. It is likely that the direct nutrient effect of manure deposits on tree health will show similarities with the action of prolonged or excessive superphosphate application, outlined in Section 4.2.3. Changes to nutrient status by grazing stock may also act indirectly by causing cumulative changes to the soil microflora and microfauna reducing soil porosity and fertility, and so affecting physical and chemical soil properties (Boyd 1965).

The impact of stock can be transmitted directly to soil physical properties by trampling and severe grazing. Trampling may result in compaction of the surface soil layer reducing penetration, permeability and storage of water (Boyd 1965). With compaction of soils there is a decrease in pore space and root penetration is more difficult.

As roots tap soil water by growing towards moister soil, this may prevent sufficient water uptake (Simpfendorfer 1978). Similarly, compaction will both inhibit ingress of oxygen and cause accumulation of carbon dioxide, leading directly to root death and so adding to the water deficit and, eventually, mimicking the branch dieback symptoms of drought (Peace 1962).

This effect of stock is aggravated at camp areas where grazing and build-up of manure remove surface vegetation, thus inhibiting water infiltration and exacerbating runoff and erosion (Boyd 1965; Stoddart *et al.* 1975; Adams 1975).

Several instances of rural dieback in Australia implicating the effects of stock have been recorded. Kile (1981a) has suggested that both nutrient redistribution and soil compaction contribute to increasing the susceptibility of eucalypts to insect attack, and Richards (1981) sees the two factors as contributing to impaired root function as one of the underlying causes of New England dieback. Soil compaction and trampling of shallow roots have been suggested as an aggravating factor in the incidence of eucalypt dieback in South Australia (Boardman 1981; Sullivan and Venning 1982) and New South Wales (Carter *et al.* 1981), while Morris (1981) states that soil aeration may affect the tolerance of eucalypts to saline soils. In Western Australia, Borough (1978) sees the poor growth of trees in grazing paddocks as probably due to the effects of large numbers of stock congregating under them for shade.

Very little emerged from the survey directly implicating the effects of stock in tree death or decline on particular properties, although it was suggested on two occasions that the build-up of manure around a decreasing number of trees had contributed to their deterioration. Interestingly, both these sites exhibited high rates of tree decline (75 and 78 per cent), with one having the highest stocking rate of all properties surveyed (up to 15 head per hectare) as well as the highest top-dressing rate.

In general, however, two observations are worthy of note. Native pastures were usually stocked at a lower rate than pastures sown with improved grasses and clovers although, in some cases, stocking rates had been higher than normal on native pastures due to the recent drought. Secondly, since the late 1940s, there has been an increase in carrying capacity on most properties ranging from 50 to 200 per cent, and attributed to pasture improvement techniques.

Both these effects, by no means restricted to sheep farming in the Midlands, together with a reduction in tree number by whatever means, can only be expected to potentiate the impact of stock on remaining trees.

4.3 Biophysical Factors as Environmental Stresses

As indicated earlier, the stresses imposed on trees in agricultural areas stem not only from land use activities but from biotic and physico-chemical environmental factors. An attempt was made in the investigation to assess the significance of several such biophysical factors in terms of their association with tree decline and covered drought, frost, flooding and waterlogging, salinity, insect pests and vertebrate pests of trees. Within the aims and constraints of the study, this was achieved through the interview questionnaire and was based on the landholder's perception of each factor as it manifested itself or affected trees on his property. These parameters had all been implicated in either a causal or predisposing capacity in rural tree decline elsewhere in Australia, some having associations with forest dieback in Tasmania.

The present discussion, as with Section 4.2, will firstly examine the principles underlying each parameter's possible role in tree decline. Within this context, examples and experience implicating particular associations will be presented, and this will be followed by discussion of relevant survey findings.

4.3.1 Drought

The concept of drought is basically associated with a relative shortage of soil moisture available for use by animal and plant communities (Gibbs and Maher 1967; Peace 1962). However, this criterion alone is insufficient in explaining drought stress in plants, which develops ultimately when the evaporative loss of water from leaves exceeds the rate of absorption by roots causing an internal water deficit. As such, it may be influenced by the action of wind affecting water loss from leaves, by soil compaction, or by competition with other vegetation affecting the availability of soil water (Whalley 1973; McCutchan 1976).

Eucalypts in general can be classified as amongst those plants able to withstand drought stress and severe wilting without sustaining permanent damage. Paradoxically, they do not economise on water use, but have wide-ranging root systems and the ability to extract water at very low soil moisture levels. Transpiration rates normally remain high, and only when water deficit is high enough to produce permanent wilting is there stomatal closure inhibiting transpiration and further water loss (Pryor 1976). While a water deficit exists stress mechanisms will be active and, if prolonged past a certain point, will produce a stress injury. Such damage may occur before symptoms of water stress are visible (Levitt 1972).

Water stress in trees adversely affects many physiological processes including water uptake, stomatal closure, transpiration, photosynthesis, respiration and enzyme activity, with the overall effect of inhibiting growth. As trees tap soil water by increasing root length towards moister soil, the inhibition of growth by severe water stress can be fatal or, at least, injurious (Whalley 1973; Kozlowski 1979; Treshow 1970).

The effects of water stress are mostly attributable to the loss of turgor in cells and are marked by a series of changes in physiological processes. An early response is a decline in the rate of cell enlargement and the subsequent inhibition of root and shoot growth. Further water deficit induces partial or complete stomatal closure, reducing gas exchange and inhibiting photosynthesis and transpiration (Rose 1976; Kozlowski 1979). The reduction in the rate of photosynthesis is greater than that of respiration and this effect, together with a fall in translocation, will result in a net depletion of carbohydrate reserves (Levitt 1972).

Continued dehydration will result in the breakdown of proteins and modification or reduction of enzyme activity in biochemical processes, and appears to further affect the efficiency of the photosynthetic system. The subsequent protein deficit and accumulation of toxic metabolites such as ammonia is known to be a source of plant injury. By this stage, respiration will have substantially decreased but, as the rate of photosynthesis will be very low or negligible, the depletion of carbohydrates will continue (Levitt 1972; Rose 1976).

These indirect metabolic effects, although not severe enough to injure by themselves, amplify the main growth inhibitory effect of dehydration injury by retarding photosynthesis and reducing carbohydrate available for root extension (Levitt 1972).

The outcome of prolonged water deficit typically is wilting of leaves with the initial loss of turgor, and progressing to withering of leaves, shoot and branch dieback and even tree death.

Repeated non-lethal drought stress greatly reduces size and density of the foliage, inhibits shoot growth and reduces diameter growth. Indirectly, drought damage is one of the commonest predisposing factors to fungal infection, it is known to predispose trees to insect attack possibly by way of the enhanced leaf nitrogen level, and stem and branch cracking allow for infestation by wood-boring insects and further infection by pathogens (Peace 1962; White 1969, 1978; Pook 1967).

Drought has been implicated in the dieback and death of eucalypts in several states of Australia both as a primary cause, and as a non-lethal incitant where death or decline results from secondary stresses (Kile 1981a). Observations of direct drought death during periods of severe water stress have been presented by Pook *et al.* (1966) and Whalley (1973). In these cases, trees most affected occurred usually on ridges, knolls, shallow stony soils and heavy clay subsoils; trees on tops of hills were more affected than those lower down as were those on northerly and westerly facing slopes. Although differences in response between species were noted within sites, generally speaking nothing is known of the relative tolerance of eucalypt species to drought (Podger 1981b).

It is more likely, however, that the indirect effects of drought have had the greater impact on tree decline. The effects and development of some diebacks may not be evident until severe drought occurs and trees, long stressed by other environmental factors, are killed (Day 1980).

In Tasmania, droughts are not as pronounced as in other parts of Australia, and are usually restricted to regions rather than being widespread (Gibbs and Maher 1967). Studies of recent eucalypt diebacks in commercial forests in eastern and southern Tasmania have suggested that drought has predisposed trees to secondary attack by insects and/or root rotting fungi (Kile 1981b; Palzer 1981; West 1979; Kile *et al.* 1981), and Felton (1981) has suggested that drought in the southeastern parts of the state has significantly affected rural dieback.

Because of their sheltered position in the rain shadow of the central highlands, the central and northern Midlands, and a small region near Jericho, are amongst the driest areas of the state. These areas, encompassing sites 1, 4, 9, 13, and 14, receive on average only about 50 centimetres of precipitation annually. In general, much of the Midlands, including the remaining sites of the study region, receive about 63 centimetres annually, with little variation in seasonal totals. Dry spells have occurred at irregular intervals, with some prolonged periods of serious rainfall deficiencies resulting in stock and crop losses (Bureau of Meteorology 1972).

Most landholders recognized the recent drought as being the driest period in the past four decades, including those experienced around 1944/5 and 1967. Despite general acknowledgement of its severity, it was not always found that this or other dry periods were considered responsible for tree deaths. In some cases, it was held that no matter how severe past droughts had been they were not associated by landholders with tree death or decline. This was, however, a minority view as most of those interviewed did see a causal relation between the two. Such a view was expressed in two ways: by general observations of an increase in the number of dead or deteriorating trees at times of extreme soil dryness and by an association of specific instances of tree death with moisture shortage.

Particular examples concerned trees dying on rocky banks and hillsides of shallow skeletal soil on site 9 and site 12, and on areas of deep sandy soils on site 14. Drought was implicated again on site 14 where most observed tree decline had increased everywhere in the past few exceptionally dry years except in "wetter gullies". It was more common to find trees retained on these marginal sites of skeletal soils, compared with the higher incidence of clearing on lower slopes and flats.

The several references to *Eucalyptus viminalis* as being shallow-rooted may also be significant regarding the effects of drought, as on several sites (5, 8, 9, 13) this species was mentioned as that most affected by the decline syndrome.

In contrast to observations by Pook *et al.* (1966) and Whalley (1973), who directly attributed tree death and decline to acute severe water shortage, these observations are more suggestive of drought acting as a subsidiary or predisposing factor and amplifying visible signs of dieback in trees long stressed by other factors. Similar observations were made by one landholder who, while denying that drought could adversely affect trees, observed that trees which died during or after such periods were "usually the sick ones anyway".

Rust coloured streaking on trunks of *E. viminalis* on site 9 has been attributed to drought-induced gum-vein bleeding. Recent investigation of the generally poor health of trees on this site showed that dieback in the area appeared to be due mainly to the prolonged drought, with insect damage a secondary factor. In this case, trees which succumbed more readily were those on flatter areas that would enjoy favourable moisture conditions in normal years, while those on hillsides commonly subject to some degree of moisture stress seemed to cope better with severe dryness and insect attack (H. Elliott, Forestry Commission, personal communication).

4.3.2 Frost

Stress or injury may be caused by frosts inducing sub-freezing temperatures in plants, but the loss of heat by conduction or radiation may also reduce plant temperatures to below freezing (Treshow 1970). Injury is caused primarily by crystallization of extracellular water causing loss of water from the cell by osmosis and subsequent cell collapse, and may be exacerbated by damage to cell membranes by ice. This produces a water stress equivalent to drought-induced water stress, and leads to "freeze dehydration" (Levitt 1972).

The extent to which frost causes injury is partly dependent on how fast and to what level temperature drops. It will also be dependent on the sensitivity of the plant at the time, and this is influenced by factors such as physiological condition and mineral nutrition. With high nitrogen levels, for instance, there is a predominance of soft tissue and thin-walled cells increasing susceptibility to frost. Damage will also be more severe on trees in wet or waterlogged soils (Treshow 1970).

Injury is further influenced by the degree to which the tree has become "frost-hardened". This varies with the particular ecotype and with the rate at which the tree has been preconditioned to cold. A small drop in average daily temperature over a few days may produce no damage on exposure to frost, whereas trees may be killed when exposed to the same frost without adequate preconditioning (Pryor 1976; Kozlowski 1979).

Frost affects above-ground plant tissue such as leaves and stem with injury ranging from growth suppression to death, while cracking and splitting of stem and branches allows secondary fungal infection (Treshow 1970). Although not implicated on a broad basis as an important causal factor in tree decline, the exposure of trees retained after clearing operations can increase their susceptibility to frost damage. This, in turn, is likely to accelerate the rate of decline by adding to existing stresses, or to predispose trees to further stresses such as insect attack or infection by pathogens (Carne and Taylor cited in Roberts and Sawtell 1981).

In the Midlands study region frosts may occur throughout the year. During the colder months, the adjacent Central Plateau is a source of cold air which drains into the Midlands forming "cold pools". Heavy frosts, of below freezing temperatures, are more frequent from late autumn to early spring, with 10 to 16 frosts per month likely from May to August and 5 to 8 per month during April, September and October (Bureau of Meteorology 1972).

In the survey, tree death following severe frost was indicated on seven of the fourteen sites. More commonly, it was found in exposed and long-cleared areas, but had also occurred in woodland on a rocky hillside (site 9). Trees of *Acacia* spp. appeared to be the most susceptible, although some scattered *Eucalyptus ovata* and planted specimens of *E. globulus* were also affected. In general, frost appeared not to have been considered a significant factor in tree decline either alone or in association with other factors.

4.3.3 Flooding and Impaired Drainage

The impact of flooding or waterlogging on tree health is essentially a product of oxygen deficit and accumulation of carbon dioxide in the soil, and in this regard is similar to that of soil compaction (Peace 1962; Kozlowski 1979).

Anaerobic soil conditions initially inhibit root and shoot growth through adverse changes to physiological processes, in particular the inhibition of aerobic respiration and accumulation of toxic metabolites of anaerobic respiration. The resultant decrease in available energy reduces mineral uptake and, with soil conditions inhibiting the activity of organisms involved in nitrification, over-all mineral nutrition declines (Kozlowski 1979; Levitt 1972). The death of fine feeder roots due to flooding impairs water uptake, induces stomatal closure and inhibits photosynthesis. This further inhibits growth and results in a water deficit with eventual leaf loss and twig and branch dieback. Severe transient flooding may thus lead to the inability of the tree to absorb sufficient water in a following dry spell, but prolonged flooding or waterlogging will result in death (Peace 1962; Kozlowski 1979).

These effects of flooding depend on the time span involved and on the sensitivity and tolerance of tree species, with adult and vigorous growing trees less sensitive than seedlings or overmature trees (Kozlowski 1979). There is a wide variation in the ability of trees to survive periods of anaerobic soil conditions, though no species of eucalypt can grow on permanently waterlogged sites and few on occasionally waterlogged sites. Ladiges and Kelso (1977) have shown that both interspecific differences within sites and intraspecific differences between sites exist with regard to the relative tolerance of *Eucalyptus ovata* and *E. viminalis* to saturated soil conditions. In this case, *E. viminalis* was excluded from waterlogged areas, and it is interesting to note that waterlogging has also been implicated in the decline of *E. nova-anglica* in New England, a eucalypt of the same subgenus (Symphyomyrtus) and series (Viminales) as *E. viminalis*. *E. nova-anglica* is the tree most severely afflicted by the New England dieback syndrome, showing poor condition on valley floors and often better condition on slopes (Williams and Nadolny 1981). In general, dieback here is worse on flat, poorly drained sites than on ridges or well-drained slopes. Although this may be due either to site characteristics or to the distribution of species on particular sites, it is notable that *E. ovata*, which exhibits relative tolerance to waterlogged sites, also performed well when tested in New England (Anon 1979; Ladiges and Kelso 1977). Similarly, Clark *et al.* (1981), in assessing the significance of some land-use and site factors in New England dieback, indicated that a trend was evident between drainage and defoliation in survey plots.

The above suggests that, if not a primary factor, prolonged flooding or waterlogging may play some part in rendering trees more susceptible to decline by other means. In the study region, heavy rains in catchment areas can cause streams to rise rapidly and, due to low river banks, large areas have been subject to flooding at times (Bureau of Meteorology 1972).

Drainage for properties in the region was generally found to be unimpaired. Patches of damp ground occurred on several sites (2, 5, 7, 9) but were not associated with tree death or decline. However, on sites 10 and 14, landholders indicated that localized poor drainage on low lying riverside paddocks had killed most, if not all, trees standing in 1947.

Despite such isolated instances, flooding or waterlogging does not appear to be a significant cause of tree death or decline, nor does it seem a likely predisposing or associated factor from information gathered at this stage.

4.3.4 Soil Salinity

Kozlowski (1979) has suggested that the most significant effect of salinity on tree health is in predisposing trees to other environmental stresses and plant diseases, and the following brief discussion will elucidate this.

The adverse effects of excessive quantities of soil salts are due mostly to sodium salts, especially sodium chloride. When the concentration of salt in the soil root media is greater than some value considered "normal", two types of stresses will be induced: an osmotic stress which inhibits the movement of water into root cells and exposes the plant to a water deficit, and an associated "deficiency stress" where growth may be inhibited by the resultant reduced mineral uptake (Bernstein 1975; Levitt 1972).

A toxic or specific ion effect may also be caused by the penetration and accumulation of injurious amounts of associated anions (e.g. chloride) or, indirectly, by inhibiting enzyme activity and disturbing several metabolic processes such as respiration, photosynthesis and protein synthesis. Regarding the latter, the inhibitory effect of high salt concentration on growth has been seen as a source of injury leading to reduced protein synthesis, protein breakdown and accumulation of amino acids in the leaves (Bernstein 1975; Levitt 1972). The resultant increased foliar nitrogen level has been suggested by White (1969, 1978) as enhancing the attractiveness of leaves to phytophagous insects.

The salt tolerance of eucalypts is determined by physiological characteristics and by genetic differences within a species (ecotype), with interspecific and intraspecific variation in tolerance influenced by environmental factors such as temperature, soil aeration and plant age (Blake 1981; Morris 1981).

Soil and water salinity can be a major factor in tree decline, and both dryland and irrigation salting have been suggested as a cause of tree death particularly in Victoria and Western Australia (Day 1980; Kile 1981a; Kimber 1981). Curry (1981) has also observed that soil and water salinity act as primary factors increasing the susceptibility of trees to insect attack.

Secondary salinization occurs in many areas of the state and, although not widespread at this stage, is symptomatic of possible future problems. Wet-pan salting of lower slopes and drainage lines is the most common form, and is associated with large-scale broadacre clearing on higher slopes and, where slopes level out, poor drainage on shallow soils with an impervious clay layer close to the surface (Colclough 1973, 1978).

Excessive soil salinity was indicated on five sites (7, 8, 9, 11, 14) and was generally restricted to localized damp patches in flat, low-lying areas. Only on site 14 was the area affected more extensive (60 hectares) this being in a shallow gully formation below rocky slopes with the trees present showing signs of deterioration. In no case, however, was excess soil salinity associated with any decline in the health of trees. The hilly nature of much of the surrounding country and the lack of broadscale clearing on steeper slopes to date has probably played some part in preventing the extensive, severe salinization that has occurred in other states.

Landholders also indicated that no forms of erosion either occurred extensively on their property or had resulted in serious land degradation. In general, while degradation due to salting and several forms of erosion exists in the state, severe or extensive degradation associated with tree decline is not a recognized problem.

4.3.5 Insect Pests

Even in an undisturbed habitat, eucalypts are subject to heavy grazing by insects. However, while chronic high levels of insect damage may reduce vigour, it does not usually cause mortality. Damage to foliage by insect pests or other catastrophic events such as severe drought, fire or fungal attack is normally followed by development of epicormic shoots, and damaged or partly eaten leaves fall from the tree (Jacobs 1955; Mackay 1978).

This means of crown regeneration utilizes the tree's carbohydrate reserves which, if defoliation is heavy or recurrent, eventually become exhausted. If defoliation is continuous and buds as well as shoots are removed, the tree is unable to re-establish photosynthetic tissue, severely depressing growth, and may die.

The implication of repeated insect defoliation as a causal factor in rural tree decline (notably on the New England tablelands of New South Wales) is based on the concept that the past equilibria that existed between insect populations and their habitat have been upset by the effects of settlement and agricultural activity (Mackay 1978; Richards 1981). In this respect it has been suggested that many biotic and physico-chemical environmental stresses, some induced by land management practices, act to predispose trees to insect attack and, by also depleting carbohydrate reserves, reduce their ability to withstand such attack (Curry 1981; Carne and Taylor cited in Roberts and Sawtell 1981; White 1969, 1978; Fox and Macauley cited in Cross 1979).

Another important aspect involves the fragmentation of woodland and loss of understorey species through clearing and grazing which, by removing their habitat, has reduced the abundance and diversity of birds and insects that act as predators and parasites of many leaf-feeding insects (Ford 1981; Davidson 1980, 1982).

Repeated defoliation by insects has been the single factor most implicated in rural dieback in several states (Carter *et al.* 1981; Kimber 1981; Boardman 1981; Cross 1979). It is not, however, generally regarded as a primary cause, often being linked with secondary infection by pathogens and following the predisposing effect of drought (Wylie and Yule 1979; Kile 1981b; Podger 1981b). In Tasmania, the observation of this mechanism has largely been restricted to dieback of eucalypts in commercial forests (Palzer 1981; West 1979; Kile *et al.* 1981).

Damage by leaf-grazing insects otherwise in Tasmania has only been occasionally significant. Severe defoliation by larvea of the moth *Stathmorrhopa aphotista* has been noted on one occasion close to Hobart, and larvae and adults of the leaf beetle *Chrysophtarta bimaculata* have been associated with the annual defoliation in forests of *Eucalyptus regnans* and *E. obliqua*. Larvae of the gum leaf skeletonizer moth *Uraba lugens* commonly damage but rarely kill trees, although they may be associated with crown dieback of some eastern forests (Felton 1981; Neumann and Marks 1976).

Other insects which may damage or defoliate trees include larval stages of both the eucalyptus weevil *Gonipterus scutellatus* and large green sawfly *Perga affinis insularis*, and the fireblight beetle *Pyrigoides orphana*, a serious pest of wattles. It is interesting to note that eucalypt species often the target for these insects include *E. amygdalina*, *E. viminalis* and *E. ovata*, which are common in the Midlands study region (Forestry Commission Leaflets 1976-1981; Jackson 1981).

Most landholders surveyed did not see the level of insect grazing on farm trees to be significant. Indeed, in situations where trees were visibly ailing and signs of damage by insects were evident, many farmers were unaware of this occurring.

A few isolated instances were found suggesting that, although not a serious threat to trees on a regional basis, localized insect damage probably contributed to the deterioration of trees in some areas. The most severe involved small, mixed plantations of *E. viminalis*, *E. perriniana*, *E. globulus* and *E. ovata* which were heavily grazed by larvae of *Uraba lugens* (gum leaf skeletonizer moth) and *Mnesampela privata* (autumn gum moth), with many of the former three species of eucalypts killed. Interestingly, the differential susceptibility to decline displayed here between *E. viminalis* and *E. ovata* is the same as that found in other situations.

Less severe, but more widespread, was the defoliation of *Acacia dealbata* and *A. mearnsii,* attributed to infestation by *Pyrgoides orphana* (fireblight beetle), although death resulting from this was rare.

In comparison to the dieback syndrome in New England, defoliation in the study region by scarab beetles *Anoplognathus montanus* was not widespread. Numbers on one site (9) had been observed to increase over the past six years, but heavy adult populations are uncommon. While scarab beetle larvae may be seen as a pest to pasture in New England, pasture pests in the study region posed no threat to trees on emerging as adults. The most ubiquitous of these indicated by landholders was the red-headed pasture cockchafer *Adoryphorus couloni* and, although the population of this species was seen as increasing on most properties, it is not regarded as a potential tree defoliating factor (P. McQuillan, Department of Agriculture, personal communication).

Investigation of dieback-affected trees on one property indicated that larvae of the eucalyptus weevil, *Gonipterus* sp., were mainly responsible for damage to new shoots on trees stressed by drought. Other insects causing slight damage included *Uraba lugens* (gum leaf skeletonizer), chrysomelids (leaf-eating beetles) and a variety of gall insects. However, in this particular situation, the principal factor was seen as being the lack of soil moisture (H. Elliott, Forestry Commission, personal communication).

4.3.6 Vertebrate Pests

Vertebrate pests are another factor that have been known to cause defoliation and death of eucalypts in rural areas. Neumann *et al.* (1981) suggest that the exposure of trees following clearing for agricultural purposes has increased damage by arboreal mammals, especially the brush-tailed possum, *Trichosurus vulpecula,* as well as foliage feeding insects and secondary leaf pathogens.

In parts of western Victoria, brush-tailed possums were found at a density of more than 8 per hectare on 120 hectares of remnant *E. camaldulensis* at about 4 per hectare (Kile *et al.* 1980), and in other parts were recorded at densities as high as 1000 per km^2 on farmland also with scattered *E. camaldulensis* at densities of 500 per km^2, where many of the trees have died. A few ring-tailed possums, *Pseudocheirus peregrinus*, have caused additional damage by removing young shoots from outer branches (Loyn and Middleton 1981).

Extra food available in pasture, and possibly the loss of natural predators, may have enabled numbers to continue to increase despite the depletion of eucalypt foliage due to agricultural activity, and increases in possum populations relative to tree numbers may be responsible for defoliation (Loyn and Middleton 1981; Kile *et al.* 1980).

In Tasmania, the brush-tailed possum is one of three major pests in eucalypt forests, where the main damage is defoliation of smaller plants. They may also reduce the growth and survival of many species of eucalypt seedlings (McIlroy 1978).

On several sites it was indicated that possum populations had changed over the period under review, with numbers of brush-tailed possums increasing and numbers of ring-tailed possums declining. Ring-tailed possums had been observed eating shoots regenerated after lopping operations or severe frosts, and they also caused problems by defoliating or removing the bark of small planted trees. Such effects were not seen by landholders as contributing to tree decline. However, one instance was given (site 13) of "plague proportions" of brush-tailed possums defoliating a small population of remnant *E. amygdalina*, and was directly associated by the landholder with deaths of trees over the past six years.

4.3.7 Root Rot Pathogens

Although not included in the survey, a brief account of the role of root rot fungi will be presented in view of their association both with rural tree decline in other areas of Australia, and with some cases of eucalypt dieback in commercial forests in Tasmania.

Despite the importance of soil-borne root rot pathogens of *Phytophthora* spp. in many mainland dieback situations (Heather and Griffin 1978), species of *Armillaria* appear to be more important in Tasmania. Indigenous weakly pathogenic *Armillaria* spp. are ubiquitous in many Australian temperate forests and are dependent for infection on the predisposing effects of drought, insect defoliation or other stress-inducing factors (Kile 1981b). Peace (1962) has indicated that drought damage is one of the most common factors predisposing trees to fungal attack, and that some fungi may more easily invade cells which are not fully turgid. Further observations suggest that damage to roots, stems or crowns sustained during a cultivation operation, for example, may enhance the chances of infection (Anderson 1978; Wylie and Yule 1979; Kile 1981c).

The indigenous *Armillaria* spp. is most often implicated as a secondary pathogen, usually in association with insect defoliation. However one species, *A. luteobubalina*, although of limited distribution exhibits a greater pathogenicity than the endemic species and may act in a causal capacity (Kile 1981c).

In general, infective microorganisms seem more significant in forest dieback than they do in rural tree decline, where they are rarely the cause of death or deterioration. However, the physiological weakening of trees by drought may have allowed the incidence of these effects to increase, possibly in association with the inhibited moisture uptake attributed to root rot pathogens, notably *Armillaria* (West 1979; Kile *et al.* 1981).

4.4 Interrelations Between Environmental Stresses

The previous two sections have outlined how various land management practices and biophysical factors may induce or predispose trees to injury. Such numerous and varied environmental stresses will, however, rarely act in isolation. Eucalypt dieback and decline syndromes are generally of a complex aetiology, involving the sequential or synchronous action of two or more (pathogenic) factors (Podger 1981a). In this vein, Richards (1981) has suggested that the problem with trying to identify associations between (New England) dieback, site attributes and agronomic practices is that so many of the factors are confounded. The following discussion, while not trying to identify associations that are causally active in the study region, will attempt to indicate the complexity of interrelations that can exist between biophysical and land-use related factors which characterize the tree decline system. Thus, while predisposing effects may exist, cumulative or synergistic associations may also act to enhance the impact of one factor as a potential source of injury. These effects are more likely to stem from man's activities rather than from naturally occurring factors for, whilst such relationships may occur within natural systems, the imposition of an agricultural system has not only added to, but greatly multiplied, the number of possible interactions between stresses.

Different primary stresses may produce the same kind of injury if the strain induced is caused by a common primary, secondary or tertiary injury. Such is the case, for example, with injury caused by water stress which may result from several environmental factors such as drought, frost or excess soil salinity and is influenced by a number of others (Levitt 1972).

Water deficit arises whenever water loss by evaporation exceeds uptake by root absorption and, as an essential component in many physiological processes, considerable impact may accompany the resultant water stress. The mechanism by which this deficit causes stress and injury has been outlined in Section 4.3.1.

Water stress resulting from drought may be influenced by several factors. The clearing of woodland for agronomic purposes exposes remaining trees to greater evaporative effects of wind; damage to surface feeder roots by cultivation acts to reduce absorption of soil water, and this may also result from the compaction of soil through trampling by livestock and by competition with sown pasture grasses and clovers.

Frost-induced water stress is similarly influenced by clearing activities, both by altered cold air drainage patterns and by enhanced radiation and conduction heat loss. As mentioned earlier, the susceptibility of trees to frost damage (and hence water stress) is influenced by waterlogging and by high levels of leaf nitrogen. In the former case, the effects of waterlogging may result from flooding, from impaired drainage or raised water table levels due to excessive clearing, or from similar anaerobic soil conditions due to livestock trampling. Raised leaf nitrogen levels are induced by several stresses including water stress itself, enhanced soil nutrient status through pasture improvement, and the toxic effect of high soil salt concentrations. As well, soil salinity *per se* may induce water stress by an osmotic effect impairing water uptake.

Secondary stresses of water deficit will also be influenced to some extent by the above factors, such as those predisposing trees to infection by root rot pathogens and to insect attack.

Another common stress is that of nutrient deficiency. This is associated with water stress by way of reduced uptake of minerals in solution and so may be influenced by factors affecting root absorption such as waterlogging, soil compaction, cultivation and competition with sown pasture species. Nutrient deficiency also results from the direct toxic effect of ions both by direct inhibition of ion exchange and indirectly by osmotic inhibition of water absorption. Such injurious soil ion concentrations may result from high levels of soil salts or chemical fertilizers.

All environmental stresses may produce injury by disturbing metabolic processes, usually through a complex sequence of metabolic changes rather than a single change to one process, including a series of abnormal physiological events eventually leading to growth inhibition or death. These metabolic disturbances are of two main types: deficiencies of essential metabolites such as carbohydrates or protein, and excesses of toxic metabolites resulting, for instance, from protein breakdown or anaerobic respiration (Levitt 1972; Kozlowski 1979).

Carbohydrate synthesis is inhibited by water stress and so may be influenced by those factors contributing to water deficit outlined above. The regeneration of crown foliage from epicormic shoots following defoliation by insects or other means utilizes carbohydrate reserves and, if defoliation is recurrent, can result in carbohydrate depletion. A synergistic relationship is possible between water deficit and insect defoliation in causing injury, as the inhibition of protein synthesis and induction of protein breakdown by water stress may increase the attractiveness of foliage to phytophagous insects through raised leaf nitrogen levels (White 1969, 1978; Levitt 1972; Anon 1979). A similar effect on protein metabolism will result from excess soil salinity.

Leaf-grazing by insects and, to a lesser extent, arboreal mammals may further be influenced by clearing practices which both induce stresses predisposing trees to further defoliation and remove predator habitat. Past fertilizer use may also have influenced leaf-grazing through raised soil nutrient levels and legume nitrogen making foliage more attractive to leaf-eating insects, or by the enhanced larval habitat of improved pastures providing for greater population numbers.

Although it has been possible to suggest stress interrelations that may exist, the present study is not in a position to identify specific underlying causes of tree decline active in the study region. However, some indication of causality might be inferred from studies of New England dieback which, although not directly applicable to the Midlands situation, is a system of similar components, especially those relating to land use.

Richards (1981) has suggested that the dieback syndrome, while not an unusual feature of eucalypts, will cause tree death if it persists for long enough. Death probably eventuates from a combination of water stress and nutrient deficiency due to a failure of the root system to extract sufficient water and nutrients to support biosynthesis and growth. Many interrelated factors may so affect root function and some of the "more probable" ones concerning New England dieback have been proposed by Richards, of which he says "any of (these) factors may be either the primary cause of, or a predisposing condition leading to tree decline and, ultimately, death. More probably, two or more of the factors interact to produce the symptoms we recognize as dieback". They are:

(1) nutrient imbalance caused by agronomic practices involved in pasture improvement;

(2) adverse changes in soil physical factors due to trampling by livestock;

(3) destruction of feeding roots (including mycorrhizas) by soil-borne pathogens;

(4) reduced mycorrhiza formation resulting from changed nutrient status which accompanies pasture improvement;

(5) inability to regenerate new feeding roots (including mycorrhizas) following depletion of starch reserves by repeated insect defoliation;

(6) deleterious community-site interactions including allelopathic effects of competing species;

(7) gradual debilitation of the root system as a result of cumulative environmental change leading to a general decline in tree vigour;

(8) change in water balance following clearing and pasture development.

In demonstrating the complexity of the system of stresses which characterize the environment of trees in pastoral areas, this chapter has focussed largely on the individual tree. However, other factors exist which are significant in the wider sense of the farm tree population. Stress factors, while influenced by land use practices, are also affected by components of climate, topography and geology, with the expression of decline further modified by way of relative species susceptibility, itself a complex "black box".

On a more holistic plane, temporal factors such as development and change of vegetation and the history of agricultural development have influenced the past expression of tree decline, while the diminishing farm tree population, its increasing age and the lack of regeneration will markedly affect its status in the future. In the following chapter, this wider view of tree decline will be discussed more fully with the intention of providing a temporal and spatial perspective for the present study and the loss of farm trees generally.

CHAPTER 5: TREE DECLINE IN THE TASMANIAN MIDLANDS: A PERSPECTIVE

This study has essentially focussed on the loss of trees from areas that have been subject to many complex disturbances stemming from European settlement and land-use pursuits.

Other disturbances had preceded this, however, with global climatic shift and the arrival of Aboriginal man producing major vegetational changes on a regional scale and, after adjustment, effectively bringing new ecosystems into existence. At the time of European settlement the environment of the Midlands was a product of these forces. The close of the last glacial period in Tasmania during the late Pleistocene period and subsequent change to a warmer, more humid climate in the early Holocene saw the replacement of a sparse, steppe-grassland association in the low-lying Midland graben by a mosaic of *Eucalyptus* dry sclerophyll forest, *Eucalyptus* savannah woodland and *Poa* grassland (Colhoun 1978; Macphail and Jackson 1978).

Few Midland vegetation communities escaped the firing associated with Aboriginal occupation of the region, which may extend back some 18 000 years. Repeated firing favoured plant species for attracting game or as a food source directly, and increased the mosaic pattern of open forest and grassland (Jones 1969). Slopes now support open forest, low open forest and woodland of *Eucalyptus ovata* - *E. pauciflora*, *E. viminalis* - *E. amygdalina* and *E. pauciflora* - *E. rubida* intermixed with small trees of *Acacia dealbata*, *Banksia marginata*, *Exocarpus cupressiformis*, *Dodonea viscosa*, *Bursaria spinosa* and, on drier sites, *Casuarina stricta*. Grasses are common as ground cover. Isolated trees extend into valley grasslands, usually on colder sites and, where unimproved, dominated by *Poa poiformis*. *Themeda australis* and *Lomandra longifolia* may be dominant on clayey soil (Macphail and Jackson 1978).

At the time of European settlement these vegetation associations had been influenced by Aboriginal man for thousands of years, and can be regarded as ecologically adjusted to the present numerous winter frosts and summer drought of the region (Jones 1969). The discovery of the Midland corridor, in 1807, between the two settlements of Hobart and Launceston and the relative ease with which the woodlands could be settled and utilized for grazing, saw the establishment of a pastoral industry. An expanding British wool market after 1820 resulted in much of the Midlands being dedicated to this end by the early 1830s, followed by clearing of woodland and open forest for expansion in the 1840s (Scott 1965; Winter and Harris 1969).

Sheep numbers rose dramatically until 1860 when stocking rates came into equilibrium with the carrying capacity of the natural grazing lands. This state was maintained until the mid-1920s, when an upward trend in the sheep population can be associated with improvement in pastures (Davidson 1938).

The 1930s were marked by the growth of mechanization, greater use of cultivation for sowing of improved seed, increasing application of artificial fertilizers and the discovery and rectification of trace element deficiencies. By the 1940s the trend to increased pasture production had gradually restored fertility to previously cropped-out lands, but during the war emphasis again reverted to cash cropping. Together with a shortage of both machinery and phosphatic fertilizer, stock numbers fell concomitantly with the area under pasture (Bevin

1930; Scott 1965; Anon 1944).

Immediately after the war agricultural recovery was slow, but the wool boom of the 1950s provided the means for much needed farm investment. On a national level there was marked expansion of the sheep population due to more specialized livestock farming, a rapid increase in the improvement of pastures associated with aerial topdressing, and curtailment of the depressing influence of rabbits on pasture carrying capacity with myxomatosis (Scott 1965; Leeper 1970). The impact in Tasmania largely reflects that felt in the Midlands, with the twelve years from 1947 seeing the area under improved pasture increase by 110 per cent and the proportion fertilized increasing from 46 to 80 per cent. Subsequently, wool production in the decade from 1950 rose by 90 per cent (Anon 1959; McRae 1961).

The settlement and introduction of sheep to the Midlands induced a series of changes typical of many savannah woodlands of temperate south-east Australia. Originally the common herbaceous components were tall warm season perennial grasses of *Themeda*, *Stipa* and *Poa* spp., with true grasslands within this zone differing little in composition. The initial effect of grazing was the elimination of tall perennial species, such as *Themeda australis*, resulting in disclimax communities of shorter perennial grasses of *Danthonia* and *Stipa*. These formed relatively stable communities until the use of superphosphate became general which, in combination with heavier grazing pressures, favoured the increase of winter growing native annuals. This was followed by the rapid establishment and dominance of exotic annuals with occasional perennials, and finally the sowing of fertilized pastures of introduced clovers and grasses (Smith 1982; Moore 1962, 1970).

This sequence was accompanied by a marked alteration to the fire regime. It is difficult to generalize about the incidence of fire before and after European settlement, but it probably involved changes to frequency, severity and season of burning. Similarly, it is equally hard to say what impact such a change might have had on the woodlands, as its effect would vary according to the new regime and properties of the ecosystem. Suffice to say, this environmental variable would now be at a considerably different state to that existing prior to white settlement (Smith 1982).

In addition to the above changes, the region has also experienced considerable modification through clearing. The area totally or partially cleared in Tasmania has been estimated to be at least 37 per cent, with the Midland region exhibiting a change of between 70 and 100 per cent. This compares with estimates for other states of 32 per cent (Western Australia), 35 per cent (Queensland) and 41 per cent (South Australia), and with a national total of 36 per cent (Wells *et al.* 1983).

The main point of the above discussion is that the cumulative effect of many changes to such pastoral woodland regions as the Midlands has produced new environments. The significance of this to the present study is, as stated by Duggin (1981), that "in some situations these environmental shifts have modified the system to the point where eucalypts now find it difficult to survive and regenerate, (and) this is seen by the high incidence of dieback and tree death".

It is in this context that findings of the present study should be seen. Given the originality of this type of investigation in Tasmania and the exploratory approach employed, the nature of these findings is essentially empiric and descriptive. Information of basically two types emerged enabling an initial characterization of tree decline in a pastoral region.

Results of the air photo analysis showed the method devised to investigate tree loss quantitatively proved workable, and suggested that there has been a considerable loss of scattered, mature eucalypts on grazing land throughout the Midlands. While this procedure yielded a range of rates of loss, the general indication was that a loss of the order of 55 per cent had occurred over the post-war period 1947 to 1979. Although not statistically derived, this figure does seem significant when compared to similar studies in other states. The implications of this trend also merit attention. Whether this loss has occurred constantly over the period or is that relevant to the beginning or end of a period of marked decline, the scenario for the future seems likely to be a depauperate farm tree population.

The second type of data described factors associated with tree decline, and showed an association between estimated rates of loss and intensity of land use as characterized by several land management parameters. While again not statistically derived, such an indication accords both with descriptions and proposed aetiologies of tree decline elsewhere.

Conversely, biotic and physico-chemical factors investigated showed no similar association. This may, in part, reflect the method used, based as it was on information gained from landholder interviews. This approach was deemed necessary in view of both study constraints and the factors implicated in studies of tree decline elsewhere, as well as the paucity of such information available in Tasmania. A protracted procedure, and one yielding a mass of information but little factual data, the inclusion of this part of the enquiry did prove worthwhile. The finding that several biophysical factors did not appear closely associated with tree decline, albeit at a crude level of enquiry, tends to emphasize the association with land use. Compared with components of other regions experiencing similar tree loss this is one of several indications of the individuality of the Midlands decline syndrome.

The situation in the Midlands can be further characterized by reference to the structure and dynamics of the remnant farm tree population. The natural senescence of many farm trees has been defined earlier in this study as one component of tree decline, and is important not only for its own sake but also because of its complicating effect.

Excessive natural senescence is a function of a population structure drastically altered by the use of woodlands for grazing. On all properties surveyed, it was both noticeable and mentioned by landholders that most pastures were devoid of eucalypt regrowth. Exceptions were restricted to lightly stocked bush runs only. This lack of recruitment is mainly due to grazing of seedling regeneration by livestock, but, as well, to inhibitory effects of competition from grass roots, desiccation by exposure to wind and sun and the sensitivity of seedlings to artificially applied fertilizer (Jacobs 1955).

The overall effect of not replacing older trees as they die or are removed is to increase the proportion of senescent trees. With time, and due to the reduced ability of trees to resist or tolerate stress, the proportion of dead trees increases. In this regard, it was generally observed that, while very old trees commonly displayed signs of dieback, many younger trees were also visibly affected by thinning crowns and branch death. Gaps subsequently created by this enhance the deleterious effects of exposure to wind, insects and desiccation on remaining trees, further increasing the number of senescent trees and, eventually, the death rate (Boyd 1965). In this way, the lack of regeneration characteristic of most farm tree decline situations is both a symptom of land use and an additional factor promoting decline.

On a longer time scale, lack of seedling recruitment to mature, viable trees greatly diminishes the chance of evolutionary adaptation to the new environment created by land-use pursuits (Kile 1981a).

Midland tree decline can also be described with reference to the spatial attributes of some components. Individual land management practices were noted in Chapter 4 as having the potential to act as environmental stresses. Yet it was seen that, because of systems of land management which predominate in the region, rarely would these act in isolation of one another. In some instances, particular management practices have appeared directly associated with tree loss, but it is their combined cumulative effect over a long period of time that correlates with tree decline. Due to interactions possible between stress factors, the relation that emerges between land-use intensity and stresses inducing decline may be likened to an exponentially rising curve. In comparison to the ubiquitous nature of land-use related stress, however, expression of biophysical factors in tree decline appeared to be more localized.

Elsewhere, consideration of decline syndromes has classified causes as active either regionally or locally (Kile 1981a). Most concern has been focussed on regional factors such as repeated insect defoliation in the New England region of New South Wales, or tree death resulting from extensive areas of excessive soil salinity in parts of Victoria. In these accounts, land management practices, while spread over a long time, are considered as local effects. However, in view of the development and pattern of land use in the Midlands and its close association with decline, the findings of the present investigation suggest that land management practices have assumed the role of regional factors.

Given that the distribution and expression of decline will also have been influenced by site and species interactions, exploratory investigation at this time does not suggest the existence of a widespread specific factor or factors directly associated with rural dieback in Tasmania. Tree decline emerges largely as a land-use related phenomenon.

In this respect, past and present exploitation of the land for agriculture has, perhaps, rendered this example of tree decline unique. Observations of the region and survey findings suggest that a balance has been achieved between land use and attendant environmental attributes. Important amongst these is the broken, hilly nature of the surrounding country which has, so far, not been extensively cleared. Retention of relatively natural habitat adjacent to a modified, grazing region may have thus played some part in preventing biophysical factors , such as insect outbreaks or severe land degradation, from surfacing as causes of decline and explain why land use has a more conspicuous causal role.

In comparison with lesser rates of tree decline indicated in mainland studies, the situation in the Midland region of Tasmania is one of considerable magnitude and should arouse concern. The significance of such an alarming rate of tree decline, as found in the present study, lies in the loss of benefits associated with the ecological function of trees on farms. In other states, the loss of tree cover combined with land usage has induced land degradation and erosion, incurring considerable costs to both landholders and governments. Usually, however, dieback of farm trees is considered of little importance by state authorities in comparison to that in commercial forests, and too often is ignored until its impact has progressed to unmanageable proportions. In this respect, a problem is not seen to exist on individual farms if landholders do not see their productivity threatened by tree loss. Responses from the interview suggested this to be the case, with only a few farmers recognizing tree decline *per se* in the region, and none associating adverse economic effects with the loss of farm trees.

Similarly, few landholders were found to apply any husbandry to ensure the longevity or replacement of remnant trees. As indicated by Chambers (1980), no inducement for this would be needed if the economic facts regarding the role and value of trees and woodland within agricultural ecosystems were more widely realized. In this regard, there is a growing body of knowledge concerning both the benefits to agricultural economics of retaining such vegetation and the costs of allowing tree decline to continue (Bottomley and Parker 1974; Lynch and Alexander 1976, 1977; Lynch and Donnelly 1980; Lynch *et al.* 1980; Bird 1981; Davidson 1981; Dengate 1983; Breckwoldt 1983).

Arguments for and against the presence of farm trees exist but, on balance, they appear to provide diverse benefits to both landholders and the community. Adequate tree cover is important in controlling land degradation, providing wildlife habitat and stock and crop protection, production of timber, oil and honey, and has scientific, recreational and landscape values (Kile 1981a). In other states, and burgeoning now in Tasmania, awareness is expanding of the need not only to ameliorate tree decline but, more particularly, of the need to regenerate native vegetation in rural areas to satisfy farm and community needs (Davidson 1980; Borough and Cameron 1981; Venning 1983; Copley and Venning 1983). In itself, this is an issue of some complexity but, without more detailed understanding of the components and processes involved in tree decline, unknown environmental factors may nullify efforts toward planting and revegetation.

Calls have been made for many types of research, but the basic information that is required is that concerning why trees on farms are now no longer surviving and how tree cover can successfully be replaced. Concurrent with this, in an integrated programme, should be elucidation of the economics regarding agricultural productivity where trees and associated vegetation are retained, with some examination of local models where such a balance has been attained. Efforts to raise the awareness of rural land managers to the above are particularly necessary in Tasmania as some level of lobby by farmers has been, in other states, involved in instigating enquiry into the problem.

While the present study has provided some initial characterization of a tree decline syndrome, further information directed toward a more comprehensive analysis is needed. This might include a more detailed account of rates of decline associated with periods of recognized soil dryness, the relation of this to site factors such as soil, parent material and topography and to land management factors such as the degree and period of exposure by clearing.

Indications from landholder interviews suggest that a species susceptibility differential exists in relation to tree decline. Whether this is a function of site quality, or is a characteristic of individual species, needs determining in order to clarify the syndrome as well as for use in replanting and revegetation programmes. Information about longevity and condition as a function of species, site factors and prevailing management regimes will also help in achieving this end. In view of the diverse nature of the factors involved, it has been suggested that only a land systems - land unit approach would have the potential of unravelling these complexities (Richards 1981).

But such research should not be at the expense of efforts toward re-establishing tree cover. Existing trees represent a gene pool of the local ecotype and are important for natural regeneration or as a seed source for broadscale direct seeding. Replanting and revegetation trials are also required in order to ascertain successful species, methods, and means of protection from local environmental factors such as possums, rabbits, insects or drought.

Preventative action may also prove successful in prolonging the life of farm trees. This may take the form of treatment with insecticides, protection from possums or eliminating cultivation and pasture or crop establishment close to trees. Lopping is another form of tree maintenance and has been widely used in the Midlands. It was found that, in view of the expense involved and, in some cases, the damage caused to regrowth by possums, the practice is no longer widely used. Subsidies in this direction may prove to be a valuable investment by Government. In this respect, the initiation of financial assistance to rural landholders in Tasmania for ameliorating the effects of tree decline is laudable, but hopefully will expand in terms of both monetary and physical resources.

Whatever the response to tree decline, the basic requirement, not only from landholders but also from Government and the community, is an awareness of the disappearance of trees from rural areas and a desire for their continued existence as part of agricultural ecosystems.

In conclusion, the present study has shown tree decline in a pastoral region of Tasmania to be of dimensions and significance worthy of recognition so far denied. As another example of an Australia-wide problem, it represents the loss of a considerable and diverse resource, affecting both landholders and the wider community. Tree decline is an extraordinarily complex issue many aspects of which have not been covered in this exploratory investigation, although some indication of the proportions and components of the system has been achieved. It is a phenomenon that should be seen in the context of the relatively short-term impact of settlement and development on an ecosystem, and one in which changes are still occurring. The effects of tree decline elsewhere should be heeded as a warning in Tasmania, and efforts need to be made toward its further explanation and amelioration.

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APPENDIX: THE QUESTIONNAIRE AS AN AIDE-MÉMOIRE IN LANDHOLDER INTERVIEWS

TENURE

1. When was the property originally established:

2. How long have you lived on the property:

3. How long has the property been under the present management:

LAND USE

4. What is the general land use:

   grazing (sheep; beef; dairy; horse)
   mixed grazing
   cropping (type)
   mixed cropping and grazing.

5. Has there been a change in general land use over the past 3 decades:

6. Using a recent aerial photograph, show the distribution of land use over the property:

   (Improved pasture; top-dressed native pasture; native pasture; bush run; crop).

7.1 Improved pastures first sown:

7.2 Species mix:

7.3 Was this with timber clearing:

8.1 Current, normal, overall carrying capacity:

8.2 Has this changed significantly over the past 3 decades:

   When:
   What change:
   Reason given (irrigation; top-dressing; pasture improvement; land-use change):

9.1 How long have you been top-dressing:

9.2 Is the whole property top-dressed:

9.3 What rates apply to different parts of the property: at present:
: in the past:

9.4 Approximate aggregate amount used over the past 3 decades:

9.5 Method of application:

VEGETATION

10.1 What are the main tree species on the property:

10.2 Could you describe the extent of trees, shrubs and bushland at the start of your tenure:

11.1 Which areas have been totally cleared in the past 3 decades:

11.2 Which areas have been partly cleared in the past 3 decades:

11.3 Which areas have been woodchipped (since 1970):

11.4 Which areas have always been grassland:

12.1 When clearing, were trees or clumps of trees retained:

12.2 In which parts of the property:

12.3 For what reasons: (stock shade; stock shelter; windbreaks; pasture shelter; soil erosion; land degradation; timber/fencing; firewood; aesthetics; other).

13.1 Was tree death or dieback noticed in trees or clumps after clearing:

13.2 Did this rate differ with paddock use/treatment:

13.3 Did this rate differ with site/topography:

13.4 What eucalypt or other species were involved:

14. Are any tree management practices carried out on the property such as:

14.1 Direct planting:

14.2 Broadscale seeding:

14.3 Fencing out stock to encourage regrowth:

14.4 Fencing out stock to protect existing trees:

14.5 Lopping:

15.1 Is tree regeneration deliberately kept down: (e.g. chemical; mechanical; burning).

15.2 Is *all* tree regeneration kept down by grazing stock:

TREE DECLINE

16.1 What are your ideas about tree death and dieback on farms generally:

(Midlands; Tasmania; Interstate).

16.2 What are your ideas about tree death and dieback on your property:

(temporal; spatial; species; age; causes).

17.1 Has there been any severe damage to trees by insects:

17.2 Tree species involved:

17.3 Type of damage:

17.4 Type of insect responsible:

17.5 When, and at what time of year:

17.6 Was this repeated at a regular interval:

18.1 Do you have a problem with pasture pests:

18.2 Type of pest:

18.3 How long has there been a problem:

18.4 Which areas of the property are affected:

18.5 How periodic is this:

19.1 Are insecticides, herbicides or weedicides used extensively on the property:

19.2 Where on the property:

19.3 What type:

19.4 What insect/plant species is the pest:

19.5 Method of application:

20.1 Can you recall prolonged dry spells over the past 3 decades:

20.2 When and of what duration:

20.3 Were indications of severe water stress or tree deaths associated with these periods:

20.4 In what part(s) of the property:

20.5 What eucalypt or other species were affected:

21.1 Are any parts of the property poorly drained or prone to waterlogging:

21.2 Have any parts of the property been affected by flooding over the past 3 decades:

21.3 Have tree deaths or dieback been associated with either flooding or waterlogging:

21.4 In what part(s) of the property:

21.5 What species were involved:

22.1 Are there any indications of erosion on the property:

22.2 What forms of erosion:

22.3 Where on the property:

22.4 Over what periods have these developed:

23.1 Are there any indications of soil salinization on the property:

23.2 Where on the property:

23.3 Over what periods have these developed:

23.4 Is tree death or dieback associated with these areas:

24.1 Is deliberate burning used on the property:

24.2 For what reason:

24.3 In which part(s) of the property:

24.4 How periodic is this practice:

24.5 Has tree death or dieback been associated with deliberate burning:

24.6 Has this practice changed over the past 3 decades:

25.1 Has tree death or dieback been associated with severe frosts:

25.2 Has the incidence of frost on the property changed with clearing: