THE USE OF REMOTELY SENSED DATA FOR MONITORING AIR POLLUTION RELATED DAMAGE TO FORESTED AREAS

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SUMMARY

Over the past fifteen years concern has been growing over the health of all tree species in central and northern Europe and the USA. This decline in health is on such a large scale that the need has arisen for accurate inventory and monitoring techniques. One such inventory method utilises colour - infrared (CIR) aerial photography which can identify the main symptoms of crown discolouration and defoliation.

In the UK levels of crown deterioration have been identified equable to those in West Germany. However, as yet there is no aerial survey of crown condition, and as a consequence this study concentrated on an area of the Black Forest in West Germany where decline is severe and CIR photographs from 1984 and 1986 already existed. In West Germany the photography is used purely as a monitoring tool and no attempt is made to analyse the imagery further.

Of continued interest to the scientific community are the causes of the forest decline which are generally believed to be a combination of local site and stand factors superimposed on larger scale pollution and climatic variations. The integration of disparate information sources has now become an important aspect of any work utilising a remote sensing input, therefore the primary aim of this research was to develop a technique for assessing and mapping the relationships between tree crown condition and its associated site and stand variables.

The initial assessment of crown condition was based on manual interpretation techniques which were deemed to be the most suitable approach for the problem in hand. Once species identification and crown condition assessment had been undertaken the next stage involved measurement of the variables that might account for the observed patterns of decline. The variables considered were elevation, aspect, topographic position, stand position, slope, distance from the stand edge, radiation index and stand composition. All these variables could be measured manually from both map and photographic sources.

When the seperate species and independant variable data sets were analysed the only significant relationship found was that between crown condition and elevation / topographic position. Therefore a method was devised to produce a thematic map of the distribution of crown condition and its relation to elevation. A two dimensional surface map was successfully combined with a Digital Elevation Model (DEM) to produce a three - dimensional crown condition surface showing the changes that had occurred between 1984 and 1986.

Key words : forest decline, CIR photography, crown condition, Digital Elevation Model, remote sensing

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Chapter 1 : Introduction

1.1 The forest decline phenomenon

1.1.1 History and causal factors

Important changes in the characteristics of major sources of air pollutants have taken place in the last two decades. In general these changes have led to more effective dispersion and consequently smaller concentrations of pollutant gases close to sources (Fowler & Cape, 1982). The mechanisms of this long - range dispersion of pollutants and their effects on forest ecosystems are considered in Chapter 4. Suffice it to say here, that it is generally recognised that these changes have led to the present decline in the health of forests in Central Europe and North America.

The first signs of decline in Sweden in 1972 were largely discounted at the time (McCormick, 1985), and a short period of damage followed by recovery in southern Sweden in 1973 - 76 was attributed by Swedish botanists to climatic stress. However, within the last ten years vast areas of forests, especially at altitudes above approximately 600m, have been damaged in Europe with a significant proportion having been severely damaged (estimated at 5 % in 1985) or even killed (0.2 % in 1985). The problem was identified as a 'new type' of forest decline (Neuartige Waldschaden) in West Germany, since it was different from the declines of fir trees (Tannensterben) encountered in previous decades (Cape et al., 1988).

The 'new type' of decline is characterised by marked thinning and change of form in the crowns of coniferous trees, most severe in silver fir (Abies alba) and less so in Norway spruce (Picea abies) and Scots pine (Pinus sylvestris). Similar decline has also been observed in deciduous trees, notably beech (Fagus sylvatica), which exhibit symptoms of leaf discolouration, early leaf fall, death of tree tops, damage to bark and lack of natural rejuvenation. The reason for the 'new' label is the widespread occurrence of similar visible symptoms in several tree species, leading eventually to tree death.

In eastern Europe, forest problems are even more severe than in central Europe. (Elsom, 1987). Nearly 700, 000 hectares (or 16 %) of Czechoslovakian forests have been damaged, particularly close to the Polish border where precipitation has an average pH of 3.8 (over 60 time more acidic than average unpolluted precipitation). The problems in eastern Europe are particularly severe due to the extensive emission of sulphur dioxide (SO_2) from uncontrolled industrial plants and sulphur content of brown coal or lignite burned which has high sulphur content when compared with bituminous coal (Elsom, 1987).

A number of different hypotheses have been proposed to explain decline, however there is wide agreement that the link between long - range air pollution and tree health cannot be ignored. Uncertainty however, surrounds the identification of damaging agents at specific sites as well as the response mechanism for triggering damage. The greatest disagreement occurs over the relative contribution of natural damaging agents such as climatic extremes and insect attack (Rehfuess, 1987; Manion, 1985). The contribution of such natural damaging agents will be considered in Chapter 4.

1.1.2 Extent of decline throughout Europe

Nilsson (1988) reported on the extent of decline attributed to air pollutants in Europe. This report considered the relative differences between national survey methods which led to misconceptions about the levels of decline and the consequent difficulty in comparing results. The requirements for forest decline inventory will be considered in section 1.2, here the aim is to acquaint the reader with the levels of decline that are being encountered as well as changes in severity since the first surveys were instigated. Table 1.1 (a) and (b) presents this data for European nations from 1984 to 1986. In the presentation of these results Nilsson (1988) considered three levels of certainty. The first level involved damage that could be attributed to specific air pollution agents. The second included damage that had a high probability of being caused by air pollution. However, these estimates have a low statistical certainty due to the variation in data collection methods. A good example is the information from eastern block countries where air pollution damage is known to exist but only rough estimates are available. The final level is the reported damage group " slight damage" (10 - 25 % loss of foliage). This class cannot be considered as a true damage group since many otherwise healthy trees exhibit such defoliation levels (Schopfer, 1987); however, it must be regarded as a risk group, which could deteriorate during future climatic extremes or exposure to air pollution.

The values in Table 1.1 (a) and (b) were obtained using the criterion outlined in Chapter 5. Use of defoliation and discolouration as the chief criterion is the coarsest measure of decline, which tends to leave the results open to different interpretation. For example the 1986 UK Forestry Commission survey results for conifers show almost 20 % occurring in the moderate damage category. This result corresponds with the levels of decline encountered in West Germany, however Innes (1987) stated that,

"....as neither of these symptoms is specific to any given cause, no easy interpretation of this similarity is possible."

Table 1.1 (a) and (b) Extent of coniferous and deciduous forest damage throughout Europe

	1984			1985			1986		
	Mod.	Sev.	Total	Mod.	Sev.	Total	Mod.	Sev.	Total
Austria	3.8	1.6	5.4	3.6	0.8	4.4	4.9	0.8	5.7
Belgium				5.7	1.0	6.7			
Bulgaria							3.5	2.4	5.9
Czechoslovakia							12.1	4.3	16.4
Denmark	n.a	n.a	4.6	n.a	n.a	4.1			
Finland				11.3	1.0	12.3			
France				12.0	1.6	13.6	10.2	2.1	12.3
FDR	20.2	1.9	22.1	20.5	2.8	23.3	19.0	2.0	21.0
Hungary				0.6	0.1	0.7			
Italy	1.7	0.6	2.3	4.3	0.6	4.9			
Luxembourg	1.9	0.5	2.4	2.8	1.2	4.0	2.6	1.6	4.2
Netherlands	11.0	1.5	12.5	13.0	2.0	15.0	18.0	5.0	23.0
Norway	10.7	2.8	13.5	11.2	0.9	12.1			
Poland				12.0	6.0	18.0			
Spain							14.1	4.1	18.2
Sweden	26.2	1.2	27.4	21.0	0.7	21.7	16.4	0.3	16.7
Switzerland	8.2	1.4	9.6	7.0	2.0	9.0	13.0	3.0	16.0
UK	8.4	2.1	10.5	4.4	0.3	4.7	19.8	1.0	20.8

Table 1.1 (a) Extent of conifer damage. Expressed as damaged trees in percent of total number of trees.

After examining all the available evidence Nilsson (1988) concluded that damage throughout Europe was concentrated in stands with certain characteristics. These are mature stands, high elevation stands for the years 1983, 1984 and 1986 (during 1986 the same patterns occurred in lower elevations), stands with lower water retention capacity, stands with less favourable nutrient conditions, stands located in harsh climate, species sensitive to natural stress factors, dominant trees and those on the stand edge, badly managed stands, regions with high concentrations of foliphagous insects and fungal pathogens.

	1984			1985			1986		
	Light	Mod.	Sev.	Light	Mod.	Sev.	Light	Mod.	Sev.
Austria				34.0	4.0	1.0	37.5	4.6	0.8
Belgium				n.a	1.2	0.3			
Bulgaria							8.0	3.0	1.0
Czechoslov.							Total = 3.8		
Denmark	n.a	0.1	n.a	n.a	0.1	n.a			
France				11.8	2.0	0.7	14.5	3.6	1.2
FDR	33.0	9.2	0.8	33.9	11.5	1.1	35.5	14.7	1.2
Hungary				8.7	0.9	0.3			
Italy				n.a	0.5	n.a			
Luxembourg	18.2	3.3	0.7	19.1	3.2	1.0	25.3	4.4	1.1
Netherlands	28.3	3.7	1.0	32.0	12.0	3.0	33.4	12.7	5.0
Poland				n.a	3.9	2.4			
Spain							1.6	2.4	0.2
Switzerland	21.7	3.0	0.2	24.0	4.0	1.0	37.0	7.0	1.0
UK				13.3	2.1	0.6	12.4	2.4	n.a

Table 1.1 (b) Extent of deciduous damage.

1.1.3 The economic cost of forest decline

According to Becker (1987) the present decline phenomena may affect the forest products market in three ways :

(1) by increasing the regular annual felling in certain years;
(2) by changing the composition of tree species and diameter classes;
(3) by changing physical and technological wood properties, with consequences for utilisation of wood from damaged trees.

However, it was noted that the defects found in timber quality would be the same no matter what the damaging agent, therefore, salvage techniques should not be changed only intensified. In West Germany a certain amount of selective thinning of damaged trees occurs as a matter of course. However, Becker et al. (1987) observed that cutting rates of timber showing signs of decline had been very low during the earlier part of the 1980's.

This reticence to harvest severely damaged trees was explained by the fact that severely damaged trees can remain at that level for years without any deterioration; and any increase in timber supply might disrupt the timber market. To conclude, Becker et al. (1987) predicted little market distortion in the short term whilst long - term forecasts depended on more information on possible causes. Mills & Kauppi (1987) also saw the lack of understanding of the mechanisms of decline as a problem. However, they were optimistic that the analysis of the sensitivity of timber markets to potential air pollution damages would be helpful in setting the priorities for future research on forest decline.

Long term forecasts have been made however, based upon present patterns. The European Timber Trends Study (ETTS IV) outlined by Oakley (1987) identified two major trends which have a direct bearing on the problem of marketing timber from damaged forests. These are : (1) a desire to maximise domestic production of wood and consequently of wood products, e.g. conversion of 'marginal' agricultural land to forestry which will have a profound effect on the demand pattern in Europe over a long time; (2) a desire to retain a market share in competition with other materials which leads to the production of value added products such as paper and paperboard.

In general it seems that the outlook is bleak, since by the year 2000 demand will exceed supply in Europe. If the extra supply is salvaged timber it can be used in the short term for pulping. However, if the additional wood has to be accommodated on a long term basis due to increased productivity or continued forest decline, then the only way of dealing with this extra supply is through the expansion of new products. Unfortunately, the scope for increased consumption of existing wood products is limited.

1.2 The requirement for forest decline inventory

According to Smith (1988) the main reasons for carrying out a decline inventory are as follows :

(1) to define causes of decline and appropriate pollution control strategies;
(2) to assist forest policy formulation and management;
(3) to predict any market disruption which may occur as a result of the decline;

(4) to assess any increase in avalanche or erosion hazard as a result of the decline.

In order to fulfill these requirements most countries in Europe initiated national field surveys based on needle / leaf colour changes and changes in canopy density. The reference year for the studies range from 1983 (France, FDR) to 1985 (Belgium, Denmark, Italy) and although similarities existed between inventory methods, the differences which remained made direct comparison difficult. It was also interesting to note that the results of the surveys reflected the observer's attitude towards the role of atmospheric pollution on forest decline (Wright & De Meyer, 1985). This inequality between monitoring methods prompted the European Commission for Europe to produce in 1986 a manual entitled Methodologies and Criteria for Harmonised Sampling, Assessment, Monitoring and Analysis of the Effects of Air Pollution on Forests.

The general procedures recommended in the monitoring programme include :

- large - scale survey and assessment;
- intensive studies on permanent plots;
- chemical analysis of needles and leaves on permanent plots;
- chemical analysis of soil on permanent plots.

The criterion used to assess the levels of decline in the field surveys are discussed in Chapter 5. Of immediate interest are the remote sensing methods used to monitor decline in tandem with the field survey. To date the methodology used exclusively in an inventory framework has been Colour - Infrared (CIR) aerial photography. The use of CIR aerial photography in vegetation condition assessment has been well documented and its applications are discussed in Chapter 4. In forest decline inventory work, such an approach uses the same discolouration and defoliation classes used in the field surveys, although the descripitive criterion used, differ because of the false - colour representation on CIR photography (refer to Chapter 7). Unfortunately, in most of the European nations the results of the aerial - photographic survey are merely used as a confirmatory data set; official forest decline statistics being provided by the field survey. However, CIR photography has certain distinct advantages over other remote sensing techniques as well as a field approach and these are discussed in Chapter 5.

Attempts have been made to apply acquired digital airborne and satellite techniques to this problem, however, the satellite approach continues to be experimental. A recent report based on Seminar on Remote Sensing and Forest Decline Attributed to Air Pollutants (Duinker & Nilsson, 1987) identified the major areas where satellite remote sensing techniques needed to be refined in order to provide the accuracy required. The use of airborne multispectral scanner (MSS) technology is more promising than satellite scanner data because it allows for the study of individual tree crowns.

The identification of individual crowns is the basic prerequisite for any analysis of forest decline because of the nature of the phenomena. That is the appearence of a healthy tree crown adjacent to a severely damaged crown. In areas of eastern Europe where SO_2 is a known damaging agent the situation is however different. Here vast tracts of forest are severely damaged, therefore the possibility of using smaller - scale imagery is introduced. The question arises however as to whether the symptoms experienced in eastern Europe can be classed as a new kind of forest decline ? The study of forests showing signs of classical pollution damage is well documented. Distinct patterns of damage, usually in the direction of prevailing winds or topographic influence can be identified and easily mapped using remote sensing techniques. If there is enough a priori information on the damaging agent then it is possible to confirm that a specific pollutant is the culprit based purely on the distribution of damage. In addition the remote sensing survey is aided by the fact that such patterns of damage can represent acute injury acting over a short time scale. Such an event was described by Murtha (1971) who noted that the levels of pollutant encountered were highly concentrated, therefore the signs of damage were prevalent after one growing season and were specifically related to the area in which the pollutant remained at high levels.

As Chapter 2 outlines, the major problem with forest decline is the lack of a concensus concerning the cause. This is due to the fact that if a pollutant is prompting the decline it is occurring at a chronic level and has been acting over a long - time scale. It would seem that forest decline has been an insidious decline which has only been appreciated when the first visible signs of damage to foliage in areas away from industrial centres have been noted. In other words the presence of symptoms now represents the culmination of a gradual decline in the health of the tree population in the industrial areas of the northern hemisphere. This view would correspond with those who espouse air pollution as the primary damaging agent since prior to the industrial revolution, the periodical declines in the health of Silver fir trees was correlated with climatic extremes (Binns, 1985).

The remote sensing scientist is therefore faced with a lack of meaningful a priori information when attempting to map forest decline. What the aerial photographic surveys are probably recording are a series of declines prompted no doubt by air pollution in conjunction with climatic extremes and biotic damaging agents. The pattern of each decline will therefore vary depending on the local or regional site conditions and the relative importance of one of the causal agents, whether they be pollutant or natural.

Inventory approaches cannot therefore attempt to define a possible cause (this being difficult enough on the ground). To date, remote sensing imagery has been used merely as a mapping and monitoring tool. This has primarily been achieved with CIR photography, a use which does not fulfill the true potential of the imagery. Within the West German inventory framework, in addition to measuring the crown condition, other measures related to the trees site and its position within the stand are noted. Although only used as descriptive data, this information provides a potential key to the possible causes of the decline. The term possible is used here since the accuracy of a field and laboratory based approach cannot be controlled. According to Kauppi (1987) what is available now, which was not available five years ago, is an opportunity to shift the research emphasis from data acquisition to data analysis. This acknowledges the refinement of the remote sensing inventory techniques using primarily (and certainly most successfully) CIR photography.

The time has come to use the imagery to obtain quantitative measures about the relationships between crown condition and stand age, elevation, stand density, soil characteristics, climatic variables and air pollution variables. It is evident that certain data input (pollution and climatic information) will have to come from field measurements, however, this is now an opportunity to intergrate both field and airborne data sets in a manner that could provide clues as to the primary cause of the observed decline.

The thrust of the author's research is therefore based upon utilising a well established inventory tool (namely CIR aerial - photography) in an analytical role. Rather than evaluating a new form of imagery and its associated manipulative techniques, there is a need to improve the analytical qualities of an existing tool - an operational as opposed to the experimental approach of which there is perhaps too much in remote sensing.

1.3 Identification of a Suitable Study Area

1.3.1 Study in the UK

The initial idea involved a study in the United Kingdom because it was one of the few countries in Europe which was not using aerial photography for the study of forest decline. As enquiries continued it became clear that this was more of a political decision than a scientific one. The attitude adopted by the Forestry Commission towards that of forest decline in the UK was that it was not and could not occur at the same levels as those on the continent. A number of areas were identified where extensive forest damage had occurred, namely, Whinlatter Pass in the Lake District and Castle O'er Forest in the Scottish Borders. In both cases the commission were able to explain the damage. The first case was caused by a combination of windthrow and frost damage and the second case resulted from waterlogging due to planting on peatland.

A series of areas were further identified by a search of the relevant literature and the resulting map of the distribution of damage is shown in Fig. 1.1. The damage is clearly occurring in remote areas as well as areas adjacent to industrial concentrations. When comparing this distribution with maps of ambient SO_2 concentrations and sulphur deposition, very few occur in areas where concentrations are high. This distribution has been confirmed by the Forestry Commission in the analysis of their 1987 inventory (Innes & Boswell, 1988). Comparisons of this kind however, have limited value because of the very nature of forest decline which is occuring away from major sources of pollution. The commission used these results as an argument for denying the presence of forest decline in this country, even though the presence of acidified water bodies was well documented. The increasing problem of acidified water in the UK was indirectly concerning the Forestry Commission in that it was known that the presence of conifers close to rivers and lakes contributes to the acidification (Miller, 1984). Conifers act as an atmospheric filter, the materials filtered being passed to the soil and hence groundwater. Therefore, the planting policy of the commission was deemed more of a problem than the potential for forest decline from atmospheric pollutants. Even though acid precipitation would be filtered from the atmosphere and consequently passed onto the nations water bodies.

The arguments for and against forest decline in the UK are discussed in Chapter 3. The fact that "acid rain" was a political ballgame prompted a shift of emphasis in the research to an area where forest decline was known to exist and importantly, a suitable library of imagery was in existance.

1.3.2 Study in West Germany

The problem of forest decline in West Germany has been studied to the greatest degree, therefore it seemed a reasonable place to find a research base. The area eventually chosen for the main analysis was located in the Black Forest in the state of Baden - Wurttemberg. The problem with a study of this kind in West Germany is the fact that the results of the field work do not allow for the identification of the individual sample points, since only the results for regional decline levels are required. However, it was fortunate that an international study undertaken in 1986 by the Institute of Terrestrial Ecology included a number of sites in West Germany. Two of these areas occurred in the Black Forest; contact with the University of Freiburg established that one of these areas was covered by 1 : 5, 000 CIR inventory photography. The characteristics of the photography used is summarised in Chapter 5.

In addition to the Black Forest site, imagery was also obtained for an area in Bavaria. The characteristics of this site and the data characteristics are summarised in Chapter 5. This area was chosen as a control for the main analysis in the Black Forest since the physical site conditions and pollution climate was different.

1.4 Aims and Objectives of the Research

The primary aim of the research was to develop a technique for assessing the relationships between a tree's crown condition and its associated site and stand variables. In this case the technique was developed using forest decline as the damage syndrome, however, it was envisaged that the methodology could be applied to any forest damage phenomena that could be assessed from a remote sensing source. The technique should be flexible in that sources other than imagery and map data can be employed in the crown condition rating system. This intergration of data sources is the main thrust of the research problem; however, it is felt by the author that if these problems can be overcome the resulting statistical and map output can be a useful tool for assessing the possible causes of damage.

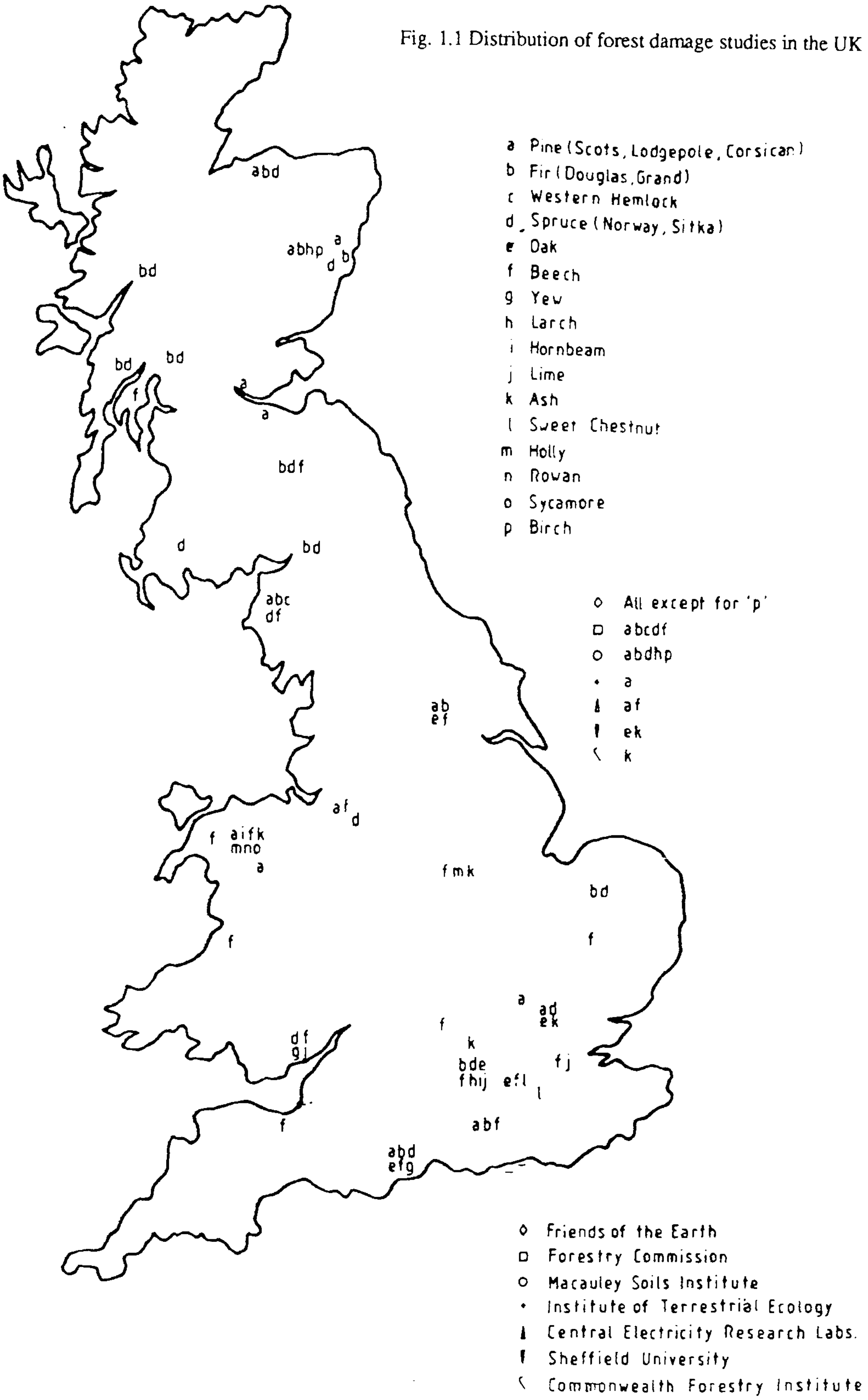


Fig. 1.1 Distribution of forest damage studies in the UK

Within this broad framework a number of narrow objectives were pursued in order to formulate the primary data collection and analysis techniques. These objectives were :

(1) consideration of the forest decline situation in the UK in order to assess the potential for a remote sensing inventory of forest decline. The Forestry Commission undertake annual surveys of forestry in the UK based upon their own sampling network and one defined by the European Commission (Innes & Boswell, 1987). However, to date, there has been no aerial - photography based survey. Whether this was for political reasons or because the Commission were adequately judging the situation, was considered.

(2) Assessment of the optimal method for interpreting crown condition on the imagery selected for the analysis. Within the framework of this objective a number of questions had to be answered. Firstly, what is the optimum remote sensing data source for assessing forest decline ? Secondly, what is the best method of quantifying the species and visible crown symptoms on the imagery ?

(3) Definition of the most appropriate method of quantifying the relationship between crown condition and the site / stand variables eventually chosen. The development of a method involved an explanatory approach since the data under study did not lend itself to standard statistical methodologies. Once a relationship or relationships had been established the final stage will involve production of a thematic map in order to represent the distribution of crown condition in relation to the correlated variable or variables.

Chapter 2 : Forest Decline - Causes and Symptomatology

2.1 Introduction

Forest decline is a disease of trees which is characterised by a gradual deterioration of crown and roots leading, over time, to death. The cause cannot be ascribed to one single factor, hence a combination of factors must be considered (Manion, 1985). Declines are therefore different to simple biotic diseases and injury since the problem cannot be ascribed to one single agent.

It is the very ambiguity of this definition that has led to the present controversy concerning the widespresd deterioration in health of tree populations in central Europe and North America. M^cLaughlin (1985) recognises that a consensus regarding the primary causal mechanisms has still not emerged. Further to this point, Cowling (1985) quantified the problem when he suggesed that the judgements being made on possible causes were beyond the documented status of knowledge. In general it seems that the scientific (and political) melee involves poorly tested hypotheses attempting to explain real world situations.

What then are the arguments put forward to explain decline ? According to Schutt & Cowling (1985), there are six main hypotheses or schools of thought (see Section 2.2.4) regarding the problem in Europe. Unfortunately, these hypotheses do not explain the possible involvement of nomal abiotic and biotic factors, in fact :

" the air pollution hypotheses do not come close to adequately explaining the many decline problems that are being lumped together." (Manion, 1985)

Kandler (1985) supports this claim by suggesting that a number of different disorders are involved and their symptoms are equable to those described in the 19th and early in the 20th Century. An example being the documented decline of Silver fir (Tannensterben) ascribed to climatic extremes.

When one looks at the hard facts, the case for a biotic / abiotic induced decline is a strong one. Certainly the pollution lobby plays down the potential importance of climatic variation, particularly drought, as a primary causal factor. Schutt & Cowling (1985) assign climatic extremes to the rank of predisposing or secondary factors without proper reasoning. Rehfuess (1987) on the other hand advocates climatic extremes as the major cause of forest decline. Certainly, the chronology of decline in

West Germany does tally with periods of drought.

Prior to the late seventies, when Norway spruce began to show widespread symptoms (even in remote areas), such declines would have been related to changes in climate (Wachter, 1978) or point sources of pollution (Farrer, 1977; Vick & Handley, 1977). McLaughlin (1985) however implies that the present regional changes in forest vitality go beyond what could be expected from normal factors. Cowling (1984) agreed and made some observations on the decline and its possible linkages with air pollution . The salient points relating to Waldsterben are :

(i) symptoms of decline occur principally on fir, spruce, beech and pine as well as hardwoods such as birch, larch, maple, alder, ash and oaks;

(ii) both natural and planted forests are affected;

(iii) effects are seen at high and low elevation and on all aspects, but are most pronounced on north - west facing slopes in north - west Germany and on west facing slopes above 800m in the Black Forest;

(iv) while effects have generally been most pronounced on older trees, they can be found on all age classes in many areas;

(v) symptoms are found on stands growing in soils of high or low fertility and on both basic and acid soils (pH range from as low as 3.5 or less to as high as 8.0).

Manion (1985) on the other hand refuted these observations as reasons for suspecting a pollution problem for the simple reason that claims of regional air pollution impacts on forests are generally based upon poorly tested hypotheses. Therefore, to link slowly changing and variable, regionally based air pollution problems with decline syndromes is meaningless. Even if one assumes the presence of air pollution it is still important to take local and regional weather conditions into account. This, unfortunately presents its own problems when attempting to explain the damage; for how does one define the primary cause ? Does the air pollution predispose a tree to extremes of weather or is weather the primary predisposing factor ? For example; temperature inversions are required to concentrate regional photo - oxidant pollutants, whilst air movement patterns transport the precursers of photo - oxidants from major population centres with high emissions to areas of low pollution emission (Manion, 1981). Therefore, climatic extremes are considered to be the most important precursers of damage. Further, it becomes necessary to investigate specific weather events required for the production, concentration and transport of secondary air pollution before implying that tree decline and mortality is associated with air pollutants.

Whatever the arguments for and against the influence of air pollution on forest health it is not disputed that a series of forest decline problems are presently being encountered in central Europe. To conclusively explain these problems Prinz (1983) postulated the following three criteria :

(i) It must be possible to relate specific symptoms of injury to the causal factor in question.

(ii) Temporal development of injury must coincide with temporal development of the causal factor in question, including accumulation effects and delayed action of the factor.

(iii) Spatial distribution of injury must largely coincide with spatial distribution of the factor in question.

Schutt (Pers. comm.) denied that such a relationship can exist for the problem in Europe and he espouses remedial action based upon the most likely cause, whether it be air pollution or a natural factor.

2.2 <u>Causal factors</u>

2.2.1 Natural factors

".....stand level dieback in forests is by no means a new phenomen on and further that, in many cases, it is due to natural causes." (Mueller - Dombois, 1987)

The term dieback in this case is equable with the decline phenomena since it refers to death of groups of neighbouring trees rather than isolated trees dying in an otherwise healthy forest. Dieback stands are defined as, "forest segments having significant loss of canopy" (Miller - Dumbois, 1987). In these stands the majority of trees are either dead or display reduced vigour. The basis for natural dieback is that the effect will be differentially felt by trees at different stages of their life cycles. The decline theories, although somewhat similar in aetiology, differ from the natural dieback theory in that the loss of vigour extends to the affected species as a whole, i.e., to all or most of the life stages. This is occurring with the Waldsterben phenomenon, although Muller - Dumbois (1987) does suggest that the uncertainty surrounding this decline may be partially explained by recognising that forest stand segments also die naturally. The author went on to conclude that the European dieback may turn out to be the effect of an additional stress superimposed on the natural dynamics of these forests. In other words, air pollution may be accelerating a process whose underlying basis is natural.

Krause et al. (1985) recognised that extreme climatic events, particularly drought, have the most significant impact on tree mortality; thereby affecting stand and ecosystem composition. Of the economically important tree species silver fir, Norway spruce and common beech are relatively drought sensitive and therefore, one would expect a loss of vigour during dry periods (Prinz, 1983 & 1985). Such drought induced decline was in fact noted throughout Europe, after the dry summers of 1976, 1983 and 1984 caused severe stress to many tree species, particularly beech (Innes, 1987).

Rehfuess (1987) illustrated the potential for climatic damage with examples of Norway spruce decline in central Europe. Since 1980 an apparently new disease has affected Norway spruce trees in the Bavarian and Black forests in West Germany; mostly at elevations above 900m. The disease starts with a pronounced yellowing of older needles, followed by necrosis and shedding, which eventually leads to a marked thinning or transparency of the crown. The decline occurrs on different soil types and has been ultimately associated with an extreme magnesium and calcium deficiency.

The working hypothesis subsequently formulated to explain this phenomenon amply illustrates the confusion surrounding the choice of causal agent. During the summer, the intensive formation of ozone and other photo - oxidants occurs at higher elevations and this leads to deterioration of cell membranes and cuticular waxes. Acid mist ($pH < 2.6$), associated with precipitation events, will leach nutrients such as magnesium and calcium from these predamaged needles, thereby creating magnesium deficiency. This deficiency subsequently slows down the photosynthetic capacity and volume growth and will decrease frost hardiness. Subsequently, damage which was initially latent became evident after a series of severe frost shocks between 1979 and 1983. The potential effect of frost is also acknowledged as a major cause of forest damage in the UK, where sudden fluctuations in temperature have induced the death of needles and shoots during the dormant season. Winter damage in the UK has also occurred when freezing conditions have been accompanied by strong winds, resulting in the dessication of conifers (Innes, 1987).

The intensity of this specific damage must be highest at the summits of the mountains where : ozone concentrations show peak values during periods of intense radiation; the number of fog days is highest; photo - oxidation of the chlorophyll is intense;

many soils are rather poor in magnesium, and frost events are frequent. The involvement of frost would offer an explanation for the tree - to - tree and stand - to - stand variation of damage intensity in the affected regions since the frost resistance of conifers is controlled by genetic factors. Therefore, the role of pollution is played down, merely acting as one predisposing factor which allows frost to create the final visible pattern and intensity of damage. Finally, the natural damage lobby have stated that since the damage is occurring on all types of geology and soil, and in areas of different pollution levels therefore the triggering factor is unlikely to be pollution or soil induced stress.

"Regarding the large scale occurance of disease phenomena all over central Europe, there is most evidence that a weather stress, either drought or frost events, acts as a trigger or synchronising factor." (Rehfuess, 1987)

2.2.2 Disease

Due to the apparent spreading of the decline from more or less specific areas of origin, viruses or virus like organisms have been considered as a possible cause of novel forest decline, (Krause et al., 1985). However, Nieuhaus (1985) considered viruses as merely predisposing factors rather than a primary cause of decline.

2.2.3 Mismanagement

Another factor whose influence on decline is difficult to assess is silvicultural practice. The major change is that over the past two centuries there has been a preference for economically important coniferous trees at the expense of deciduous tree species. Such change creates its own problems when the coniferous species are planted without due regard for natural requirements in terms of site and climate. For example, plantations of shallow - rooting conifers have led to the compaction of the deeper layers of the soil, thereby increasing the susceptiblity of trees to drought (Krause et al., 1985). Manion (1981) concluded that damage is not limited to unsuitable sites or particular forest types, but is also found on optimal sites and in well managed forest stands. Burschel (1986) went even further, finding that managed forest were more susceptible than unmanaged forests to large - scale damage by wind, snow and insects. However, no link could be found with forest decline. To place the problem in some perspective, Innes (1987) emphasised the natural competition by trees for light, nutrients and water as a stand ages. This occurs in both managed and unmanaged stands, and therefore suppression by the dominant overstory must be taken into account when examining the health of individual trees within a stand.

2.2.4 Airborne Pollutants

> "If one tries to explain the causes of novel forest decline by evaluation of the level of air pollution, one has to concentrate on the typically damaged areas .... These areas, apart from some characteristic exceptions exhibit low to extremely low concentrations of sulphur dioxide, nitrogen oxides and other primary air pollutants." (Prinz, 1985)

Although this sounds like a case for natural causes of damage, it is in fact the mainstay of the pollution lobby's argument. The most striking feature of forest decline is the fact that symptoms were first observed and became most severe in remote areas away from industrial and urban agglomerations (Krause et al., 1985). In order to explain this phenomenon two major schools of thought have emerged concerning the mechanisms of damage to trees in remote area. The first of these concerns the direct effects of gaseous air pollutants (including interaction with wet deposition) on above ground biomass, with indirect effects on the root system. The second concerns accumulation of dry and wet deposited substances in soils, resulting in changes in soil properties and subsequent effects on plants via the root system.

The first theory, espoused by Prinz (1983, 1985), was based upon field observations of foliar symptoms and measurement of ozone concentrations in parts of West Germany as well as on controlled exposures of seedlings of various tree species. Such direct effects of gaseous pollutants are primarily a consequence of their diffusion through the stomatal pores of foliage, dissolution in water in the mesophyll cells of the walls of the stomatal cavity and subsequent alteration of a wide variety of biochemical and cytological processes that ultimately affect plant growth and development (McLaughlin, 1985). Certainly as regards silver fir and Norway spruce, ozone in combination with (acid) precipitation and fog plays a key role in the development of decline symptoms.

Opposed to this so called "top - down" theory is the "down - up" theory of Ulrich who espouses impairment of the root system due to aluminium toxicity which subsequently affects the above ground biomass. Ulrich (1980, 1981) stated that the natural acidification of forest soils (due to humus disintergration, nitrification and greater uptake of positive ions from the soil) is accelerated as a direct result of deposition of acidic or acidifying substances from the atmosphere. Increased acidity in the soil leads to increased concentrations of soluble aluminium ions. Aluminium toxicity results in necrosis of fine roots, which in turn leads to increased moisture and / or nutrient stress and eventually to "drying - out" and death of the trees.

These theories are two of the six possible pollution theories mentioned by Cowling & Schutt (1985). To make an informed judgement on the applicability of any one theory, further information on local conditions is required. In fact Cowling & Schutt recognise that each of these pollution related hypotheses is inadequate to explain observations made in the field. However, presuming an air pollution triggering mechanism, the six theories cover all possible scenarios so it is worthwhile investigating them all further.

2.2.4.1 Magnesium deficiency hypothesis

This theory is perhaps not a cause but a symptom, since it is generally acknowledged that magnesium deficiency is noted in all trees affected by the decline syndrome. The basic hypothesis is based upon the simple concept that the demand from a forest for nutrients can sometimes be greater than the supply returned to the soil by normal litterfall, root turnover and decomposition (Waring, 1987). In the case of acid deposition acting on a coniferous species, the calcium and magnesium within the soil is directly displaced from the upper horizons. Alternatively, reduced microbial decomposition releases the nutrients from soil organic matter (M^{c}Laughlin, 1985). As a result of leaching, the magnesium is lost from the soil profile and is no longer available for uptake by the tree.

The chief symptom of magnesium deficiency is a yellowing of older needles, followed by necrosis and shedding which leads to a marked thinning or transparency of the crowns, usually at the center and the base. Rehfuess (1987) studied Norway spruce in the Bavarian Alps and found that the major difference between healthy and diseased trees was that diseased trees contained a lower foliar content of calcium and magnesium. Soil differences were ruled out by Krause et al. (1985), Prinz (1985) and Rehfuess (1987), since decline occurs on soils with both high and low concentrations of magnesium. Unfortunately, the influence of air pollution is still disputed, although in an earlier publication on this problem, Rehfuess (1983), did note that acid deposition,

> "may contribute to these growth disturbances : it adds nitrogen to the ecosystem but may leach out magnesium and calcium from needles and soils."

2.2.4.2 General stress hypothesis

This hypothesis is based upon field and laboratory observations of spruce and beech in Bavaria (Hinrichsen, 1987). Observations indicate that air pollution and atmospheric deposition have led, in recent years, to a decrease in net photosynthesis. As a result this process leads to a poorer energy status in the tree's root system. This, coupled to an increase in toxic substances in the shoots, prompts the poor development of fine roots and causes foliar decline symptoms. Since the trees overall energy balance is reduced it is much more susceptible to other stress agents, like drought, frost and wind, as well as any number of secondary biotic pathogens.

2.2.4.3 Excess nitrogen - nitrate - ammonia deposition

Nitrogen in the form of ammonium or nitrates is one of the most important nutrients for plants since it forms necessary amino acids and proteins (Nihlgard, 1985). Most plants have adapted to exist with low levels of nitrogen hence they are good at scavenging this essential nutrient from the soil and the atmosphere. Unfortunately, this very ability has led to "over - saturation" with nitrogen during the decades since the war. The increased application of agricultural fertilizers during this period, as well as sewage sludge treatment, chemical fertilizer plants and vehicle emissions, have led to the release of increased levels of nitrogen into the atmosphere (Hinrichsen, 1987). For example, at present rates of manufacture, the Swedish fertilizer industry produces approximately 340 metric tonnes of nitrogen waste per year (Nihlgard, 1985).

What effects does this increased nitrogen have on tree species ? Schutt & Cowling (1985) suggested the following as symptoms of excess nitrogen :

(1) increased growth and hence increased demand for other essential nutrients and trace elements, leading to deficiencies in the latter;
(2) inhibition or necrosis of the fine root system;
(3) increased susceptiblity to frost, leading to a delay in cuticular development and the conversion of starch to sugars;
(4) increased susceptibility to root - disease fungi and fungal attack;
(5) changes in root - to - shoot ratios;
(6) altered patterns of nitrification, denitrification and nitrogen fixation.

Nihlgard (1985) concluded that, although excess nitrogen may make trees more productive in the beginning, it will in the long run make trees more sensitive to other airborne pollutants.

2.2.4.4 Airborne transport of growth - altering organic substances.

This is the most speculative of the theories and is based on the possiblity that among the thousands of synthetic organic compounds produced every year in central Europe, any number might contribute to forest decline. One known example which demonstrates the potential for such damage was documented by Cheesman et al. (1978) who studied loblolly pines in the vicinity of two chemical plants in the USA. As a result of the plant emissions the trees began to exhibit twisted needles and abcission of needles whilst still green. These symptoms represented an alteration in the normal balance of growth regulators which is one of the broad indicators of forest decline.

2.2.4.5 Acid deposition hypothesis.

In its strictest sense acid deposition refers to the wet precipitation of the oxides of sulphur (SO_2 / SO_3) and nitrogen (NO_2 / HNO_3). When dissolved in cloud and rain droplets these oxides form the concomitant sulphuric and nitric acids (ECSC, 1983), and hence the phenomenon of acid deposition reflects the disturbance of hydrochemical cycles. This term has also been applied to dry precipitation of gaseous and particulate pollutants (Innes, 1987).Therefore, according to Fuhrer (1985), the term acid deposition must include : (i) wet deposition by rain or snowfall and dry deposition by sedimentation of particles (precipitation deposition); and (ii) impaction of aerosols and mist, fog or cloud droplets together with the absorbtion of gases on wet surfaces or inside the stomata of leaves and needles (interception precipitation). The latter type being referred to as occult precipitation (Innes, 1987).

Originally dry deposition was believed to produce only localised degenerative effects. However, over the last two decades changes in the characteristics of air pollution have taken place. In general these changes have led to more effective dispersion and consequently smaller concentrations of pollutant gases close to their sources (Fowler & Cape, 1982). This has meant that previously remote areas have become affected. The gases themselves are produced naturally (60×10^6 tonnes sulphur per year globally); but unfortunately man contributes a far greater amount by the combustion of fossil fuels (50×10^6 tonnes SO_2 and 30×10^6 tonnes NOx annually from the United States and Western Europe). In fact, over 90% of SO_2 emissions in Europe are from man - made sources (ECSC, 1983). It is worth emphasising however, that the relative proportions of man - made and natural sulphur in the atmosphere are dependant on the location being investigated (Innes, 1987). The major portion of the emitted SO_2 derives from coal combustion, petroleum refining, petroleum combustion and smelting operations (Chadwick, 1983). The two main oxides of nitrogen, NO and NO_2 (collectively known as NOx) are derived from coal combustion and transport sources; the latter contributing about 45% of total NOx concentrations in the USA.

Krause et al. (1985) considered both of these gases with respect to forst decline by crudely analysing their recent emission chronology. Comparisons of the data for both gases show a decrease in the levels of emitted SO_2 since 1970 and an increase in the levels of emitted NOx during the same period. The emission chronology for the UK, shown in Fig. , is mirrored in West Germany where emitted NOx has increased by 50% between 1966 and 1970. Ambient concentrations of SO_2 in the Black Forest and in those parts of Switzerland which exhibit widespread decline symptoms, range between 15 and 40 ug / m^3. With reference to the International Union of Forest Research Organisations (IUFRO) standards, such ambient levels are well below the recommended minimum for damage to occur. The instances when the minimum levels are exceeded last only for a matter of several hours and are associated with strong wind speed and directionality. In general Krause et al. (1985) concluded that,

> "there is neither the necessary spatial nor temporal correlation between affected areas and SO_2 concentrations..........sulphur dioxide can be eliminated as an overall cause of forest decline."

Since the gases themselves can be discounted as a primary cause of decline attention has focused on acid deposition. Ulrich (1980) first noted that in central Germany rainfall had exhibited acidic pH values of around 4.1 since the mid - sixties. Therefore, large scale pollution had existed in this area for 15 years. The effects of such wet and dry deposition will depend on the chemical conditions of the soil; for example, a soil containing calcium carbonate uniformly distributed through the fine soil fraction will tend to render the acid input ecologically harmless. This process is known as the buffer capacity and is measured in terms of the number of milliequivalents of hydrogen or hydroxyl ions that must be added to raise or lower the pH of one kilogram of soil by 1 pH unit (Innes, 1987). Unfortunately, most soils have an inadequate buffer capacity, and therefore, even forests growing on limestone soils may suffer from the effects of acid deposition. Consequently, disruption of the decay chain (bacteria are damaged) and the damage to vegetation (short roots are damaged) occurs. Disturbance in the decay chain leads to a greater contribution from fungi in the mineralization process and thus the humus and nitrogen reserves stored in the root system are depleted. This process triggers a slow and gradual increase in acididty that persists for several decades, depending on how rich in humus the soil is.

An increase in acidity will also cause the loss of any mobile basic cations (positive ions) such as magnesium (Mg^{2+}) and calcium (Ca^{2+}) present in the soil. Leaching of such ions can result in a change in the soil's acidity, leading in turn to permanent changes in the soil which could be harmful through effects such as the mobilization of toxic elements (e.g. aluminium (Al^{3+})). According to Ulrich (1980), the presence of aluminium in the soil solution triggers a drastic decline from 2,500 to a few hundred kg / ha in the fine root biomass. If the soil is not able to buffer the increased acidity swiftly enough, the long root system will begin to decline. Further mobilization of the aluminium that is contained in the bark of all roots leading to the loss of larger roots. Continuation of this process over a number of years causes a reduction in the buffer capacity of the aerial parts of a tree, which as a consequence reduces its resistance to direct damage by air pollutants.

2.2.4.6 The ozone hypothesis

Naturally occuring ozone (O_3) is present at high concentrations in the stratosphere (about 25km above the earths surface), where it is the product of UV - light induced dissocation of molecular oxygen. Such stratospheric ozone can be induced into the troposphere by turbulence, thereby creating natural background ozone concentrations in the area of 45 pbb at temperate latitudes and 25 pbb in the tropics. However, during short time periods, extremely intensive vertical exchange may lead to concentrations of up to 100 pbb, as observed during the dry summer of 1976 in the UK (Fuhrer, 1985).

Formation of ozone at or near the ground surface is influenced by UV - light which controls the photochemical reactions between NOx and hydrocarbons; both of which are products of man made processes (Krause et al., 1985). It has been established that ozone is unique amongst atmospheric pollutants in that it can occur in high concentrations in remote areas away from population centres (Ashmore, 1985). Thus the effects of ozone provide a plausible theory for forest decline in many areas of Europe, where the forest stock is not directly under the influence of high pollution concentrations. One such area is the Black Forest of West Germany which experiences SO_2 levels considered to be too low to damage trees (Innes, 1987, Lefohn & Mohnen, 1986, Cape et al., 1988). However, it is important to differentiate between mean annual values and peak values, since specific air pollutant exposure patterns that affect vegetation are usually associated with short - term, high concentration levels (Lefohn & Mohnen, 1986). In the Black Forest, the flecking (microscopic yellow patches) noted on Norway spruce is regarded as a typical sign of ozone damage (Innes, 1987), although this symptom was questioned by Fink (1987) who saw it as a sign of local frost damage combined with intensive insolation during the winter. In addition Fink (1987) demanded a more comprehensive description of this symptom since flecks may be caused by biotic pests and pathogens such as mites or fungi. Jacobson & Clyde - Hill (1970), however, had previously outlined the factors that should be considered when attempting to determine if ozone is the cause of injury. These are knowledge of the concentration in the atmosphere, the concentration required to injure the more sensitive species and the species that are most susceptible to damage. Jacobson & Clyde - Hill also identified the major symptoms of ozone damage which are primarily restricted to the upper leaf surface. The symptoms range from the flecking described by Innes (1987) to upper - surface or either surface bleaching (small unpigmented necrotic spots or an overall spread) and chlorosis of the upper - leaf surface.

Pilgrim & Arndt (1987) favoured ozone as the agent responsible for damage to indicator species (hybrid poplar) at selected sites in the Black Forest. The authors noted that the most severe injuries occured on western slopes exposed to prevailing winds above 800m elevation; a distribution which Krause et al. (1985) identified as a major argument for ozone, since throughout Europe and the USA the worst damage has been observed at higher elevations. In fact Krause et al. (1985) were unequivocal in their belief in the ozone hypothesis :

"Distribution and formation of O_3 in the atmosphere also correlates well with spatial and temporal development of forest decline, so that it is reasonable to assume that O_3 is the major contributing factor of all air pollutants involved."

This view has been disputed by Manion (1985) who saw Krause's observation, that gaseous air pollutants affect the windward side of trees, as a misinterpretation. He stated that the symptoms of ozone air pollution in trees are affected by the trees ability to take up the gas and this in turn is affected by sunlight. Therefore, the edge of the stand and the upper crowns of the stand interior are equally sensitive to ozone damage. As a final rejection of the ozone hypothesis Manion (1985) concluded that if chlorotic flecking and tip burn symptoms occur only along the windward side of a stand or only to large trees, even though small trees occur in full sunlight, it is highly probable that ozone is not the primary cause of decline.

Ashmore et al. (1985) and Prinz (1985) voiced a widely held view that forest decline could not be attributed to one single cause but was the result of complex interactions between more than one pollutant and other environmental stresses. One combination considered to be particularly important, in view of their common characteristic of spreading into forested areas remote from the sources of their precursers, was that of ozone and acid precipitation. Such a mixture of damaging agents has been shown to reduce the frost hardiness of conifers and it is known that Norway spruce seedlings are less sensitive to individual gases than to combinations of gases (Innes, 1987). This is consistent with the observations made of decline when it coincides with severe winter weather and dry summers. Prinz (1985) emphasised the importance of such climatic extremes since he was convinced that application of the ozone theory (or any other air pollution theory) did not solve the problem of the speed at which the decline occured. Prinz therefore recognised that climatic episodes must be regarded, at the very least, as a triggering or synchronising factor. In addition to monitoring the effect of different combinations of pollutants Lefohn & Mohnen (1986) recommended characterizing the timing of multi - pollutant exposures at any monitoring site. With reference to ozone these authors recommended relating episodic ozone exposure data to the timing of SO_2 and NOx and other pollutant exposures.

For the relative importance of ozone to be resolved, Ashmore (1985) recommended a direct experimental approach. At that time, as is the case now, the status of knowledge can be summed up in the statement,

"Ozone could conceivably be the prime cause of the forest decline, it could be one important component of a combination of stresses, or it could be merely a secondary factor influencing trees already weakened by some other primary stress." (Ashmore, 1985)

2.3 Multiple stress hypothesis

Since each of the aforementioned air pollution hypotheses has their own "master," the objectivity of the arguments put forward has tended to be lost in the political wrangling surrounding forest decline. Krause et al. (1985) summarised the problem in scientific terms as one of finding a set of globally applicable rules that define forest decline,

".....it is absolutely necessary to overcome this substantial deficit in establishing generally acceptable criteria attributable to novel forest decline. This lack is probably the reason for the changing emphasis of possible causes in discussions, from acid rain, to sulphur dioxide, photooxidants, and nitrogen input, apart from natural factors."

Perhaps a more realistic approach to the problem is the idea of a multiple stress syndrome. In other words, no single mechanism is seen as responsible for the decline, rather the decline is the result of the cumulative effects of a number of stresses (Innes, 1987). Again, however, Krause et al. (1985) warned of an "undefined broth of possible causes" and emphasised the importance of a definition of the observed phenomena. The idea of multiple stress, however, is a structured argument, based upon the fact that some factors predispose a tree to damage, whilst others incite or contribute to the damage. Predisposing stresses are those that operate over long time scales, such as climatic change and changes in soil properties. They place the tree under permanent stress and may weaken it's ability to resist other forms of stresses. Inciting stresses are those such as drought, frost and short term pollution episodes, that operate over short time scales. An example of such a multiple stress scenario was provided by Rhefuess (1987) who studied Norway spruce decline in the Bavarian and Black forests of West Germany (See Section 2.2.1)

To conclude, it does seem that a combination of stresses, particularly of pollution and climatic input, may well be the primary cause of forest decline (Innes, 1987, Rehfuess, 1987, McLaughlin, 1985, Prinz, 1985, Ashmore et al., 1985, Smith, 1985). On the other hand Krause et al. (1985) preferred to remain pessimistic regarding the establishment of a cause - effect relationship :

"it is indeed very questionable if this will ever be possible in the strict sense and hence the only concept of proof is that of highest probability."

Krause et al. (1985) did provide a hypothetical forest decline scenario which provided an apparently realistic diagnosis of the problem. Firstly; they stated that forest decline was caused by an imbalance of the source - sink relationship (nutrient status) between the crown and the root system of the tree. The imbalance was expressed in the appearance of yellow needles and leaves as generally associated with this phenomenon. This observation was supported by Cape et al. (1988) who noted that nutrient content alone was a good indicator of the degree of decline. In conjunction with this process, within the soil, leaching due to acidic deposition enhanced by an interaction with photooxidants could lead to nutrient depletion within the fine root system. Consequently the uptake of nutrients would is disturbed which leads to steadily decreased vitality. This process may be triggered by climatic extremes; for example the dry summers of 1976, 1980, 1982 and 1983, which corresponded with an increase in the levels of forest decline. In addition, the weakened trees may be attacked by contributing stresses such as insect pests and root fungi. However, perhaps the most important consideration when considering such a scenario is the recognition of regional and temporal variations in species, climate and pollution levels.

2.4 Conclusions

The above sections emphasise the difficulty faced by any remote sensing system in determining the presence of forest decline. The primary visible symptom of decline, namely yellowing and subsequent loss of older needles / leaves can be monitored quite satisfactorily with large - scale CIR photography. There is no dispute that this symptom is universal to all trees affected by the decline syndrome. What this chapter has shown is the difficulty faced by all workers in this field when attempting to identify a primary causal factor for forest decline.

The chief area of disagreement involves the relative contribution from air pollution and climatic extremes to the problem. These two phenomena either acting alone or in conjunction seem to be the primary damaging agents. However, the problem is one of the chicken and the egg - with doubt over the type of chicken and size of egg thrown in for good measure. Does atmospheric pollution weaken a tree and leave it exposed to climatic extremes, or do climatic phenomena affect the distribution and hence the impact of pollution episodes ? Unfortunately, both scenarios appear to be true, therefore, one must look at the problem from in more detail, for the relative importance of these elements will vary with the physical characteristics of the forest area.

A national forest inventory using remote sensing cannot attempt, therefore, to explain the presence of decline, however, it does remain an ideal monitoring tool. The various approaches adopted by some European forest agencies (discussed in Chapter 5) all fulfill the monitoring role to some effect. Unfortunately, inherent in the large - scale inventory approach is the lack of detailed assessment. The CIR imagery used for this purpose though offers the chance to intensively study smaller areas in order to take some account of the variation in "pollution climate" (see Chapter 8) and hence to define a possible decline scenario for the area in question.

Chapter 3 : Forest decline - A British perspective

3.1 History of pollution control

"Environmental awareness and concern have grown rapidly in the 1980's, but in order to appreciate and understand some of the pressures that have arisen within Europe, and particularly those focussed on Britain, it is neccessary to describe some of the historical attitudes generating those feelings." (Brackley, 1987)

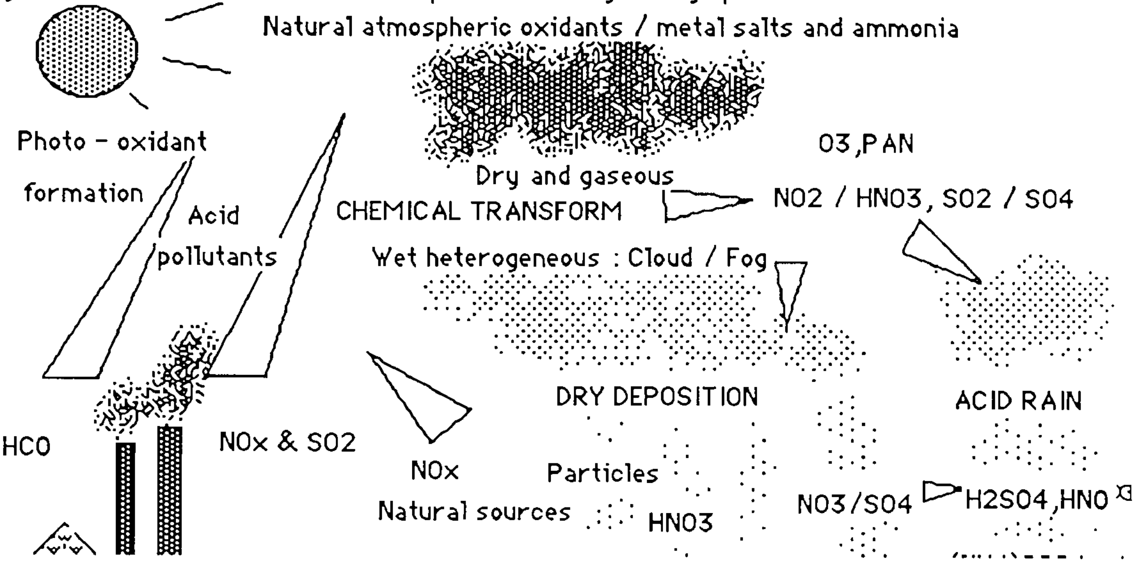
The environment in the UK has traditionally been accepted without any appreciation of the mechanisms involved and its importance to everyday life. Hence, the deep seated concern and understanding of environmental heritage prevalent in countries such as Sweden and West Germany does not form part of the British psyche. A cursory look at the response to the problems of air pollution and its associated environmental impact is required to illustrate this difference in priorities. The positive action taken by Sweden, for example, to combat the effects of air pollution are based on a desire for preventative action now. This is exemplified by the formation of the "30 % club", outlined in Section 3.2, which was created as a result of political pressure from the Scandinavian nations. In fact Scandinavian scientists at the time (1983 - 1985) were the only voice calling for a greater than 60 % reduction in emissions. This figure has since been justified by the work undertaken both in North America and Europe on 'critical loads', which are defined as the levels of pollutant required to harm particular ecosystems. In 1986 the Nordic council convened a United Nations sponsored meeting which has defined a myriad of such critical loads for all conditions (WWF, 1987), thereby creating a framework on which legislation can be structured. The record of successive British governments on the other hand has according to Patterson (1989) been characterised by,

"posturing, bombast, self - congratulation, self - exculpation, monitory finger - waving, obfuscation, demands for more research while cutting funds..."

Unfortunately these features along with the inertia shown by the contemporary British Government in response to calls for tighter controls on transboundary pollution (section 3.2) does not reflect the long tradition of political action that Britain has displayed in the domestic field. In fact it is worth noting that the first written report on air pollution was produced by the London pamphleteer John Evelyn in 1661, entitled 'Fumifugium or the Aer and Smoake of London Dissipated' (Elsom, 1987). Unfortunately these initial appeals were ignored and it was not until the early part of the 19th Century that legislation was initiated, culminating in the Alkali Act of 1863. As a result, 95% of offensive emissions were required to be arrested whilst the remainder had to be diluted before emission. Notably, a second Alkali Act followed in 1874 and this required industrialists to apply the 'best practicable means' to reduce pollution emissions. This concept exists to this day and comprises the cornerstone of government policy when required to apply emission controls. A policy that has subsequently been discredited by the European Community (EC), who prefer to take an air quality management approach to pollution control. Many members of the EC have serious doubts as to the validity of a system based on voluntery compliance.

Recent developments in Britain's air pollution control strategy have been influenced to a large extent by the occurrence of the infamous London 'pea - souper' on the 5 - 8th December 1952 (Ashby, 1975). The 4,700 deaths attributed to this smog provided the major impetus for the 1956 Clean Air Act. The scope of the original legislation was widened by a revised act of 1968 which required domestic smoke control strategies to be implemented by local government. Industrial emissions also came under the auspices of these acts and again local authorities were required to apply the best practicable means of emission reduction. Additionally the act stipulated minimum chimney heights in an attempt to control ground level sulphur dioxide (SO_2) levels. This attempt to improve the immediate environment led to the tall - stack policy, whereby minimum chimney heights were imposed in order to dispense emissions. Unfortunately the legislation has unwittingly led to the present controversy over the impact of long - range transboundary air - pollution. Fig. 3.1 simplistically reflects the mechanism of movement of emissions from such tall stacks with their potential for affecting areas away from the source.

Fig. 3.1 Mechanism of emission & deposition of long - range pollution



In Britain itself, the Clean Air Acts contributed to a rapid decline in urban smoke levels. Unfortunately, Sulphur dioxide (SO_2) emissions fell by little more than 30% between 1960 and 1984 due to inadequate controls on power station, refinery and industrial output which provide the major portion of the total. The need for Britain to reduce high SO_2 levels in cities such as London and Sheffield, as well to respond to a European Commission (EC) directive, led to the 1974 Control of Pollution Act. This act stipulated limitations on the sulphur content of fuel oil as well as providing local authorities with the powers to investigate emission rates. Unfortunately, the sections that directly dealt with the control of pollution have not been properly implemented (Patterson, 1989).

Whilst attempts were being made to contain national SO_2 levels, the emissions of hydrocarbons and carbon monoxide continued to increase throughout the 1970's. The most important sources of these gases are motor vehicles and leakages from gas pipelines, the latter accounting for two - thirds of hydrocarbon emissions in 1983 (Elsom, 1987). In 1984 motor vehicles accounted for 86% of carbon monoxide emissions and 42% of Nitrogen oxide (NOx) emissions (DTI, 1985). Unlike carbon monoxide (CO) emissions which have consistently increased since the mid - 1970's, NOx output declined from 1, 690 thousand tonnes in 1974 to 1, 634 thousand tonnes in 1982. The sources of NOx have changed during the last 15 years since vehicle emissions of nitrogen oxides have taken up the mantle as the major NOx source whilst power station emissions peaked in 1979 and have subsequently declined.

Fig. 3.2 refers to the output of the important 'primary' pollutants which are emitted directly into the lower atmosphere. An increasing problem in the UK and elsewhere in Europe is increased levels of SO_2 and NOx by - products which are known as secondary pollutants. Ozone (O_3), formed by the interaction of NOx and hydrocarbons in the atmosphere (Innes, 1987) is a good example of a secondary pollutant. Further consideration of the processes involved was given in Chapter 2, but suffice it to say here that the ozone experienced at ground level can be differentiated from the stratospheric ozone, which is currently under intense study (Bell, 1987). In the UK, recent high O_3 concentration periods have occurred during the dry summers of 1975 and 1976 (Elsom, 1987). For example, between 22nd June and 12th July 1976 surface ozone concentrations in the London area exceeded 200ppb (urban level) and 250ppb (rural level) for the first time (Ball, 1987). London is by far the biggest producer of primary pollutants, it therefore contributes the greater part of ozone formation in southern England. However, conditions favourable for ozone formation in the UK, namely anticyclones and / or weak pressure gradients are often experienced simultaneously over the continent. As a result; within a day or so of the commencement of an episode, oxidants generated over the continent will be advected into south - east England to combine with those produced locally. This situation therefore indicates that the UK, although geographically isolated from the continent cannot solve its pollution problems in isolation and :

"Co - operation with other European governments is essential if a transfrontier pollution problem, such as photochemical pollution, is to be tackled effectively." (Elsom, 1987)

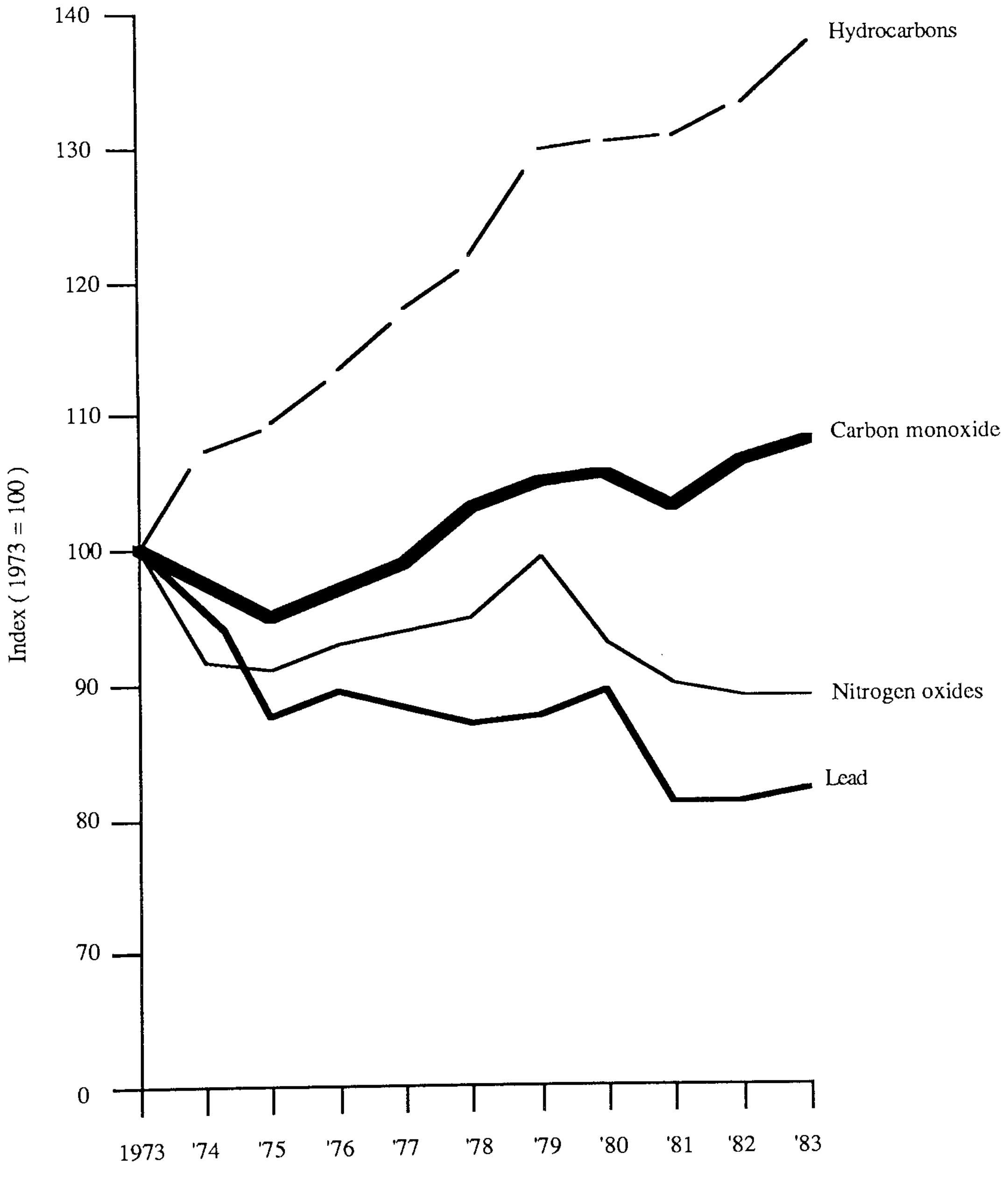


Fig. 2.2 Estimated emissions of hydrocarbons, carbon monoxide, oxides of nitrogen and lead in the UK, 1973 - 83

(After Elsom, 1987)

3.2 Present policies and attitudes in relation to pollution control

As outlined in section 3.1; emissions of SO_2 have been decreasing in the UK since the mid - 1960's. Consequently, this trend has been used as an excuse for the government's failure to ratify the SO_2 protocol to the 1979 Convention on Long - range Transboundary Air Pollution (LTAP). This is despite the fact that the government has ratified (on the 12th Aug. 1985) the protocol to the 1979 Convention on LTAP on long - term financing of the Co - operative Programme Monitoring and Evaluation of the Long - range Transmission of Air Pollutants in Europe (EMEP). The SO_2 protocol, known as the '30% club', allows for a 30% reduction (at 1985 levels) of SO_2 emissions or their transboundary fluxes by 1993 (Aniansson, 1987). The UK authorities cite the continuing fall in emissions as one reason for not complying with the agreement; a second reason is a desire to establish a link between emissions, deposition and environmental damage (Brackley, 1987).

The acidity of rainwater was measured annually at 40 rural sites in the UK between 1978 and 1980 (Warren Spring, 1984). Average annual acidity of rainwater was found to be unacceptably high, with pH values between 4.7 and 4.1. A spatial trend was evident, with acidity increasing from west to east across the country, whilst in northern Britain acidity increased from north - west to south - east. Concern has been voiced over the potential threat of such acidic loadings (see Section 3.4.2) to aquatic and terrestrial ecosystems. The House of Commons Environment Committee concerned itself with the whole problem of "acid rain" (House of Commons, 1984) and made a number of recommendations, which included the UK's joining of the '30% club' and an extension of the research effort by bodies such as the CEGB and the Forestry Commission. Several water authorities have extensive monitoring programmes and have undertaken experiments to unravel the effects of various agricultural and forestry practices upon the quality of water runoff (see for example Eminton, 1986 and Garrett, 1986).

Despite the mounting evidence indicating increased acidification of freshwater bodies the government has been slow to respond with legislation. The acidification problem may not be in dispute, what is causing disagreement between environmentalists and the relevant government agencies is the relative impact of acidification on the environment. The Department of the Environment noted that the government's overall policy is to only take action on the best scientific evidence, the best technical and economic analysis and the best possible assessment of priorities (Brackley, 1987).

However, as pointed out by the House of Commons Select Committee this policy completely ignores the 'insurance' element involved. This element has been described by the House of Commons Select Committee (House of Commons, 1984) who asserted that acidification as a result of man's activities, including intensive land use and afforestation, posed a serious threat which had to be tackled to prevent the possibility of permanent damage. Like lead in petrol, it had become,

> "a matter of public political will, something will have to be done......there is sufficient evidence on which action should be taken." (House of Commons, 1984)

These remarks were made in 1984 and the subsequent so called 'greening' of the Thatcher Government has prompted the recent drop in levies on unleaded petrol (a move that had been previously resisted by Governments of all parties). Britain however, has unfortunately lost its lead in emission control technology. For example, in 1981 the UK exported £8 of air pollution control technology for every £1 it imported, however, by 1985 this figure had declined to £1 of exports to £1 of imports (Elkington, 1989). This lack of interest in emission control technologies and its unwillingness to encourage investment in such measures is perhaps explained by the present governments denial of their cost effectiveness. The prevailing attitude towards acidification is reflected in a voiced desire to learn more about the technical basis and veracity of proposed changes before taking remedial measures.

By comparison with British policy, West Germany policy decisions have been based upon convenient, but untested hypotheses (see Chapter 2). The ascendant Green movement and publicity surrounding forest decline made it inevitable that successive German goverments (both before and after the 1988 federal elections) were involved and legislated for stricter control of emissions. Britain on the other hand views these policy decisions with scepticism, preferring to wait for more scientific evidence of the link between environmnetal damage and pollution. Unfortunately the British government has not fully appreciated the severity of the political imperatives arising in other countries, which have to be transmitted externally out of political necessity. On the other hand, neither Sweden nor West Germany has appreciated that damage has to be observed and experienced before a country will react politically and commit public money to correct an unfamiliar threat. West Germany certainly had to experience a dramatic political / environmental trauma before taking action and certainly does not recognise the difficulty the UK might have in implementing remedial measures without the same internal crisis.

To summarise, the present relationship between Britain and its European neighbours, with reference to the effects of airborne pollutants on the environment, is based upon mutual mistrust and misunderstanding. At the heart of this dispute is the fact that SO_2 emission reductions would be very expensive to instigate, since it would require retrofitting of flue - gas desulphurisation (FGD) units to existing coal fired power stations. Britain argues that since no clear cause - effect realtionship has been established either between emissions and acidification problems, at home or abroad, it should wait for more scientific evidence. Unfortunately, this stance ignores the moral issue at stake, which cannot be assessed solely in economic terms - no country has the right to pollute another's environment, let alone its own environment. There is no doubt that forest decline and water acidification are major problems on the continent, however, debate continues as to its importance in the UK. The presence of acid waters has been established, but the blame has been laid partly at the door of afforestation, since it seems that in acid polluted areas trees facilitate the passage of pollution - derived acidity into streams (Miller, 1984). This phenomenon must in turn affect the government's avowed policy of increasing the forest stock.

3.3 UK Forest Policy

3.3.1 Planting Strategy

A milestone in British forestry was achieved in 1984 when the total area of productive forest land reached 2 million ha (Forestry Commission, 1984), thereby bringing the total forest area up to 10% of the land surface. However, Britain remains a major importer of wood, producing only 10% of its own requirements from domestic sources. It is therefore, government policy to continue planting at a rate of approximately 30, 000 ha per annum (Foot, 1985).

Present forest policy was formulated in the post war years when expansion into uncultivated upland areas (used mainly for sheep farming) was instigated. As a result, since 1945, some 891, 000 ha have been planted in these upland areas which occupy approximately one - third of the country. Within these regions, afforestation has taken place in the upper 'middle' ground leaving the exposed mountain tops bare. In common with most man - made forests worldwide, the silvicultural system is one of even aged uniform plantations with periodic clearfelling and replanting. Much of the post - war planting has been of Sitka spruce, which reaches economic maturity in 40 to 60 years. Other widely used commercial species are Lodgepole pine, Douglas fir, larches, Norway spruce and Scots pine, the latter being the only native commercial coniferous species.

Although primed for commercial timber production the Forestry Commission has extended its remit into environmental management for nature conservation. For example, the Commission is under obligation to administer a total of 350 Sites of Special Scientific Interest (SSSI) covering 70, 000 ha. Consideration is also given to the plantation of broadleaved trees which are generally problematic from an economic and silvicultural point of view due to their slow growth and establishment difficulties in extreme surroundings. It has been suggested that judicious planting of broadleaves (5 - 10% of the area) would enhance the conservation and amenity value of coniferous landscapes (Foot, 1985).

Although the Forestry Commission attempts to regulate its own planting strategy, in reality there are no planning controls on afforestation in areas not considered ecologically valuable. All new planting is channelled through the Forestry Grant Scheme, whether the work is done by the Commission or privately. However, it is a condition of this scheme that timber production should be the prime objective. It is this combination of incentive and motive that brings the Commission's commitment to conservation into question and has brought it into conflict with environmental groups. Foot (1985) maintained that new proposals were scrutinised to ensure the characteristics of the traditional landscape. However, reports by Smith (1987) and Lean & Rosie (1988) point to the £100 per acre grant provided by the Forestry Commission for landowners willing to afforest; as just one of the incentives leading to widespread afforestation for purely commercial reasons.

Already one sixth of the Flow country, a unique blanket bog area in Sutherland and Caithness, northern Scotland has been planted, more than 90% by private investement encouraged by tax incentives. The Royal Society for the Protection of Birds (RSPB) estimated that £12 million pounds of public money has been given in grants and tax relief to fewer than 100 investors in Flow country forestry, whilst the predicted return on all this investment is only 1.3% (Smith, 1987). The Forestry Commission points to the jobs that such developments create as an offset to the environmental impact. However, the truth of the matter is a decline in the numbers employed due to increased mechanisation. For example, between 1971 and 1985 the total number of forestry jobs in the Scottish Borders declined, whilst the forested area increased (Lean & Rosie, 1988).

Looking to the future, the Forestry Commission are intent on increased plantation and in 1985 Foot stated that :

> "Countryside policy is a changing scene but there appears to be ample opportunity for sustaining the expansion of the forest resource at an even level well into the next century."

However, as Lean and Rosie (1988) pointed out,

> "Britain is perhaps the only country in the world where environmentalists campaign against the planting of trees."

Until a sound environmental management plan is applied to UK forestry, perhaps through licensing agreements, increased local interest and more species diversity, forestry will remain the environmental contradiction it is today. If forestry remains a political "ball game" it will be all too easy for the government to avoid facing up to the threat of pollution, assessing the impact and taking the neccessary remedial measures.

3.3.2 Forest survey techniques

Regular surveys of the Forestry Commissions tree stock are useful as a management tool and update the locational information on land use and growth potential that are utilised in budget plans, production forecasts, valuations and work programmes (Thallon & Horne, 1984). The requirement for detailed survey extends to soil and site type information, used to provide guidance on choice of species, growth potential, the need for site treatment, crop stability and harvesting method. The regular major resurveys (see Section 3.3.2.1 & 3.3.2.2) result in provision of new stock and specialist maps and the replacement of the basic forest management data, which are now held on a computer database.

3.3.2.1 Census survey

The Census of Woodlands is carried out on a 15 year cycle in order to provide information on woodlands and trees for strategic planning purposes. The latest census, 1980, was conducted in two phases, 'woodland' and 'hedgerow.' The woodland census provided an estimate of total woody growth greater than 0.25 ha in extent and minimum 20m width. Information was also obtained on woodland types, species, age, size class and volume. The hedgerow survey assessed 'non - woodland' trees in order to estimate total number of isolated and hedgerow trees and the occurrence of clumps and linear features.

The 1980 census used the Ordnance Survey 'green plate' (the woodland cover overlay for 1 : 50, 000 maps), digitised to provide a sampling frame based upon grid squares. Digitising of soil group boundaries and administrative areas provided overlays to stratify census results. Aerial photography was used to confirm external and species type boundaries in the woodland samples and to give tree counts for isolated trees and areas of tree clumps in the non - woodland samples. Ground samples provided detail of species, timber volume and health whilst providing control for aerial estimates.

3.3.2.2 Forest Survey

In Britain, the Ordnance Survey provides map co - ordinate control for forest surveys of detailed stock and other special information. The Forestry Commission use the 1 : 10, 000 map as a base for all stock maps. Much of the country's forest stock is composed of plantations of relatively small stand area - a minimum stand area of 0.5 ha is recognised for mapping and management purposes. A maximum error of 10m is permitted for boundary error.

The commission uses B & W aerial photograhy as the main source of survey information. Ideal photo - scales are 1 : 10, 000 for ground work, equating to the standard commission mapping scale, whilst 1 : 20, 000 photography is employed for machine plotting to maximise the photo - coverage. External and internal crop and feature boundaries are plotted from the photography and transferred to 1 : 10, 000 scale Ordnance Survey base maps. Boundary detail information is subsequently confirmed by field survey which also supplies data on other crops and site characteristics unobtainable from the photography. On completion of the survey, crop and site data are listed for input to a forest database and the final maps are drawn up.

3.3.2.3 Soil and Site Survey

Stereo aerial photography is used to interpret possible soil type boundaries, using vegetation and land form differences as indicators, prior to field work. The photo units are checked on the ground and are subdivided or amended as necessary. Existing older photography may be used as soils do not change radically with time. Other site factor data are also collected. Exposure, when combined with mean wind speed zone, provides an index of potential windthrow hazard; data related to lithology and terrain classification provide useful information on production extraction problems and thus on likely machinery requirements.

3.3.3 Development of Remote Sensing Techniques

In 1984 Horne & Thallon concluded that aerial photography would continue to satisfy most of the Commission's survey needs for the forseeable future. Development work is concentrated on extending the use to other forest applications such as landscaping, programme planning, windblow assessment, change monitoring and importantly, disease detection. However, problems exist with cloud cover , particularly in Scotland, where photo - acquisition can be impossible. The high cost of photography, particularly for scattered areas, is another consideration as is the staff input needed for conventional interpretation.

For these reasons, the Forestry Commission have been investigating satellite and airborne Synthetic Aperture Radar (SAR) data for mapping purposes. The inherent resolution and processing problems associated with these systems led the Commission to conclude that their main needs for detailed survey from such sensors may only be met in the future. Larger scale changes in woodland area as well as windthrow could be monitored using digital satellite or airborne data. However, for many of these systems, the terrain implications of our predominantly upland forestry would present problems unless digital terrain models were linked into full forest digital information systems (Dury, 1989).

Horne & Thallon (1984) recommended a multisampling and multitemporal system which combines conventional photograhpy with space - or airborne digital data; the whole being linked to digital mapping and related data bases for fast analysis and output.

3.4 Forest Condition Surveys

3.4.1 Forest Health Surveys (1984 - 1987)

Forest decline on the continent prompted the Forestry Commission to undertake a national survey of forest health. In Britain, the principle aims of the survey are to establish the presence of any deterioration in crown condition and to relate any damage found to specific causes as far as is possible. The first of these surveys was undertaken in 1984 when 141 plots of Sitka spruce, Norway spruce and Scots pine were assessed. In the 1984 and 1985 surveys an upper age limit of 45 years was imposed, as trees are commonly harvested within 50 - 60 years of planting in Britain (Innes, 1987). In 1986 the survey was extended to include Norway spruce up to 110 years old. This was done as German findings indicated that the older trees had been affected first. In 1987 the remit of the survey was extended to include :

(i) two major broadleaf species - beech and oak;
(ii) older Scots pine and Sitka spruce (up to 100 years old);
(iii) better survey coverage across the country.

In addition, to comply with EEC regulations, an inventory based upon a 16 x 16 km grid survey was established. This inventory extends across all member states of the EEC thereby allowing meaningful comparisons of national data (Innes & Boswell, 1987).

3.4.2 Survey procedures for 1987 forest health surveys

The country was divided into 12 regions based upon climate and pollution characteristics. For conifers (Norway spruce, Sitka spruce and Scots pine) a minimum of five different aged plots of each species was sought in each region. For broadleaves, three different age plots of beech and oak were established in each region. Criteria retained from the 1984 survey included those that required that the stand should not consist of forest edge trees, nor should it have had an edge exposed during the previous 5 years or had edge trees removed for road widening at any time. In addition, no windthrow must have occurred in the stand.

The restrictions on potential sites and the requirement that each of the 24 trees be visible from the ground meant that the sample network was incomplete. For example, Sitka spruce is relatively rare in the east of Britain as it is normally planted in areas with more than 1000mm annual rainfall. With the addition of new sites since 1984, the 1987 survey incorporated 264 plots.

The following is a list of the assessment procedures for conifer species :

(1) Needle discolouration was assessed on a 4 - point scale with 0 - 10, 11- 25, 26 - 60 and > 60 % classes. The distinction between the healthy and the 1 - 10

% classes was dropped. However, yellowing and browning were still distinguished.

(2) Overall defoliation of the tree was scored. The scale described above was used in order to provide a better comparison with continental data.

(3) Top - dying was dropped as an index of health as it was rare in plots. If it occurred, it was classified under defoliation type.

(4) Shoot death in the live crown was scored as absent, rare (1 - 10 shoots) or common (> 10 shoots).

(5) The degree of flowering on Scots pine was recorded, using a 4 - point scale : absent, light, medium and heavy.

As part of the Forestry Commission Beech Health Study 1985, Lonsdale (1986) derived measures for the assessment of broadleaved species. Incorporation of broadleaves into the national survey required some modification of conifer assesment techniques. Crown density was scored in 10 % classes as with conifers and the same disclouration classes were used for browning and yellowing. For beech, premature leaf loss was recorded by assessing the frequency of green leaves on the ground. In addition, the degree of leaf rolling was assessed since this effect has been attributed to air pollution. The assessment of epicormic shoots was applied to oak tree branches in order to quantify their impact on the overall crown density.

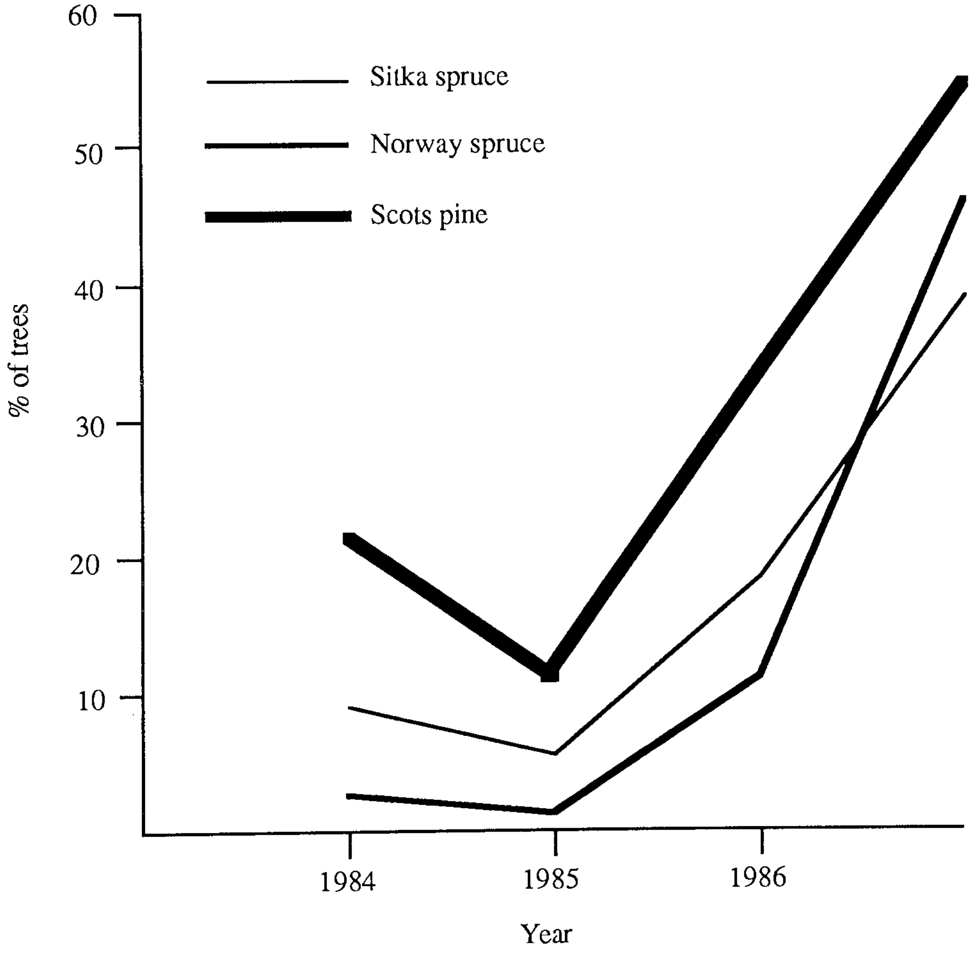
The EEC survey, which was instigated in 1987 was based upon a 16 x 16 km sampling grid. As a result, 71 sample points were established in Britain wherever grid intersections coincided with woodland of 0.5 ha or more, regardless of species, age or ownership. The methods of assessment applied to the EEC survey were almost identical to the main survey procedures. Each tree was scored according to the two tier German system (see Chapter 5) and any easily identifiable causes of damage were noted.

3.4.3 Results

The 1987 survey indicated that both crown thinning and the yellowing of needles are present in the UK at levels similar to those existing in West Germany. According to the results there had been a significant reduction in crown densities of Sitka spruce, Norway spruce and Scots pine since the previous year. Crown density (needle loss) is estimated by comparing the density of a crown in 10 % increments, with that of a perfect tree. Fig. 3.3 shows the results for three species from 1984 to 1987. Innes (1987) queried whether this increase in low crown density values could be explained by a recent deterioration in condition or whether the observers were better at recognising reduced crown density. This is an important consideration since Innes (Pers. Comm. 1986) stated that the observer training procedures for 1984 - 1986 had been inadequate, therefore comparisons with the previous years results must be viewed with caution.

Foresters involved in the 1987 survey benefited from training in Switzerland and West Germany, therefore a more meaningful comparison can be made between the main and grid surveys. The comparison can be achieved graphically (Fig. 3.4) and it is readily apparent that the crown densities of the trees examined in the grid survey are better than those in the main survey. On the other hand, discolouration is much greater in the grid survey examples. The 1987 survey went a step further and attempted to infer a spatial or temporal pattern in the data (Innes & Boswell, 1988). A comparison with the previous years data was deemed impracticable for the reasons outlined above.

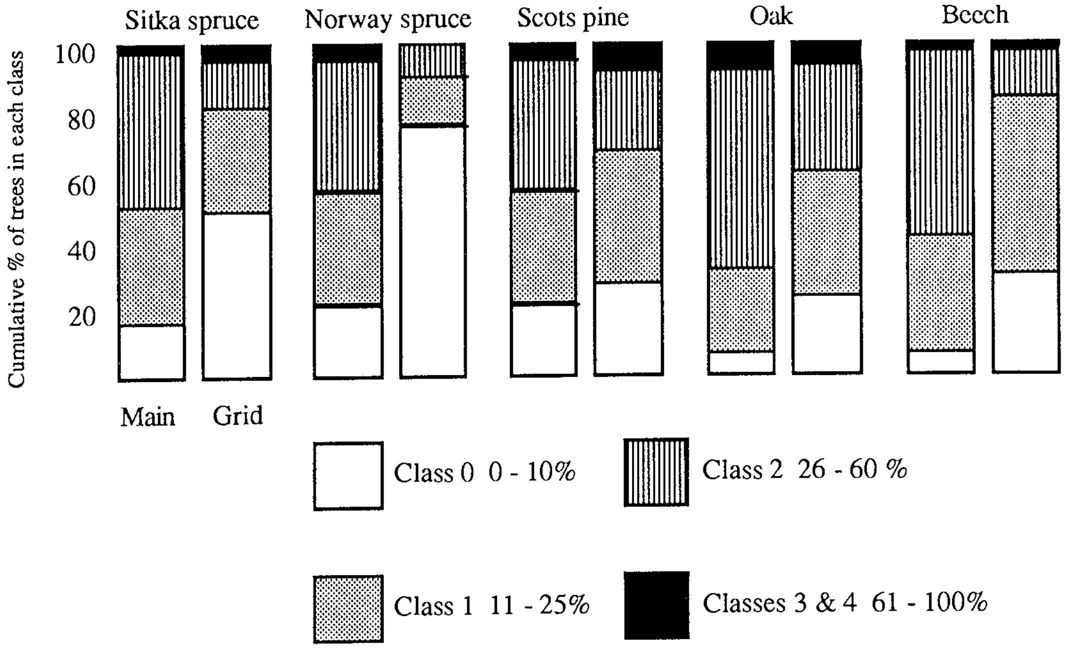
Fig. 2.3 Percentage of trees with more than 25% reduction in crown density



After Innes & Boswell (1987)

Additionally, Innes (1988) cautioned against temporal comparisons since crown density can vary annually and can exhibit a persistant lag effect in conifers. Consequently, the emphasis was placed on spatial trends and an attempt was made to use any pattern in the distribution of crown density and crown discoloration to identify an association between pollution levles and one or more variables from topographic indices. As might be expected from such a wide - ranging project, the results proved inconclusive. A combination of regression and principal component techniques were applied to the data, however, these were unsatisfactory due to the inter - correlations between the variables. Admittedly, some associations were identified, although the authors noted that any interpretations of these results must be subjective. The survey successfully identified a range of insect and fungal attack which caused a deterioration in crown condition. The climatic and pollution variables used tended to be of a long - term nature (chronic effects) and therefore their influence was more difficult to assess. It was certainly clear that Scots pine, oak and beech showed decreasing crown density towards the north and west of Britain. Although this is consistent with existing knowledge, the analysis could not differentiate between the relative influence of rainfall or temperature. The crown density distribution of Norway spruce and Sitka spruce seemed to be influenced by tree age and topographic features.

Fig. 2.4 Comparison of distribution of crown thinning revealed by main (FC) survey and the grid (EEC) survey



After Innes & Boswell (1987)

Although several correlations between crown condition and pollution levels were identified, a number of explanatory scenarios were put forward : (1) high levels of pollution occur in areas suitable for tree growth, therefore any pollution effects might be rendered insignificant by the climatic factors, (2) deposition of sulphate, nitrate and ammonia is having a fertilising effect on the trees. It was not possible to establish a relationship with ozone, which was in part due to the paucity of long term data; although ambient and peak levels are amongst the highest in the EC (ECSC, EEC, EAEC, 1983). In short, the commission concluded that interpretation of any relationships was difficult due to multicollinearity. Any observed patterns were attributed to climatic factors and although some correlations between pollution and crown density were found, they were of a positive nature, i.e. the presence of airborne pollutants seemed to stimulate growth. However, according to Innes & Boswell (1988) note was made of an apparent association between low crown densities and background ozone concentrations, although there was no experimental evidence to support this.

3.5 Independant Surveys

A number of independant surveys of tree health have been undertaken, the majority on individual test sites. Notable exceptions include ones undertaken by the Nature Conservancy Council (NCC) (Fry & Cooke, 1984) and Friends of the Earth (Rose & Neville, 1985). The Nature Conservancy Report identified areas in the UK where excessive pollution levels are known to affect trees. Perhaps the most intensively studied area is the Pennines where Farrer et al. (1977) studied the sensitivity of Scots pine to SO_2 pollution. A low occurrence of Scots pine in a corridor extending north and east from Liverpool and Manchester was positively correlated with SO_2 emmissions. The effects of acid deposition have also been assessed in this area and Lines (1984) observed that the range of commercial forest species that can be grown successfully on the Pennines is much smaller than on comparable sites elsewhere. In Scotland also, the effects of acid deposition on Scots pine suggest that there will be a resultant reduction in dry matter of around 5% in rural areas (Fry & Cooke, 1984). Whilst acknowledging the contribution of upland afforestation to groundwater acidification the NCC concluded that ,

> "For nature conservation interests, the only long - term remedy to the uncontrollable changes initiated by acidification is a reduction in emmissions of sulphur and nitrogen compounds" (Fry & Cooke, 1984).

The Friends of the Earth survey of tree dieback (Rose & Neville, 1985) was extremely critical of the Forestry Commission's seeming complacency over the potential for decline in the UK. The survey involved assessment of Yew and Beech trees, since both are native species over most of their ecological range in Britain. To save time and money the survey was not rigorous and took the form of random samples analysed by volunteers following illustrated guidelines. In all, beech were surveyed at 372 sites and yew at 472. Four dieback categories were defined, from healthy to complete dieback, depending on discolouration, defoliation and abnormal growth.

Overall results indicated the presence of moderate or advanced damage in every county surveyed, although beech appeared to be more severely damaged in north Wales and central / southern England. In the main it was found that the degree of damage was greatest on exposed sites and in rural areas. As a result the authors were forced to conclude that,

> "Damage is most probably due to a combination of pollution episodes and long term stresses, and symptoms of dieback are probably precipitated by natural stresses such as droughts or frosts" (Rose & Neville, 1985).

3.6 <u>Does Forest Decline Exist in Britain ?</u>

In the UK we have been faced with the question of forest decline for some years. Undoubtedly the Forestry Commission 1987 Health Survey (Innes & Boswell, 1988) identified levels of defoliation and discolouration of similar orders of magnitude to those existing in West Germany; this would seem a clearcut case for affirming decline. However, in the UK the political and scientific emphasis is different from that on the continent and the survey results have been interpreted as such. The Forestry Commission refuses to acknowledge that the symptoms observed on British trees are anything new (Binns, 1985; Lonsdale, 1985 & Innes, 1988) and can be explained by natural causes. If this is the case then the argument for forest decline in the UK comparable to that on the continent loses credibility - the West German decline has been christened 'Neuartige Waldschaden' or 'new kind of forest damage'.

The Forestry Commission have consistently argued that the conditions do not exist in the UK for decline to occur. Binns (1985) cited the marked differences in the environment experienced by forests in a maritime climate, such as in Britain, and the continental climate of Central Europe. In fact this point was also raised by Friends of the Earth in their evidence to the House of Commons Environment Committee

(HMSO, 1984). The main differences between maritime and continental climates are indicated in Table 3.1 In addition to climatic differences Binns (1985) and Lonsdale (1986) emphasised the importance of natural damaging agents,

> "...the symptoms of poor health in trees must always take account of the 'background' of damage that is brought about in any population by pests, diseases and natural abiotic factors" (Lonsdale, 1986).

Binns (1985) expanded this argument by detailing some of the common symptoms and their likely causes (Table 3.2). The Commission conclude that any interpretation of forest condition should allow for such forms of damage whilst acknowledging that this is difficult due to ignorance of the interactions between these factors and other inputs such as pollution.

This returns us to the political attitude towards the decline problem adopted by the government (Section 3.2). A protagonist of government policy is the Central Electricity Generating Board (CEGB) - an organisation charged with two major duties under the Electricity Acts. These are to generate electricity as economically as possible, while having due regard for the effect of its actions on the environment (Skeffington, 1986). In its evidence to the House of Commons Environment Committee the CEGB voiced the general feeling that more scientific evidence of a cause and effect was required before remedial action would be plausible (House of Commons, 1984).To this end the board has initiated an extensive research programme involving pollution monitoring around emmission sources as well as continuous exposure tests on plant species simulating field conditions (Roberts, 1981 & Chester, 1987).

The overriding conclusion from this work has further confirmed the CEGB view that undoubtedly pollution can affect plants. However, in the UK context such problems have tended to be localised and there is still insufficient evidence for decline on a regional or national level. This mirrors the attitude adopted by the Forestry Commission until it was forced to undertake a national health survey which, as section 3.4.3 illustrated, has shown possible links between ozone formation and low crown densities (Innes & Boswell, 1988). Undoubtedly, a similar situation existed in Scandinavia until the autumn of 1983 when signs of damage, similar to central European decline, were noted (Binns, 1985). As Friends of the Earth pointed out (House of Commons, 1984), unless one looks for the damage its presence cannot be established. It would seem that the UK has reached the stage where the mechanism for damage assessment is in place, however, reliable figures from one year can only establish general crown condition. As Binns (1985) pointed out, "What will be more important is how the stands that are being surveyed develop over the years to come....."

Feature	Maritime	Continental
Winters	Cloudy and mild, large temp. fluctuations. Grass grows for 60% of the winter.	Sunny & cold. Temperatures stable. No grass growth in winter.
Summers	Normally mild, often rainy, with anti - cyclonic spells.	Hot and dry.
Rainfall	High, well distributed; higher in winter in west. Droughts unusual,	Moderate, mainly summer; thunder - storms important. Droughts common.
Wind	High; pollutants rapidly mixed & moved laterally by depressions.	Moderate; pollutants persistant; powerful vertical mixing on hot days.
Wind damage	Endemic and catastrophic, both frequent.	Endemiclesscommon, catastrophic rare.
Frost - winter	Intensity and frequency irregular; soil freezing rare in forests.	Regular; soils occasionally frozen in forests.
Frost - unseasonable.	Common.	Less common.
Snow.	1 % - 5 % of rainfall. Large transient falls of wet snow. Ablation common.	Usual, up to 25 % of precipitation. Small frequent falls of dry snow. Ablation common.
Incoming radiation.	Winter - very low. Summer - variable : low in cloud, very high on clear days (unstable air).	Winter - high. Summer - moderate to high (dust particles).
Occult precipitation.	Moderate at high altitudes.	Important; as hoar frost in winter.
Effects of apect.	Moderate	Very marked.
Humidity.	Moderate to high. Frequent dew.	Low. Dew less important and local.

Table 3.1 Main characteristics of British (Maritime) and Central European (Continental) climates

Table 3.2 Some types of tree and forest damage (excluding pollutants) encountered in Britain

Symptoms	Common Causes
Leaf or needle discolouration	Fungal diseases.
	Sap - sucking insects and mites.
	Chewing and mining insects.
	Late frosts.
	Droughts.
	Winter cold (evergreen conifers).
	Widely fluctuating winter temperatures (evergreen conifers).
	Sea spray.
	Fungal root and bark diseases.
	Destruction of bark by mammals or insects.
	Nutrient deficiency.
	Herbicides (young plants)
Premature defoliation	Fungal leaf diseases.
	Sap - sucking insects.
	Chewing and mining insects.
	Bark - feeding insects.
	Drought.
	Wind (evergreen conifers).
Shoot and stem death	Fungal bark diseases.
	Bark - eating insects and mammals.
	Drought.
	Late and early frosts.
	Winter cold.
	Transplanting shock (young plants).
Tree death	Fungal root and stem diseases.
	Root and bark eating insects.
	Mammals.
	Leaf - chewing insects.
	Lightning.
	Herbicides (young plants).
	Transplanting shock (young plants).

Since the Commission's figures from 1984 to 1986 are not reliable, the 1987 results must neccessarily provide the baseline from which to compare figures from subsequent years. If one was to presume a deteriorating situation the next hurdle to be faced in the UK would be an explanation for such a decline in tree crown condition. The evidence from the continent, admittedly circumstantial, points to an air pollution input to forest decline (Krause et al., 1985; Cowling & Schutt, 1985). As a result of Britain's acceptance of the '30 % club', the CEGB has agreed to retrofit £1200 million worth of desulpherisation equipment without government aid (Anon., 1988). However, these plans to reduce emissions could be in doubt since the new private generating companies will have more pronounced commercial goals. Unfortunately, the reduction of emmissions is just one answer to the problem if a decline in the condition of plant and marine ecosystems is to be avoided. In the long - run, there must be implementation of environmental management plans in conjunction with a more conservation orientated energy policy.

Chapter 4 : Vegetation Damage Assessment by Remote Sensing

4.1 Definitions

Before concerning ourselves with a description of vegetation damage assessment techniques it seems logical to define the phenomena under review. The simple term vegetation damage hides many possible causes and manifestations, however, Murtha (1976) rationalised the problem :

> " a collective term to indicate both dead and dying vegetation which has been noted because of a deviation from the normal pattern (both morphologic and physiologic) displayed by the vegetation."

This idea of deviation from the norm was refined for the study of a stand of Douglas Fir (Pseudotsuga mesziesii) in British Columbia (Murtha and McLean, 1981). In cases of chronic injury (low levels of damage acting over long periods, usually several years), the decline in health is slow and the tree may linger in a sub-healthy state for some years. These trees are the slow - growers that the forest manager needs to remove since they are weak and prone to further damage. On the aerial photograph these trees should be defined as abnormal, leaving the remaining trees to be defined as normal. The effectiveness of aerial photography in identifying such non-normal tree crowns will be discussed in a Section 4.3. However, it does raise the point, which is the essence of damage assessment, that each case must be taken on its own merits and survey methodologies, imagery types and interpretation techniques must be refined for that particular application. What this example does highlight is that damage, as manifested on aerianl photography, is not absolute but is a deviation or residual which should be related to the healthy tree population. A more precise definition of damage was given by Murtha (1976) which he described as :

> " any type and intensity of an effect on one or more plants, or parts thereof, produced by an external agent, that temporarily or permanently reduces the financial or aesthetic value, or impairs or removes the biological capacity for growth and reproduction, or both."

This definition leads to two terms that also need defining. The "external agent" or stress according to Levitt (1972) and Murtha (1978) is defined as any environmental factor capable of inducing a potentially injurious strain on a plant. It follows that "the strain" is any physical or chemical change in a plant produced by stress. Levitt (1972) describes such strains as " elastic " (reversible) or " plastic " (irreversible). Most forms of environmental stress cause irreversible strain; however, some stresses cause " elastic " strains which are only visible for short period of time and from which the plants may recover (Table 4.1 summarises the terminology). A good example of elastic strain is provided by Nelson (1983) who described the "temporal window" during which it was possible to quantify Gypsy moth defoliation using LANDSAT MSS data. The moth larvae emerge in late April or May and begin to feed immediately. Therefore by late June it is possible to identify leaf loss on the MSS imagery. However, as the summer progresses the canopies may refoliate thereby masking the defoliation effects - thus the optimum period for detecting Gypsy moth defoliation occurs in late June or early July.

Term	Category	Definition
Stress	Cause	Any environmental factor capable of producing a potentially injurious strain in living organisms.
Strain	Effect	Any biochemical or physical change caused by stress.
Elastic strain	Effect	Strains immediately reversed upon release of stress.
Plastic strain	Effect	Strains that persist in the organism after stress has been relieved.
Damage	Effect	Any type and intensity of strain, on one or more trees, produced by a stress that temporarily or permanently reduces the financial value, or impairs or removes the biological ability of growth and reproduction, or both.
Nonvisual strain	Effect	Strains not evident visually that can be detected by remote sensing systems.

After Puritch (1981), Levitt (1972) & Murtha (1972)

Table 4.1 Terminology of stress, strain and damage

The above definitions have all been of a general nature and can not be tailored for individual case studies. Previously, Murtha (1972) had brought together these general damage syndromes in a comprehensive reference guide to photo - interpretation of forest damage, based on his experiences in Canada. The aim was to identify all possible damage syndromes and their manifestations on aerial photography in order to allow the forester / photo-interpreter to define more accurately the damage syndrome encountered. Firstly, damage to forest trees was divided into two major categories; namely morphological and physiological. Morphological damage is defined as an alteration in shape or outline whilst physiological damage involves a change in function manifested as a slight deviation from the normal spectral response. Both phenomena influence each other and either may induce a change in the other (Dochinger and Jensen, 1975). Their appearence oń aerial photography is simply defined, since morphological damage appears as a change in shape, whilst physiological damage leads to a change in colour. The two types are not mutually exclusive, therefore assessments of the amount of damage will usually involve a combination of both. This is certainly true of the damage classification system used in the West German federal inventories of forest decline (Hildebrant & Kadro, 1984).

By restricting damage definition to two categories photo interpreters are still handicapped in their attempt to assess the symptoms observed. Therefore, in order to narrow down the damage prognosis, morphological and physiological changes can be subdivided into four main categories.

According to Murtha (1972), these are :

Damage Type I :	trees that are completely, or almost completely defoliated;
Damage Type II :	trees that show some defoliation through the presence of bare branches, or malformation;
Damage Type III :	trees that show the foliage as another colour which is not consistent with the normal foliage colour of the species involved;
Damage Type IV :	trees that show no visible sign of damage, but have a deviation from normal reflectance pattern in the non-visible light range.

Type I can be interpreted at photo scales up to 1 : 16, 000 although some ommission errors will occur. If this damage is occurring in groups or stands of trees, interpretation is possible on 1 : 160, 000 colour-infrared (CIR) photography. Type II damage requires good quality 1: 5, 000 to 1: 1, 200 photography (either colour or panchromatic since a change in crown form occurs). Type III damage requires colour photography for an accurate assessment, whilst Type IV damage requires CIR photography which picks up a change in near-infrared reflectance (see Chapter 7).

The final and most detailed phase of the damage assessment system is a dichotomous key built around the four possible damage types. The term "possible" is used wisely here, since it is still necessary to verify these observations by checking individuals or groups of trees on the ground; a process which, as Murtha (1976) states :

> " will be necessary until remote sensing interpretations have produced the necessary catalogue of a priori information to increase the confidence level of interpretation to the point where randomly selected verification checks are adequate. "

4.2 Physical and Physiological basis for Tree Damage

4.2.1 Normal Spectral Reflectance Pattern

As solar radiation comes into contact with the tree, it is primarily intercepted by the leaves or needles and it is the spectral reflectance of these structures that is mainly detected with the remote sensing systems. The interaction of radiation with the leaves is dependant upon many factors, including cuticular composition and structure, cellular organisation, intercellular air spaces, pigments, water content, emissivity characteristics and temperature (Puritch, 1981).

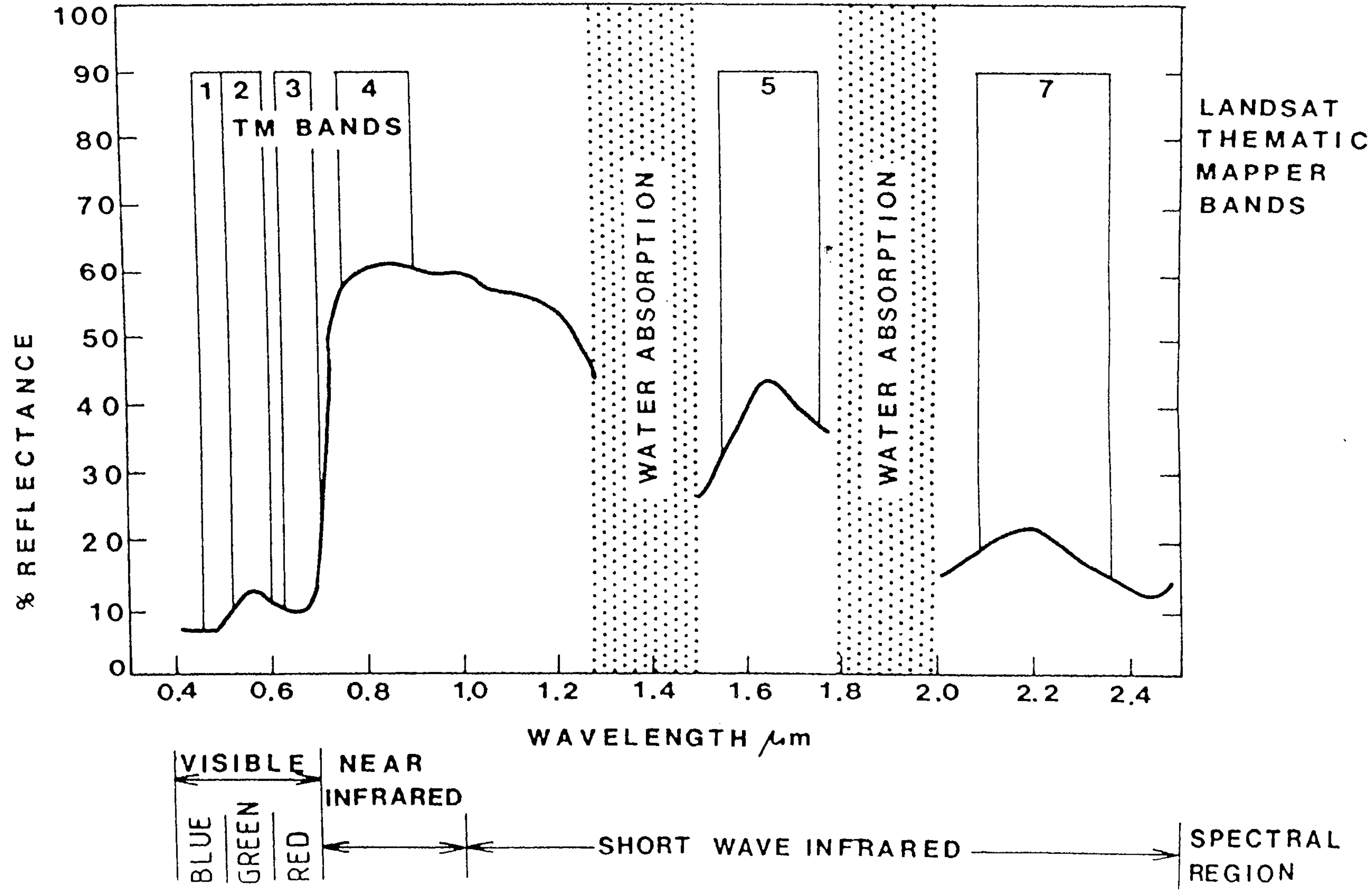
As radiation reaches the leaves, a small amount is immediately reflected by the cuticular wax, whilst the bulk is transmitted into the inner surface of the leaf. Within the epidermis the radiation is diffused and scattered, further scattering occurs within the spongy mesophyll cells when the radiation encounters intercellular air spaces (Knipling, 1970). Much of this radiation is reflected back through the leaf surface. The remaining radiation passes through the leaf where it is termed transmitted radiation. On its passage through the leaf, certain wavelengths of radiation are absorbed by internal constituents of the leaf, such as chloroplasts and cellular water. All the radiation contacting the leaf is thus reflected, transmitted or absorbed.

Fig.4.1 shows a generalised reflectance curve. It illustrates the low reflectance (approximately 10%) in the visible part of the spectrum. Within this region peak reflectance occurs at 0.55 µm (green) due to the presence of chlorophyll; this acounts for the green appearence of vegetation. At approximately 0.7 µm (near - infrared) the reflectance peaks and remains high (the infrared plateau) until 1.3 µm where it rapidly decreases, reaching a low point at 1.4 µm, which is one of the water absorbtion bands. Water also absorbs at 0.9, 1.1 and 1.9 µm (Puritch, 1981).

Spectral reflectance of healthy green vegetation

Adapted from Smith (1988)

Fig. 4.1 Generalised vegetation reflectance curve



4.2.2 Reflectance Pattern of Damaged Trees

Any destruction of leaf pigments or defoliation will lead to reduced absorbtion of incoming radiation and increased reflectance in the visible spectrum (0.5 - 0.75 μm). Such increases in visible reflectance with increasing tree damage have been observed for both single tree crowns and groups of crowns (Smith, 1988). Reflectance in the near infrared portion of the spectrum (0.75 - 1.35 μm) is due to multiple refractions along mesophyll cell wall - water - air interfaces in leaves (Knipling, 1970). Therefore, reflectance is largely dependant on leaf structure and the amount of healthy tissue present. A reduction in the amount of highly reflective, healthy foliage and increase in branch material and shadow will lead to reduced infrared reflectance. This phenomenon has been noted for both single crowns and groups of trees.

Within the near infrared portion of the spectrum there exists an area of sharp reflectance change (0.67 - 0.68 μm) between the high chlorophyll absorbtion and high near - infrared reflectance parts of the vegetation spectra. As chlorophyll content decreases, the position of the maximum slope of this so called red - edge shifts towards the visible part of the spectrum. Such a change is known as the 'blue shift' and characterises the progression of damage to forest canopies in the near infrared region. In the visible a corresponding shift in the peak (green) reflectance occurs towards the red spectral region (Murtha, 1983).

4.3 History and Development

The earliest recorded use of aerial photography for forest damage assessment was a successful Spruce budworm (Choristoseura fumiferana Clem.) impact survey in Northern Ontario (Craig, 1920). Such forest surveys were based on panchromatic photography, therefore only morphological changes such as fire, windstorms, or severe outbreaks of hardwood defoliators could be assessed. The development of colour film emulsions during the Second World War, however, prompted their use for insect defoliation studies. Wear and Bongberg (1951) investigated panchromatic, infrared, colour and colour-infrared (CIR) films at scales of 1: 2, 500, 1: 5, 000 and 1: 7,500 for use in forest insect surveys. This was one of the first such studies to investigate colour photography and to highlight its potential for this purpose. At that time feeling was unanimous over the superiority of colour over panchromatic film. However, this unanimity did not stretch to the choice of colour film type. Therefore, the stage was set for a long - running battle over the relative superiority of normal colour and CIR films.

Bowden (1933) reported that a near-infrared photograph could sucessfully depict diseased parts of a leaf before they were visible to the naked eye. Thus began the controversy that continues to this day; namely, can infrared sensitive films identify a change in the near-infrared reflectance of a plant leaf before any visible change occurs ? It is possible that in many instances a change in near-infrared reflectance might occur before and during a change in visible reflectance. Lillesand (1975) supported Bowden's claim and provided further evidence of the previsual detection capability of photographic film. Unfortunately, both this and the Bowden (1933) study were undertaken in the laboratory and according to Murtha (1981) there has been no repeatable aerial photographic evidence of such a capability. The only documented form of previsual detection from the field concerns thermal imaging of moisture stress in plant canopies (Fox, 1978). Little success has been achieved when attempting to measure this phenomenon over forest canopies (Weber, 1968).

Murtha (1976 & 1978) rationalised the problem by dividing the change into two categories. The first category is characterised by a change in near-infrared reflectance. This effect is consequently termed " extra visual " since it is implied that the near-infrared change may not necessarily be followed by a visual change. The second category involves a permanent change in near - infrared reflectance, therefore a true previsual change has occured. Puritch (1981) preferred the term 'nonvisual' to describe strains that can be detected by sensing systems that are not visually evident; since these reflectance changes would be useful as early indicators of strain in stressed plants.

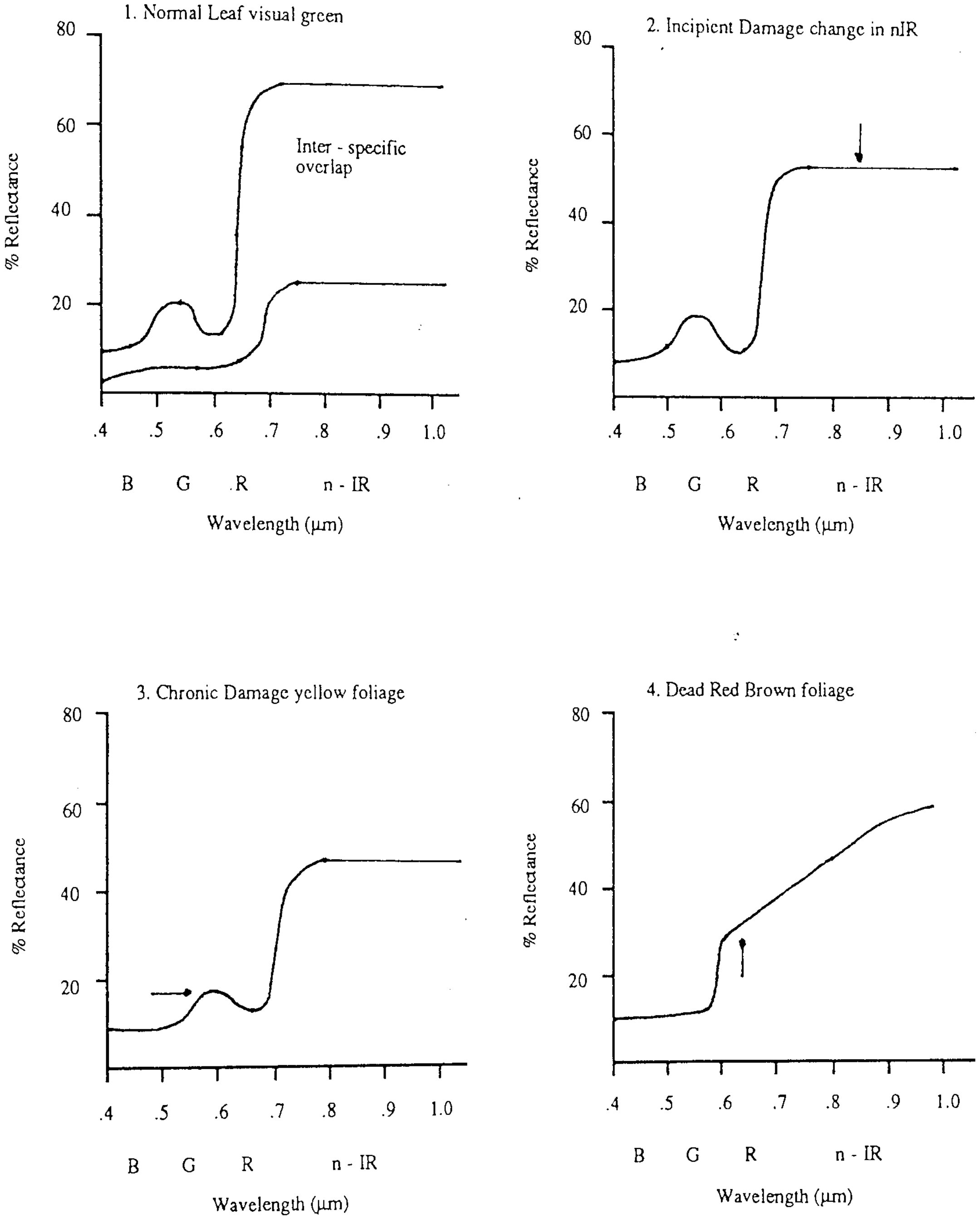


Fig. 4.2 Spectral Reflectance Patterns
Effects of Physiological Damage

(After Murtha, 1983)

The major drawback with this definition is the fact that in most cases the visual and the non-visual change overlap to such an extent that the differentiation is invariably impossible. This view is supported by Gausmann (1977) who reported that cellular constituents account for about 8% of the reflected near-infrared radiation whilst the cell wall to airspace interface accounted for 25-50% of reflection. Unfortunately the 8% near-infrared reflectance is associated with a previsual change whilst the 25-50%

reflectance is normally associated with a visual change. Chronic injury to a plant would affect the cellular constituants, therefore one would expect a change in near-infrared reflectance. Murtha (1983) stated that continuing chronic injury will cause deterioration of the chloroplasts and a green to red shift in visual reflectance (Fig. 4.2). The important consideration here is the speed at which the visual reflectance change occurs. Such a move from previsual to visual might not allow enough time for efficient remedial measures to be planned or executed.

Despite the claims and counter claims made for the use of infrared sensitive films for detecting damage (Hildbrandt & Kenneweg, 1970; Benson & Sims, 1967), there is no doubt that the superior haze penetrating ability and greater spectral separability (see Chapter 7) have allowed CIR film to become the mainstay of present vegetation damage assessment studies. Within this relatively broad field the greatest usage of this type of film has occurred in the study of forest pest damage .

4.4 Applications

4.4.1 Pest damage appraisal.

Johnson and Wright (1957) reported on one of the first successful uses of colour photography for assessing balsam woolly aphid damage. More recently normal colour photography at a variety of scales has been used to monitor *Fomes annosus* root rot damage to Incense cedars (Libocedrus decurrens) (Schultz, 1978), bark beetle damage to Ponderosa pine (Schultz, 1978), root rot damage to Jarrah (Bradshaw & Chandler, 1978), Pandora moth damage to Ponderosa pine (Pinus ponderosa) (Ciesla, 1983), Spruce budworm damage to balsam fir (Abies balsamea) and white spruce (Picea glauca) (McCarthy et al, 1982) and Douglas -fir beetle damage (Wert & Roettgering, 1968).

The use of normal colour films as the sole aerial photographic data source for pest damage assessment is unusual. The majority of studies of this type presently rely on CIR photography either solely or as part of a multispectral aquisition project. The two most widely documented uses of this film have been in the detection of Spruce budworm and Gypsy moth defoliation in the United States.

In recent years the Gypsy moth has wrought havoc in the hardwood forests of the northeastern United States; in 1981, for example, over 12 million acres were completely defoliated. Although recovery is usual, successive years of this type of infestation can lead to premature tree death. Since the problem occurs over such large areas the monitoring problem was first addressed using Landsat MSS data, which was successful in determining areas of heavy defoliation (Williams & Stauffer, 1978 , Nelson, 1983). Unfortunately it could not consistently identify moderately damaged areas. Ciesla (1984) had greater success using an optical bar panoramic camera for this purpose. The camera system scans a 70° swath on either side of the flight line allowing one film to cover distance of 37 nautical miles. The resulting high resolution imagery allows the moderate damage areas to be identified. This technique has now become a fully intergrated part of the US Forest Service survey of this damage type.

4.4.2 Urban Tree Stress

The dominant remote sensing approach in this field has involved the digitisation of CIR photography by means of a densitometer (the physical background to densitometry is discussed in Chapter 7). Of the studies conducted in this field the most successful and certainly the most comprehensive have been undertaken by Lillesand (Lillesand et al., 1979; Lillesand, 1980; and Lillesand et al., 1981.) The work involved quantification of stress on Maple trees in Syracuse, New York state using a densitometer to obtain an average raw density reading on each tree crown. This process consisted of measuring three spectral readings; one for each film dye layer. These readings were then related to ground observations and a series of stress indices developed which best predicted trees likely to suffer from Dutch Elm Disease. Lillesand and fellow workers recognised the importance of ground observation in the model building phase as well as a check on model accuracy. They concluded that multiple spectral observations were required and the effective combinations utilised in the estimation of stress levels would vary with every situation. The overriding message from their studies was recognition of the need for a multivariate definition of tree stress, whether this stress was measured on the ground and / or from the air.

4.4.3 Remote Sensing of Air Pollution damage

4.4.3.1 Application of aerial photography

The application of remote sensing to air pollution damage assessment has had limited but successful use when applied to point source pollution damage. However, with the growing concern over the effects of long - range pollutants, the usefulness of remote sensing for this purpose has become more apparent. In fact one of the most successful uses of colour and CIR film has been the detection of air pollution injury to forest trees. Wert (1969) and Heller (1969) studied the effects of ozone air pollution on ponderosa pine foliage in the San Bernadino and San Gabriel mountains near Los Angeles. The major symptoms observed, due to vehicle and industrial emissions, were chlorosis (yellowing), low density and shortness of needles and a high frequency of bare branches .

A feasibility study was undertaken by Wert (1969) to compare four films and five scales. It was concluded that Kodak Anscochrome D / 200 CIR film with a didymium rare - earth filter at a scale of 1 : 15, 584 was the best combination for classifying all vigor classes; whilst normal colour film at a scale of 1 : 7, 220 proved the most efficient for detecting advanced smog injury. Time of aquisition was an important factor and for California, December imagery provided the best correlation with ground observations and also good shadow penetration. Final results indicated that approximately 50% of all ponderosa pine trees were affected to some extent.

Zealer & Heller (1971) had similar success monitoring forest plots fumigated with SO_2. The best scale / film combination proved to be 1: 8, 000 Kodak Anscochrome D / 200 film with a didymium filter. Subsequently however, this film / filter combination has been displaced by Kodak Ektachrome 2443 film with a Wratten 12 (minus blue) filter. Murtha (1972) concerned himself with point source pollution as opposed to the blanket pollution previously examined in Los Angeles. In a study of the effect of SO_2 emitted from an iron - sintering plant in Wawa, Ontario, high altitude CIR photography at a scale of 1 : 160, 000 was used to monitor 350 sq. miles of forest. The fume damage area could be differentiated into total kill, heavy damage, medium damage and light damage zones. All zones were easily differentiated apart from the boundary between light damage and non - damage.

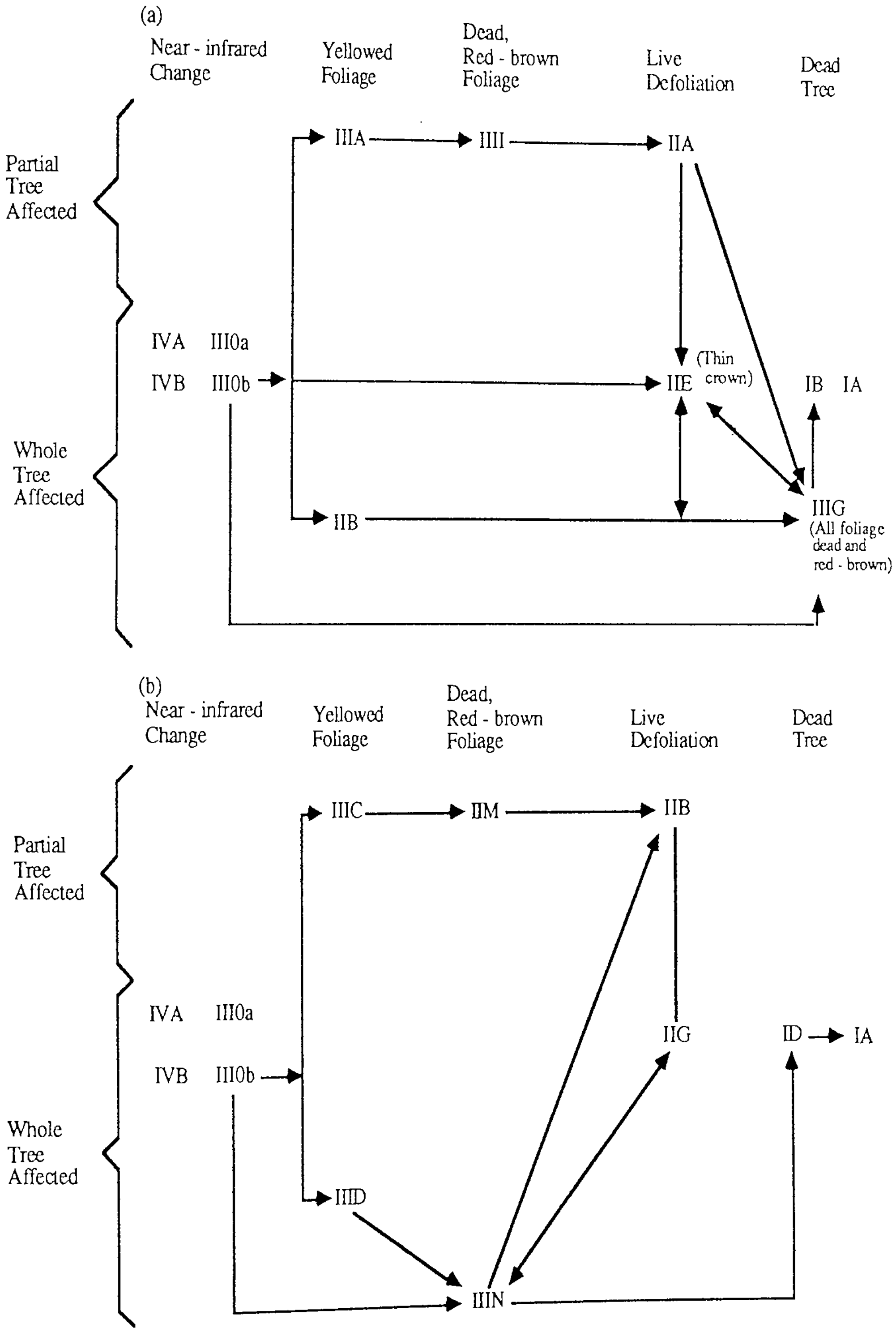
One major problem with this study was the lack of adequate field data. The stressed vegetation was readily identifiable; however a direct cause / effect relationship could not be established with SO_2. The damage occurred downwind of the plant and decreased with increasing distance, therefore windblown SO_2 was assumed to be the main damaging agent. Unfortunately, assumptions of this kind can be misleading Londsdale (Pers. Comm. 1986) indicated that :

" The main problem in the recognition of pollution damage in trees is that we know of no reliable way of distinguishing it from other kinds of damage."

To further isolate the problem; Murtha (1976) stated that :

" one particular agent can cause a wide variety of damage syndromes and conversely a given syndrome can be caused by any one of a large number of agents."

Murtha (1980) related this problem to a specific damaging agent when recognising that there are a number of SO_2 caused strain syndromes or damage types.



Sequence of damage types as (a) conifer and (b) hardwood progressively declines from the injurious effects of SO (After Murtha, 1972) Fig. 4.3

Using Canadian Forestry Service key to photo - interpretation of damage types (Murtha, 1972) he devised a method by which the photo - interpreter could describe the syndromes as they were perceived during photo - interpretation. Figs.4.3 (a) & (b) show the sequence of damage types that the photo - interpreter would expect to encounter with conifer and hardwood species.It is important to remember that when following these guide lines the percentage or number of trees displaying a particular damage type will vary with the intensity of the SO_2 fumigation, the distance from the source of SO_2 and the tree species present in the affected area. Although other forms of air pollution may cause similar patterns, it is possible to differentiate this damage from insect or disease attack or even poor site conditions. Most insect and disease syndromes are host specific whilst site effects can be evaluated with reference to the terrain. However, even with the modelled SO_2 strain indicators, firm guidelines must be established to describe what constitutes absolute proof of air pollution caused damage (Murtha, 1980).

A damage survey including such guidelines was documented by Carlson (1974). The aim was to assess the environmental impact of SO_2 emissions from a pulp and paper mill in Western Montana, USA. The original damage survey was field based and established the presence of severe stress symptoms (needle loss and necrocis, small dead branches) on Douglas fir.

To undertake a survey on the ground of the full extent and severity of the stress would have been costly in both time and money. However, the problem had been identified and the cause established, therefore a decision was made to use normal colour and CIR aerial photography to assess the patterns of damage.The patterns so identified confirmed field checks since the long axis of the damage zone lay in the direction of the prevailing wind and damage severity decreased with distance from the plant. These particular studies were established in order to monitor the damage sustained by the natural environment from industrial emissions. Evans (1981) took this a stage further and suggested using intentionally planted " indicator " vegetation as a method of detecting severity and distribution of air pollution in industrial areas. The approach involved setting up indicator plant stations located at points of high pollutant concentration around a pollution source. Use of 35 mm CIR film to locate potentially stressed plants was recommended, as this allowed field visits to be made to those sites indicating signs of stress. The proposed methodology was recommended for areas in which orchards, vineyards and other commercial crops may be found. Unfortunately, the expense of monitoring such relatively large areas on a regular basis can be prohibitive. A nominal scale of 1 : 8, 000 was recommended for the aerial survey component; such coverage providing the best offset between accuracy and cost. With the correct equipment the indicator species could be identified whilst allowing coverage of a 13.7 acre area with each exposure.

Up to this point consideration has been given to chronic pollution injury; namely injury caused by long exposure of foliage to relatively low concentrations of a gas. Acute injury is caused by high concentrations of a pollutant acting over relatively short time periods (Murtha, 1980). One such incident was assessed by Murtha & Trerise (1977) who described the derailment in 1974 of a train containing elemental sulphur in which the resulting fire released high concentrations of SO_2. Foliage discolouration occurred almost immediately on deciduous and coniferous tree species. Within two weeks of the accident CIR coverage at a scale of 1 : 12, 000 was obtained but unfortunately, none of this photography showed any tree mortality that could be attributed to SO_2 damage. In order to assess the amount and rate of recovery from the incident a series of 1 : 15, 840 colour and CIR photographs were taken of the old damage zones in 1975. Comparisons with the original photography indicated that approximately 25% of black cottonwood suffered top killing, some ponderosa pine had lost older foliage (physiological damage) and experienced a 50% decrease in diameter growth increment (as measured in the field) in the year following the SO_2 damage. It was predicted that during the five years from 1975 - 1980 that new tree growth would cover any residual symptoms of SO_2 damage.

Two important conclusions drawn from this study concern the imagery used. Firstly, the authors recommended the use of 1 : 10, 000 transparencies for the analysis and counting of defoliated branches. Secondly, although not addressing the technical problems encountered, the study involved temporal analysis in order to quantify the impact. Such a technique presents its own difficulties which have been dealt with, to a great extent, by Daels & Antrop (1978) who stated that :

> " A temporal analysis allows the study of the evolution of the environmental phenomena which is vital to understand hidden forces of causes. "

Three major pitfalls identified by Daels & Antrop when applying this technique were:

(i) ignorance of the influence exerted by terrain conditions upon the final image;
(ii) ignorance of the photographic and geometric aspects of the information transfer;
(iii) incautious comparisons between the interpretations of a different datum.

The point most often ignored by photo - interpreters is point number (ii) : neglect of the combined effect of the radial image displacement and the direction of the suns rays. The field of view on aerial photographs can be divided into high contrast and low contrast zones. In the high contrast zone the shadowed side of the tree canopy is seen as well as its complete shadow image. Whilst in the low contrast zone the illuminated side of the canopy is seen and this partially covers the background shadow. Therefore, similar trees growing under the same conditions will show a different colour according to their position on the aerial photograph. The authors made a number of recommendations based on their experiences with photo - interpretation of pollution damage. The recommendations, which were general and can be applied to other damage syndromes, were :

(i) the colour on CIR photographs of damaged trees should be considered always as relative differences towards the healthy trees (again the idea of the "standard normal tree" as recognised by Murtha & McClean (1981) is proposed as the bench mark for any damage interpretation)

(ii) the interpreter should not rely on colour tone, but use the tree's aspect as well as its situation in the environment;

(iii) the interpreter should always keep in mind the influence of radial displacement, topography, illumination conditions and background radiation;

(iv) stereo vision should always be used and the evaluation of a tree should be made from different viewing angles.

Attention in this section has been focused on manual interpretation techniques due to the large body of knowlege in existence. Hildebrandt (1981) rightly summerised the situation regarding damage assessment when he stated that :

" The best practical results of damage inventories or relevant specific studies until now, have been produced by stereoscopic evaluations of infrared colour aerial photos."

4.4.3.2 Application of airborne and spaceborne scanners

The present concern over forest decline has prompted greater experimentaton with the interpretation of digital data and these studies are dealt with in Chapter 7. For the purpose of " classical " pollution damage assessment, Murtha (1974) made the first attempt to use Landsat MSS data. A scene of the area adjacent to a smelter in Wawa, Ontario was visually interpreted in order to assess SO_2 damage severity. This approach proved unsatisfactory for the task since the boundaries between the three damage zones (light, medium and severe) were not clearly defined. Subsequently, Fritz & Pennypacker (1975) applied Landsat MSS to the problem of zinc oxide damage proximate to a zinc smelter in Pennsylvania. A cluster analysis algorithm was utilised to classify the scene into healthy forest, mild decline, medium decline, and severe decline. The major drawback encountered with the MSS imagery proved to be that of insufficient spatial resolution. The damage in this instance was restricted to small areas of susceptible species which were spectrally and spatially inseperable from healthy vegetation. Since Landsat MSS offers an effective ground resolution of 79 m the data were insufficient to identify the small damage zones. It is now ten years since Heller (1978) predicted that :

> "Colour and CIR aerial photography will continue to be main stays. Both very large and very small scales will be used.............. increasing standardisation and calibration of these films."

In recent years attention has been focused on the problem of " forest decline " in Western Europe and North America. This phenomenon can not be termed pollution damage in the classical sense and therefore it is felt by the author that it is necessary for specific consideration to be given to remote sensing studies of forest decline.

4.4.4 Remote Sensing of Forest Decline

The widespread decline in the health of both coniferous and deciduous species in Europe and the USA (Matzner et al, 1985 and Johnson & Siccama, 1984) has prompted a vast research effort into methods of monitoring the severity and distribution of the decline. Inventory methods have been formulated using CIR photography as the main source of information (Hildebrandt, 1983 and Ciesla, 1986). However, such a wide - scale problem has also prompted a more intense research effort into the applicability of airborne scanning devices and Landsat TM for this purpose (Kadro, 1985; Kadro 1986 & Goosem et al, 1984). The eventual aim of these techniques being to displace CIR photography as the standard inventory imagery.

Well established inventory procedures, employing CIR photography, are applied in the Federal Republic of Germany (FDR). Hildebrandt & Kadro (1984) described in great detail the inventory procedures for the state of Baden - Wurttemberg. The remaining states of FDR have their own aerial surveys which are described in the literature by Kuhl (1985), Trankner (1985) and Densdorf (1984). These approaches to the same problem will be discussed in Chapter 5. in this section attention will vbe focused on the experimental work undertaken using airborne scanner data to assess levels of decline. The main body of this work comes from West Germany and the United States.

In West Germany, Kadro (1984, 1985, 1986), Kadro & Kuntz (1986) and Koch et al. (1984) have applied a Bendix 11 channel multispectral scanner modified to simulate TM channels. Kadro (1986) outlined the problems associated with the data for this type of work. The area studied was the Black Forest which is a mountainous area, and therefore single trees, groups of trees or stands will experience differential solar illumination. It follows that viewing a tree crown from different angles results in different radiance values. Kadro (1985) had previously quantified the scale of the problems by recognising that the reflected radiance from a single tree depends on the density of the foliage and in the case of a damaged tree (loss of needles or leaves) the detected radiance may be reflected from the soil or ground vegetation through the tree crown.

Data from the Bendix scanner at a variety of altitudes consistently identified healthy and damaged spruce / fir crowns. In the visible region of the spectrum, severely damaged crowns have a higher reflectance. This is explained by the presence of greater amounts of chlorophyll in the healthy crowns. According to Gates (1970), chlorophyll absorbs blue and red radiation leading to lower reflection values in this region of the spectrum. The opposite occurs in the near - infrared portion of the spectrum where reflection depends on cellular structure; in this region healthy crowns have the highest reflectance.

Vogelmann & Rock (1986) and Rock et al. (1985) applied a more sophisticated technique to raw Bendix scanner data. These data were obtained of the Camels Hump area of Vermont, USA; an area which had been experiencing red spruce decline since the early 1960's (Johnson & Siccama, 1984). As encountered in West Germany, the reflectance differences between sick and healthy species were most notable in the 0.83 μm region of the near - infrared plateau. However, rather than rely on single measurements, ratios of one reflectance region to another were applied, thereby reducing the influence of shadow and canopy density. The ratios applied were 1.65 / 1.23 μm and 1.65 / 0.83 μm, and these gave high reflectance values for high damage sites and low values for low damage sites. This result was explained by the influence of moisture on spectral reflectance values in the 1.65 and 2.2 μm region. Since at 0.83 μm and 1.23 μm the mesophyll cell stucture is the dominant controlling factor it was hypothesised that moisture stress is responsible for the high ratio values at high damage sites.

This section has dealt with the use of digital data for decline assessment which could be considered the state of the art. However, the approaches described above are all experimental. Where remote sensing has been applied in an operational context, large - scale CIR photography has been utilised since this imagery offers the necessary spatial and spectral resolution required to analyse individual tree crowns. Perhaps then CIR photography is the true state of the art since it is being used for national inventories. Like all techniques however there is room for improvement and one such approach is the continued refinement of airborne scanner imagery and video. An alternative approach is to use the existing CIR imagery (since scanner imagery would be as expensive to acquire with no guarantee of result) and refine the analysis techniques in order to secure maximum information retreival.

4.5 Conclusions

The sections have attempted to highlight the strengths and weaknesses of various remote sensing tools for vegetation damage assessment, in order to justify the choice of imagery for a study of forest decline. In their review of the "Seminar on Remote Sensing and Forest Decline Attributed to Air Pollutants", Duinker & Nilsson (1987) concluded that commercially available satellite imagery needed further refinement before it could be considered a viable forest decline inventory tool. They also emphasised the importance of the multi - source approach to this problem including CIR aerial photography and field survey in addition to satellite imagery.

It can be seen that in the vegetation damage assessment role, the use of satellite imagery has been confined to assessment of vegetation communities due to the inherent resolution problems. This general rule applies to pollution damage and section 4.3.3 outlined the dearth of studies in this field which had made use of satellite imagery. As well as the problems associated with small scale digital imagery, in the vegetation assessment role competition is fierce from the ideal imagery for this work; namely CIR aerial photography.

Since outgrowing its military parentage one of the primary uses of CIR photography has been in the vegetation assessment role, with particular reference to the identification of damage. Even given its emulsion instability and cost, CIR photography remains superior to any other film emulsion or digital data source for this purpose. Certainly, when a decision was made in West Germany to instigate a remote sensing survey of forest decline, airborne scanner data were considered but eventually rejected in favour of CIR photograhy. To date, the debate continues in West Germany as to the primary data source and in the author's own experience there is a strong pro - satellite / airborne scanner lobby. However, on the other hand there are those who feel that the technical difficulties (including specific species and damage class identification problems) are of such critical importance to the success of a national inventory that much more research is required.

The ongoing research effort with digital imagery continues whilst CIR photography continues to be used in the inventory role. However, with the present moves towards Geographical Information Systems consideration is being given to the integration of a plethora of information sources. The inventory data derived from the photography is one source of data in a system to monitor any patterns of visible damage specific to forest decline. The symptoms of forest decline are well documented and CIR photography is ideal for assessing the visible signs, therefore within the framework of this study, large - scale CIR photography was selected as the primary data source.

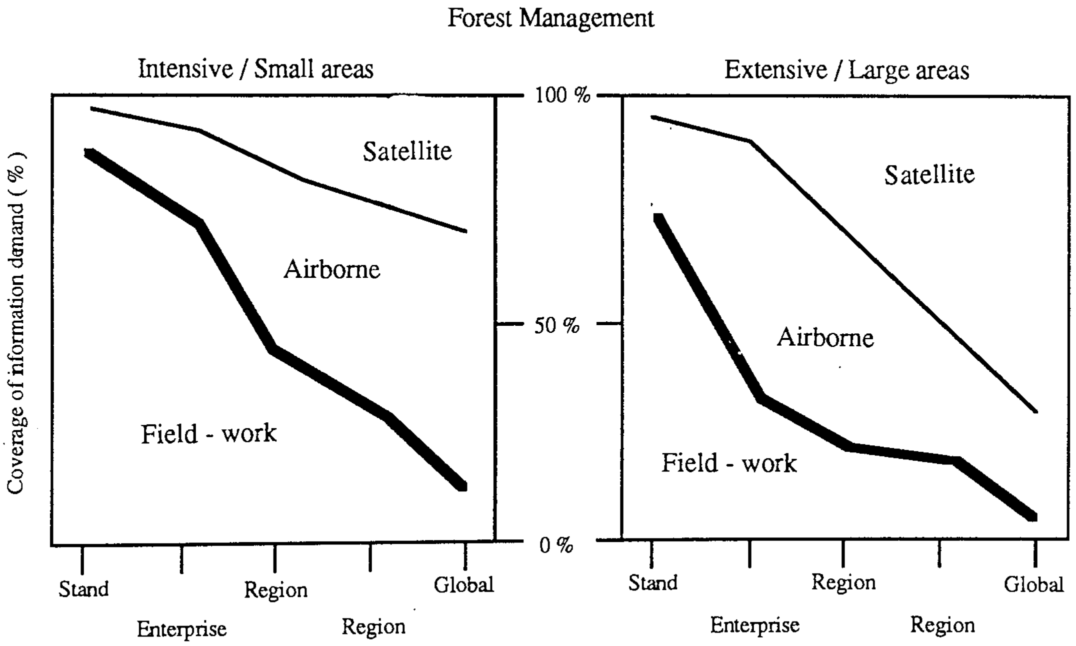
Having decided on a form of imagery suitable for the purposes of this study, it is worth considering the problem in more detail. By so doing it will be possible to assess the suitability of CIR photography in addition to the limitations of remote sensing within the field of forest decline monitoring.

Chapter 5 : Forest Decline Inventory - Potential approaches and the problems of traditional airphotointerpretation techniques in the Black Forest

5.1 Introduction

Olsen (1983) defined the term inventory, in a forestry context, as "the determination of value at some point in some utilisation cycle." In other words an inventory method attempts to reduce or eliminate uncertainty, thereby allowing more considered management decisions to be made. The idea of the so called utilisation cycle is perhaps the most important point to grasp. Taking the case of forest decline, if the cycle is changed from measurement of tree mortality to tree health, the whole inventory approach would change. For example, the primary objective of the West German forest inventory is the assessment of living tree condition. Data on tree mortality from a remote sensing source would be of little use since dead and dying trees are salvaged almost immediately (Ciesla & Hildebrandt, 1986). Therefore, the time between inventories would need to decrease in order to record the rate of mortality.

Fig. 5.1 Possible Coverage of Information Need



(After Hildebrandt, 1971)

The question arises; how can remote sensing be used for inventory purposes? Hildebrandt (1971) defined three main areas where remote sensing could be applied in forest areas :

(i) large area inventories serving the purpose of forest policy decisions;
(ii) inventory and mapping on a regional level for management planning;
(iii) forest and landscape protection.

When dealing with each of these catorgories the amount of information actually required will dictate the best possible measurement techniques. Fig. 5.1 illustrates possible scenarios for varying information requirement over small and large areas. When dealing with forest decline one is dealing with a phenomenon that needs to be studied intensively because of the within stand variation of damage symptoms. The lack of success with satellite data for mapping forest decline confirms this point (Kadro, 1986; Kadro & Kuntz, 1986). Hildebrandt (1983) proposed a permanent inventory and monitoring system for European forestry. The approach involved two different inventory techniques : a forest cover monitoring (FCM) program to be undertaken at 2-3 year intervals, and a permanent forest resource inventory (FRI) to be undertaken at 10 year intervals. Both surveys would use three basic sources of information :

(i) satellite images - covering the total inventory area;
(ii) CIR aerial photography at medium scale - covering sample strips;
(iii) field measurements on sample plots.

Satellite imagery (or high altitude aerial photography) would be incorporated into both surveys. Since the aim of the FCN is area estimation, satellite data would be the basic information source. The objective of the FRI is the reliable survey of timber volume, growth, health condition and to forecast sustained timber yield. This type of data can only be reliably obtained from a combination of aerial and field measurements.

Various methods of combining small and large scale imagery have been proposed. Perhaps the most applicable was the technique developed by Langley & Norick in 1968 at the US Pacific Southwest Forest and Range Experiment Station in Berkeley, California. Langley (1969) described the theory behind multistage sampling with arbitrary probabilities of selection at each stage of the process. The sampling probabilities were formulated from the additional information available from the finer resolution remote sensing data at each stage. In this case, the first stage of the sampling design involved the acquisition of a series of photographs of the Mississippi River Valley taken on an Apollo - 9 mission. The images were divided into 6.4 km square blocks and the area of forest in each unit subsequently related to the timber volume.

Within the forested blocks, subunits were then selected using probability proportional to size (PPS) sampling; i.e. the greater the predicted volume in each subunit, the greater was the probability of its selection. This procedure was repeated using larger scale imagery flown for a selection of high timber volume subunits. The final survey stage consisted of field sampling using the largest scale imagery to locate appropriate sites. In order to obtain timber volume estimates applicable to the entire survey area, the measured tree volumes (from field sampling) were projected back through the sampling formula by using the probabilities and area expansion factors computed at each stage. Using only ten ground plots in 6 million acres, the timber volume was estimated to be 2, 225 billion gross cubic feet to a sampling accuracy of 87% and at a cost of less than half that of a field survey.

This type of sampling can lead to greatly inflated variances. To overcome this, Titus et al (1975) utililized an equal selection propability system which included a growth parameter as well as simple volume estimates. Using MSS data in conjunction with aerial photography a 7.82% sampling error was obtained for a timber resource inventory. Similar systems have been applied to temperate forest inventory (Robinson-Barker et al., 1975; Olang, 1983), tropical forest inventory (Lee et al., 1984) and wild land inventory (Hall & Hales, 1979; Thomas & De Gloria, 1979).

5.2 National Inventory Procedures

5.2.1 Comparability of results

"Most of the European countries have adopted different methods for the observation of forest damage. In spite of the efforts to coordinate the national surveys and improve the comparability of the results" (Kuusela, 1987).

The efforts made to standardise European inventory procedures are perhaps best illustrated by the 1986 UN / ECE Manual for Methodologies and Criteria for Harmonized Sampling, Assessment, Monitoring and Analysis of the Effects of Air Pollution on Forests (WWF, 1986). In 1987 the national field surveys were required to include samples taken from a 16 x 16 km grid extending over all member states of the EEC (see Section 5.2.2). Unfortunately, where undertaken, aerial photographic inventories have not been subjected to the same rigorous controls as the field surveys.

Hildebrandt (1985) outlined a pilot - inventory for forest decline based upon CIR photography. The proposed methodology was based upon the considerable experience in assessing crown condition built up in Baden - Wurttemberg, West Germany (Section 5.2.2). Unfortunately, the techniques outlined have not been universally adopted, and therefore, further investigation of the techniques employed in Europe must be undertaken in order to make a meaningful prediction of the approach likely to succeed in a UK context.

Smith (1988) reviewed the European forest decline surveys, placing particular emphasis on the aerial photographic component. The major drawback associated with this approach would seem to be the resolution of the systematic sampling grids. Smith (1988) observed that they were generally coarser than the corresponding field surveys, therefore patterns of damage may be missed. However, the point was made that the permanent record of forest health that photographs provide reduces the problem of comparability of information over wide areas.

For the purpose of this research, consideration has been given to a number of the European national surveys. The emphasis is placed on West Germany since in addition to the vast pool of experience available in this field the author's own study is based there . Inventory procedures adopted in North America are not considered here for two reasons : (i) in the USA, there is no national inventory of forest decline, only specific state - wide surveys, (ii) the vastly different silvicultural conditions.

5.2.2 West Germany

The first damage survey to take place prompted by the Waldsterben phenomenon was initiated in 1982 by the West German Federal Ministry of Food Agriculture and Forestry (Hildebrandt & Kadro,1984). The methodology was improved in 1983 when the majority of German states conducted well planned damage inventories based on traditional field sampling measurements supported by remote sensing techniques. Table 5.1 is a summary of the areas covered by aerial surveys in each federal state and the characteristics of the photographic coverage.

Federal Republic of Germany : Aerial Photographic Damage Inventory Coverage 1982 / 83

Table 5.1

Federal State	Film/Scale	Entire Forest	Forest Regions	District/ Estate
Baden-Wurttemberg	CIR 1 : 5000	Ss		Cc/s
Bayern	CIR 1 : 3000 CIR 1 : 5000		Ss	Cc/s
Hessen	CIR 1 : 6000		Ss	Cc/s
Niedersachsen	CIR 1 : 6000	Ss		Cc/s
Nordrhein-Westfalen	CIR 1 : 5000		Cc/s	
Rheinland-Pfalz	Nothing reported so far			
Saarland	CIR 1 : 16,000	Ss		
Schleswig-Holstein	CIR 1 : 6000	Ss		

S = Aerial photog. from sample strips C = Complete photo. coverage
s = Interpretation of photo-sample plots c = Interp. for all stands

A decision was made in 1983 to use manual interpretation of CIR photographs as the chief aerial survey technique (Hildebrandt & Kenneweg, 1968). Further, it was felt that digital classifications using airborne MSS data would not provide the level of detail required, since a tree - by - tree classification was required by each federal state.

The classification system currently employed is a two variable rating system based upon percent defoliation and percent foliage discolouration (Table 5.2). Both the field and aerial survey components of the inventory utilise this method (Ciesla & Hildebrandt, 1986). As well as rating trees in this way the field crews record the following data :

(i) location - state, forest district, plot number etc;
(ii) stand data - age, topographic position, elevation;
(iii) tree species or species group;
(iv) incidence of known damaging agents such as insects, fungi, animals.

In order to aid observers, narrative descriptions of damage classes 0 - 3 have been developed for each tree species or species group (Table 5.3). Similar narrative descriptions have been developed for photo - interpretation of forest damage and these are discussed in section 5.4.

The nation - wide field inventory provides statistics on the status of forest decline, whilst the aerial survey is used purely as a supplement to the field results. The whole survey design is based upon assesment of a fixed number of trees at a sample point rather than ennumeration of the number of dead or dying trees on a sample plot.

Table 5.2 Modified two variable rating system used to rate forest decline in West Germany

Defoliation %	Foliage discolouration %			
	0 - 10	11 - 25	26 - 60	> 60
0 - 10	0	0	1	2
11 - 25	1	1	2	3
26 - 60	2	2	3	3
61 - 99	3	3	4	4
Dead	4	-	-	-

Of particular interest to the author's research is the inventory procedure developed in Baden - Wurttemberg. The field sampling using a 4 x 4 km grid over the whole state is described in the literature by Schopfer & Hradetzky (1983). Table 5.4 summarises the photographic parameters employed, however it does not include details of the sampling procedure. The flight lines coincide with the West German national grid (Gauss - Kuger network) and areas with less than 10% forest cover, detected from the flight plan, are eliminated from the analysis. Circular plots are established on every third photograph along each flight line. These are defined using a regular sample point grid containing 25 points which is overlayed on each of the third photographs. Six to nine of these points are randomly selected and at these points either 20 conifers nearest to each point or, in the case of a young conifer or deciduous stand, a defined area of the stand is interpreted and classified according to the standard damage rating system. To augment this classification a series of contextual parameters are registered, namely : elevation (from maps); slope and aspect; geomorphological situation of the point; age class and density of stand; forest type and location of sample point within the stand area. Additionally, the geology, climatic region and forest district are registered for each sample point.

Summary of narrative descriptions for ground classification of decline on three major West German tree species
Table 5.3

Damage Class	Tree species		
	Norway spruce	Silver fir	Beech
0 - Healthy	Foliage a deep green colour. No chlorotic or yellow foliage presen Crown with a thick compliment of foliage. Little or no sunlight visible through crown. Branches and mainstem not visible through most of crown.	Foliage a rich green colour. No chlorotic or yellow foliage present. Tip of crown with distinct point on trees less than 100 years old. Some flattening of crown normal on older trees. Little sunlight through crown.	Rounded crown with dense foliage. Little or no sunlight visible through crown. Less than 10% foliage loss.
1 - Sickly	Incipient crown thinning in inter of crown, progressing outward. Secondary branches growing irregularly. Occasional lateral twigs partly defoliated and drooping. Light needle yellowing usually of 2 or 3 year old needles.	Incipient crown thinning starting in interior and progressig outward in lower and midcrown. (Crown has transparent look). Decreased height growth even in young trees. Incipient development of flat tops.	Individual spear or clawlike branches begin to appear along periphery of crown. Sparse foliage in peripheral crown areas. Some yellowing of foliage.
2 - Sick	Thinning of entire crown. Lateral second order branches drooping and partly defoliated ("Tinsel effect"). Commonly concurrent yellowing and browning of older needles.	Severe thinning of lower and mid crown. Branch mortality in crown with heavy lichen growth. Dense, stout water sprouts. Upper crown fully foliated stands out (storks nest). Stunted terminal shoots & irreg. yellow needles.	Distinct thinning of exterior region of crown. Leaf necrosis. Some branch dieback present.
3 - Very sick	Severely thinned crown, branches visible throughout crown, many individual dead branches. Dead tops common. Resin flow from stem common in crown where needles are still present. Epicormic branching common. Yellow foliage on 60% of crown.	Progressive defoliation until crow mortality occurs. Flat top storks nest dies only during terminal phase. Water sprouts often remain green after primary crown has died.	Mortality of a portion of the crown. Crown has an open appearence.

In 1984 the European Economic Community recognised the need for a multinational forest decline inventory which would provide meaningful comparisons between member nations. The inventory procedures developed in Baden - Wurttenberg were tested in 1985 over the Black Forest as part of a pilot project. The only change in inventory design as described above was the use of nine sample

Photographic parameters of West German Damage Inventories

Table 5.4

State	Area covered	Average scale (1 : n)	Flight distance (km)	Orientation
Baden - Wurttemberg	State	5, 000 (s)	8	N - S
Bayern ('81 & '82)	East Bayern	5, 000 (f)	--	--
Bayern ('83)	(a) Allgau	5, 000 (s)	4	N - S E - W
	(b) Alps	5, 000 7, 000 (s)	3	E - W
	(c) Schwaben Spessart	3, 000 (s)	8	N - S
Hessen	Four small areas	4, 500 (s)	--	N - S
Niedersachsen	State	6, 000 (s)	4	N - S
Nordrhein - Westphalia	(a) Rothaargeb	5, 500 (s)	2	N - S
	(b) 12 small areas	5, 500 (f)	--	N - S
Rheinland - Pfaltz	(a) --------------	5, 000 (f)	--	--
	(b) 8 test areas	2, 500	--	--
Saarland	State	16, 000	--	E - W
Shleswig - Holstein	State Southern half '83 Northern half '84	6, 000 (s)	4	N - S
Hamburg ('82)	State	4, 000 (f)	--	N - S

(s) ~ Sampling

(f) ~ Full coverage

State	Area covered (sq km)	Crown status classes
Baden - Wurttemberg	4250	4
Bayern	340	5
Bayern ('83)	1590, 2170, 380	5
Hessen	200	5
Niedersachsen	5180	5
Nordrhein - Westphalia	1300	5
Rheinland - Pfaltz	30	5
Saarland	920	3
Schleswig - Holstein	1320	5
Hamburg	747	4

plots and the rating of 15 trees within each one. Greater emphasis was also placed on collection of contextual data. The variables measured were described by Hildebrandt (1985) and these are : age class, crown condition, stand structure, stand shape, slope, landform, aspect and position in stand.

Each federal state has its own survey methodology. The state wide forest decline inventory in Lower Saxony was described by Hartmann (1984). Here, most areas are flown on north - south flight lines at 4 km intervals, corresponding with the Gauss - Kruger grid. The Harz Mountains on the East German border come in for detailed scrutiny due to severe decline symptoms and flight lines occur at 2 km intervals. As well as providing statistics on levels and distribution of decline, the Lower Saxony inventory is designed to obtain decline data on a stand - by - stand basis. Stand boundaries are transferred to aerial photographs from topographic maps and a systematic dot grid (16 dots per hectare) is placed over sample stands. The species of the tree nearest to each dot is then identified and given a decline rating. The advantages of such a methodology were outlined by Denstorf (1984) :

- direct comparability between the results of the interpretation of aerial photographs and the data relating to localities and stands;
- results can be presented not only for large data unit (growth districts, forestry officers, administrative districts etc), but also for particular stands which can be used at the local level as examples for comparison, indication or demonstration;
- intensification of the evaluation in terms of the surface area examined and the sampling density is associated with a much smaller increase in effort than would be the case with analagous field work.

Denstorf (1984) described the inventory in Schleswig - Holstein which, like all the state inventories was conducted at the end of the growing season in the late July / early August. In this case, the only species studied was the Norway spruce since it was considered to be a good bio - indicator. The classification scheme employed was the same as the nationally adopted system with the addition of some narrative grades to describe local decline symtoms.

Other states have their own sampling methods. Khul (1985) described the "Hexagon" method employed in Northrhine - Westphalia. This involves interpretation from every second photograph in the flight strip. The chosen photo is covered with a square overlay containing a 6 - pointed star. At the end points of the arms of each star the nearest tree is classified into one of the five national health catergories. The position of the star centre is randomly selected within the photo - overlap area. This technique provides the forest authorities with the required information levels of forest decline on a state wide basis.

All the surveys so far described have one major advantage over conventional field survey results. That is, aerial surveys provide a permanent pictorial record of decline at a given point in time (Ciesla & Hildebrandt, 1986). This provides an opportunity to assess change in damage states by sequential photography of permanent sample plots. Such a technique has been employed in Baden - Wurttemberg and Bavaria (Trankner, 1985), where each tree within a plot is identified by species and given a decline rating. Such plots can be re - photographed periodically and used to provide an index of change in decline states (Marx,1985).

The pictorial records obtained provide a source of statistical data which need to be verified in some way. The only reliable method employs the corresponding field data in a multistage sampling procedure as outlined in Section 5.1. Unfortunately in West Germany, no attempt has been made to introduce a combined field and aerial survey. The field data is used primarily for the development of photo - interpretation keys and to maintain an informal check on photo - interpretation accuracy.

The major problem encountered when intergrating photographic and field data is the fact that similar symptoms of forest decline may appear differently to field and photo - interpreter. Denstorf (1984) encountered such problems in Schleswig - Holstein where damage was thought to be under - evaluated from photo - interpretation. This phenomenon was explained by the difficulties photo - interpreters had in classifying early damage phases where needle loss was occurring in the crown interior and in small trees in stands of variable age. However, the photo - interpretation did have the advantage of greater reproductability, in that repetition of the classification by the original or different interpreters produced a negligible change in result. During an appraisal of trees on the ground, the same trees were classified into different vitality groups in 20 - 30% of cases if viewed from different directions or under different lighting conditions.

Generally in West Germany, it is believed that the visible symptoms of forest decline are more readily identifiable on large scale CIR photos than on the ground. In the case of Norway spruce this can be explained by the prevalence of yellowing on upper needle surfaces (Ciesla & Hildebrandt, 1986). Identification of dead and dying trees is also more accurate with aerial photography (Denstorf, 1984). In Schleswig - Holstein, 2% of the photo - sample was classified dead (Class 4) as opposed to a field survey total of 5%. Two reasons were put forward for this discrepancy :

(i) dead trees are highly conspicuous on CIR aerial photography whilst on the ground there is a general tendancy for overestimation since the trees can be partially obscured from view;
(ii) subjective influences cannot be excluded from a selection process on the ground, whilst the aerial survey displays greater objectivity due to the strict sampling strategy.

Whilst providing a model for future damage inventories, the West German methodologies do not and cannot pursue the full range of possibilities offered by remote sensing. Therefore, some assessment of the techniques employed elsewhere is required to build up a full picture of the possible forest decline inventory techniques in use.

5.2.3 Switzerland

In 1984 - 1985, CIR photographs at a scale of 1: 9, 000 were taken of approximately a quarter of the forest area of Switzerland (Schwarzenbach et al., 1986). By the end of 1985, 70% of the photographs taken in July and August 1984 had been interpreted and forest decline over an area of more than 70, 000 ha assessed. The resulting maps produced after interpretation represented the aerial percentage of damaged and healthy trees (preferred by the majority of cantonal authorities) as well as damage intensity.The classification system employed was similar to that used in West Germany and consisted of five damage classes. These were :

1. no damage detectable on the photograph,
2. discolouration of foliage,
3. slight foliage loss,
4. severe foliage loss,
5. dead.

An important feature of the inventory as a whole was the organisation of flights and staff training on a centralised basis, as opposed to the West German federal organisation. This led to a uniform national standard although the actual interpretation was undertaken on a decentralised basis by cantonal staff (county) staff. This method contributed to uniform data quality and rapid practical implementation of the experiences gained. A problem encountered by the West Germans has been the decentralisation of photographic missions and incompatibility of data due to organisation at a federal level and the sheer size of forest area. In Baden - Wurttemberg alone, six companies were involved in the 1983 survey, producing a total of 8, 400 aerial photographs. In addition to the national inventory the Swiss Federal Institute of Forest Research have conducted a detailed assessment of forest damage and air pollution in the Rhone valley (Bosshard, 1981). Studies involved air pollution monitoring, tree ring analysis, soil measurement as well as the assessment of Scots pine (Pinus silvestris) condition using medium scale (1 : 13, 000 to 1 : 20, 000) (see Section 7.2.2) and large scale (1 : 2, 000) CIR photography.

5.2.4 Sweden

A Swedish program for 'inventory, description and analysis of forest damage' was established during the winter of 1983 / 84 (Wastenson et al., 1987). The photo - interpretation component of the system involved comparison of the 1 : 10, 000 scale with 1 : 20, 000 scale CIR transparencies taken over a test area. Holmgren & Wastenson (1985) described the comparison study in detail. A classification system based upon the following needle loss classes for Norway spruce was used to test the imagery :

1.	% needle loss	0 -19
2.	"	20 - 39
3.	"	40 - 59
4.	"	60 - 79
5.	"	> 80

Accepting a deviation of + / - 10 % , the air photo - interpretation and field determination of needle loss coincided for 77 % of the trees at 1 : 10, 000. Although the difference in accuracy between the scales was minimal, the 1 : 10, 000 imagery was recommended because the interpretation time was much lower.

Having established the optimum scale, an applied inventory of Norway spruce needle loss was instigated in south - west Sweden. The primary aims were to investigate the geographical distribution of forest damages and to establish damage levels, with the findings acting as a baseline for future surveys. The inventory also acted as a core data set for an investigation of the correlation between needle loss and forest stand parameters such as : age, density, tree species mixture, field vegetation layer, topography, soil, bedrock, hydrography and geographical position in relation to local air pollution sources. In July 1985 400 CIR photographs were taken at a scale of 1 : 10, 000. The flight strips were oriented in a WSW - ENE direction in order to get coast to inland profiles and minimise differential solar illumination. Each strip was 2 km wide and they were randomly distributed over the study area.

Comparisons between ground observations and photo - interpretation results highlighted the correspondence between spruce colour difference on the photography and the following needle loss classes :

1. 0 - 10% needle loss	- no visible damage (brown / magenta)
2. 11 - 30%	- slight damage
3. 31 - 60%	- damaged (rose / pink)
4. 61 - 80%	- severely damaged
5. 81 - 100%	- very severe damage / dead (blue)

The sampling system employed was a systemmatic 10 x 10 mm grid (corresponding to 1 ha on the ground). In every area containing more than 25 spruce trees older than 40 years, each of the trees were rated according to the system outlined above. A total of 15, 000 one hectare areas were assessed in this way. The result from both ground and aerial surveys have provided an accurate picture of damage levels in this area of Sweden. Where this survey does go further the results have been impressive, namely the attempt to correlate needle loss with geographical and stand factors (Wastenson et al., 1987).

5.2.5 Belgium

Surveying of Flemish forests, initially undertaken in 1984, takes the form of a detailed mapping exercise using CIR photography at 1 : 30, 000 (De Roover et al., 1985). The imagery flown in July - August is interpreted and the resulting information transferred to 1 : 5, 000 base maps. After photogrammetric correction the maps produced are orthophotomaps. The items developed in this way are as follows.

(i) Species composition (deciduous, mixed deciduous, coniferous, mixed coniferous, poplars).

(ii) Management practice / development stage for deciduous species; age classes for coniferous stands. Additional information on percentage canopy cover and reforestation.

(iii) Growth, health and damage situation (normal, stress, dead, windfall, fire damage).

The final stage of the inventory process involves storage of the map data in digital form. Using standard vector digitisation techniques the position and area of each interpretation unit (such as a forest stand boundary), is calculated.

This methodology is the most automated of the forest decline inventory approaches. Admittedly, the extraction of damage information is not a primary aim, however, the final product in digital form allows for the introduction of more detailed information on the health status of individual trees or stands based upon interpretation of larger scale photography. The advantages of such a technique, in terms of data handling, is illustrated by the fact that for the whole Flemish forest region a 5mb storage capacity would be adequate. Given the ability of a standard microcomputer to store 40mb of data, then the advantages are self evident. Unfortunately the majority of forest health surveys require rapid results in order to implement control strategies, which is, perhaps, a stumbling block to the incorporation of the data into this form of Geographical Infromation System (GIS). The beauty of the Flemish system, however, is that it relies on the initial interpretation of the photography as a primary input. Therefore, figures for health status can be obtained first then converted to a digital format later to provide a baseline against which to compare future results.

5.3 Identification of tree species and crown condition

5.3.1 General considerations

The problems encountered when attempting to identify tree species can be solved by a knowledge of the characteristics of photographic images. For example, the texture of an image can be an indicator of forest composition on small scale photographs (1 : 50, 000) and of individual tree characteristics on large - scale photographs (1 : 3, 000). Texture in this case can be defined as tonal repetitions in groups of objects too small to be discerned as individuals (Rabben, 1960). When dealing with medium - scale photography the interpreter would use a combination of texture and pattern (the spatial arrangement of discrete objects) for the determination of species composition and stand structure.

Although the preceding rules characterise panchromatic image interpretation, the same rules can also be applied to colour photography. In addition, this type of imagery relies on image tone, particularly in large scale photography, where tonal contrast provides clues to species composition. However, it must be remembered that since tone is an unstable value, depending upon time of day, season, atmospheric haze, flight altitude and processing techniques, reliable ground correlations are required.

Generally speaking, aerial photographs provide an unusual perspective through which to view tree species. However, in his guide to species identification, Sayn - Wittgenstein (1978) recognised that this unusual angle could mask normal identification characteristics whilst highlighting new ones. For example, the trunk may be hidden by the crown whilst branching habit in the upper crown will be clearly seen. Oblique aerial photography can provide details of both characteristics. Unfortunately the photography normally available for forest surveys is vertical inventory photography specifically flown for identification purposes.

5.3.2 Photographic scale

The extent to which the advantages of air - photo identification surpassed field methods was, according to Sayn - Wittgenstein (1978), dependant primarily on photographic scale. As the scale decreases, so the morphological characteristics such as crown shape and branching habit (pattern and texture) become secondary to tonal characteristics for identification purposes. Reliance purely on image tone turns the identification technique into more of an art than a science due to the influence of the variables mentioned in Section 5.3.1. The detail identifiable at different scales varies with the quality and method of photography as well as the nature of the forest being studied, but Table 5.5 may serve as a general guide.

5.3.3 Silviculture and Ecology

When dealing with vertical photography it is essential that trees be viewed stereoscopically in order to assess detailed crown characteristics. The forests of northern and central Europe contain relatively few tree species. In West Germany, only five species; Norway spruce, silver fir, Scots pine, beech and oak are considered to be of prime importance.

Scale	Detail Identified	Characteristics / Comments
1 : 500	Tree species arrangement	Twig structure & leaf
1: 3, 000	Tree species	Small / medium branch arrangement
1 : 8, 000	Tree species (except in dense stands); other boundary features	Describing crown shape difficult
1 : 15, 000 - 1 : 50, 000	Stand species composition and density	Crown shape determined from tree shadows or large trees at 1 : 15, 000 to 1 : 20, 000.
1 : 80, 000 +	Forest type where heterogeneous	Hardwood / conifer separation possible with high resolution, high altitude films; eg. Kodak SO - 131 at 1 : 160, 000.

After Lachowski (1983) & Sayn - Wittgenstein (1978)

Table 5.5 Information content of different scales of photography

Additionally, intensive management for over two hundred years has led to large regulated stands of single species which are well documented (Ciesla & Hildebrandt, 1986). Therefore, this bank of a priori silvicultural knowledge aids the task of identification enormously (Sayn - Wittgenstein, 1978).

North American forests, consist of large areas of wild unmanaged land supporting a more diverse collection of species. For example, over 100 species of commercial importance may be found in parts of the central and southern Appalachian mountains. This problem is intensified in the tropics where there is further species diversification. Benson & Myers (1981) defined a diversity value for north Queensland, Australia as approximately 80 - 170 species per hectare. This value exceeds the results for comparable areas in the United States.

The problems encountered when building up a database on the species mixture are therefore severe in tropical areas. However, the problems are compounded when attempting to classify individuals. Versteegh (1974) found that the large variability in crown shape and tone meant little advantage could be gleaned from the use of colour film. Where distinctive crown characteristics can be recognised, Sayn - Wittgenstein (1978) recommended an initial study of branching habit. Branching characteristics which should be recognisable are :

- length and thickness of branches,
- variation in branch size,
- branch direction, eg. ascending, horizontal, drooping,
- branch form, eg. straight, crooked, twisted,
- arrangement of branches,
- density and coarseness of twigs,
- colour of bark.

Foliage characteristcs, namely tone and colour of leaves, also influence crown appearance. For example, due to specular reflection, trees with large leaf areas tend to appear in lighter tones and produce highlights. Dense foliage can produce the appearance of a 'solid' crown, which, in conjunction with a regular branching habit, gives the impression of a regular geometric solid. Such characteristic crown patterns have been observed in the Black Forest where healthy silver fir appear as regular cones due to dense assymetric branching and needle pattern.

A further indirect aid to identification is the use of within crown and cast shadows. A dark shadow cast on the ground will indicate a compact crown and dense foliage whilst the opposite is true of a light shadow. In addition, trees with dense foliage will show a greater tonal contrast between the shaded and sunlit side of the crown than those with little foliage. If no large shadows are visible inside the crown this may mean that the individual branches are not prominent or that the crown is closed.

5.3.4 Film type

Advances in the use of film / filter combinations for tree species identification have followed technical developments in photographic emulsions. However, unlike vegetation damage assessment, CIR photography is not conclusively the optimum emulsion for this task. Black & white photography at a scale larger than 1 : 20, 000 is satisfactory for interpretation in simple forest ecosystems with a limited species diversity (Sayn - Wittgenstein, 1978). It is now accepted that normal colour photography is superior in the identification role since interpretation rates are enhanced due to its true colour representation. Comparisons between normal colour and CIR films have proven less conclusive. Myers & Benson (1981) evaluated both types of emulsion for tropical species identification. CIR transparencies proved to be inadequate due to degraded resolution and colour range when compared with normal colour film. Another drawback associated with CIR film was the enhanced contrast which led to the dissapearence of the shadowed crown area, visible in normal colour film.

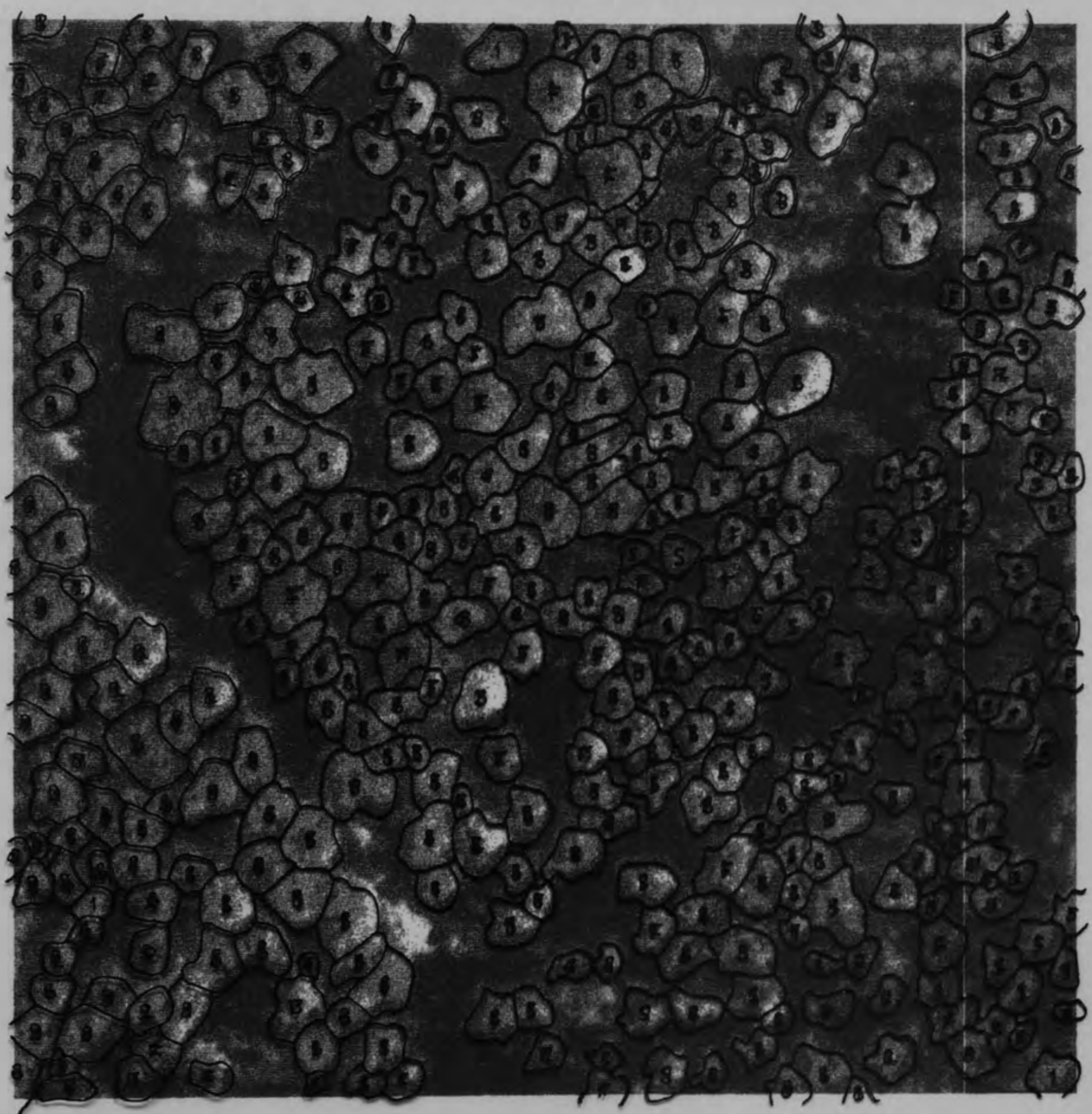


Fig. 5.2 Colour - infrared photograph of part of the Black Forest study site

2 - DAMAGE CLASS

B - SPECIES

F ~ FIR
B ~ BEECH
S ~ SPRUCE

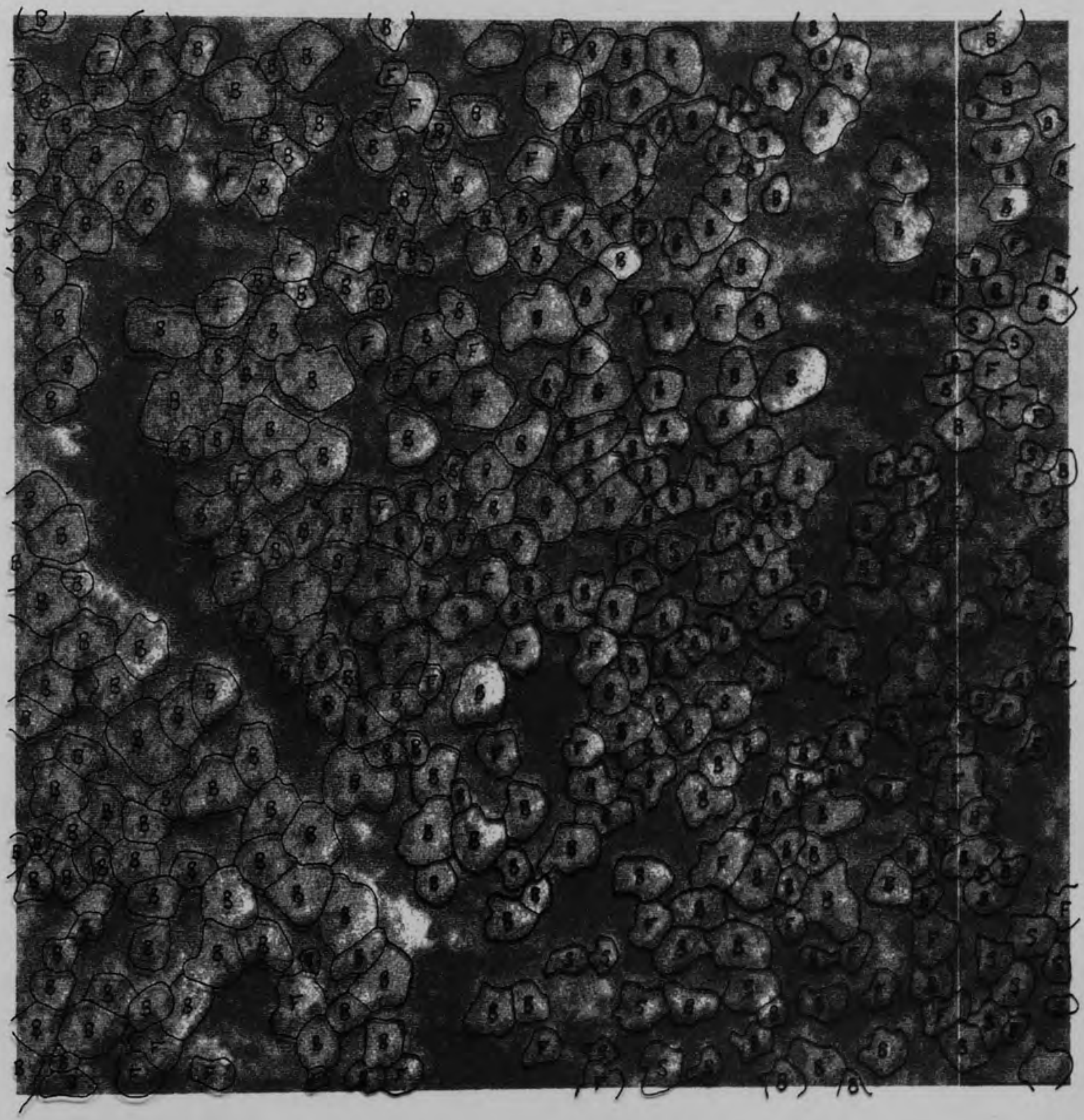


Fig. 5.2 Colour - infrared photograph of part of the Black Forest study site

B - SPECIES
F - FIR
B - BEECH
S - SPRUCE

A major problem associated with the CIR film is the false colour representation of vegetation. The physical background to this characteristic is explained in Chapter 7. Successful interpretation of tree species requires considerable experience and a priori knowledge. In temperate climates CIR film has been used successfully to identify species as part of damage inventory procedures. Ciesla (1986) and Weiss et al. (1986) outlined identification techniques as part of a survey of Red spruce (Picea rubens) and Balsam fir (Abies balsamea) decline. The survey entailed separation of hardwood communities from mixed - wood and conifers as well as identification of major conifer communities. Separating hardwoods from conifers proved simple due to the darker appearence of conifers resulting from their lower near - infrared reflectance - partly explained by the smaller leaf / needle area. In addition to the crown characteristics, the situation of conifer species was incorporated into the identification process. For example, it was recognised that certain conifers were likely to occur in plantations at lower elevations and that these plantations were usually geometric blocks containing distinct rows of trees. Thus, species such as Norway spruce and Balsam fir could be identified using this characteristic. On the other hand, Red spruce is not a plantation tree. This basic difference is a situation Sayn - Wittgenstein (1978) defined as the first stage of identification; i.e. the elimination of improbable species due to locational, physiographical and climatic constraints.

In Europe, the identification process has to a large extent been based on CIR photography due to its long established use in damage inventories. Stellingwerf (1969) recommended 1 : 5, 000 CIR film for both damage assessment and identification purposes. However, Lackner (1966), preferred to use 1 : 15, 000 black and white infrared prints as opposed to normal colour diapositives at the same scale, particularly for studying mixed conifer - deciduous stands. More recently the inventories of forest decline described in section 5.2, have all made use of CIR film as the primary remote sensing data source. Therefore, keys have been developed to aid the interpreter in the assessment of species using this film.

5.3.5 Identification keys

Photo - interpretation keys are guidelines used to assist interpreters in rapidly identifying photographic features (Avery, 1968). Colwell (1965) stipulated that a key to forest types should contain the following four elements :

(i) oblique view photo illustrations, which reveal the ecological site preferred by each type;

(ii) vertical view stereo - views of each type similar to the normal interpretation images;
(iii) a worded description which outlines in a systemmatic manner the image recognition features for each type;
(iv) a statement describing the significance of each type.

The simplest form of key is a selective one where the photo - interpreter identifies the example tree and referring to a list of general descriptive / diagrammatic features selects the features that best describe the crown. Such descriptive keys were developed by Heller (1964) to identify tree species on large scale colour scenes. Keys of this type have been devised for the major West German species (Tepasse, 1984). In the Black Forest, Norway spruce, silver fir and Scots pine are the predominant coniferous species and these can be identified and differentiated relatively easily on CIR photographs with the aid of such keys. However, Douglas fir does occur in small numbers and problems do occur when attempting to differentiate this species from Norway spruce and silver fir. Table 5.6 is a list of the major differences between these three species as witnessed on CIR photography.

Norway spruce	Douglas fir	silver fir
Crown margin deeply lobed giving starlike appearence	Star structure visible but not distinct	Star structure difficult to identify
Single branches straight	Presence of slight bend in branches producing sickle like appearance	Single branches broad and straight
Foliage dark red - brown Deep red foliage or red - violet in colour		Deep red foliage
Branches narrow in profile	Branches broader giving crown a more irregular and fluffy form	Branches narrow and dense

After Tepasse (Pers. comm.) and Ciesla (1986)

Table 5.6 Appearence of three coniferous species on CIR aerial photography

Tepasse (Pers. comm.) concluded that Douglas fir is more likely to be identified as Norway spruce rather than silver fir. The latter two species occur in appreciable numbers in the Black Forest, whilst Douglas firs tend to be isolated, occuring in very small numbers. However, even given some confusion between spruce and Douglas fir the problem of conifer species misclassification is not deemed to be significant in this case. The important differentiation is that between norway spruce and silver fir, which from experience are easily identified.

Of the commercially important hardwoods only european beech was included in the authors Black Forest study. Characterised by its dentate margins and fine foliage texture (forming a pattern of small fans) the beech were readily identified. The major problem associated with beech was seperation of the individual crowns due to the ill - defined margins and dense volume per unit area. Sayn - Wittgenstein (1978) encountered similar problems and explained that most conifers have a definite and characteristic shape whilst hardwoods tended to be irregular. Fig. 5.2 serves to illustrate this point.

5.4 Classification of Crown Status

5.4.1 Classification Keys

More sophisticated than a selective interpretation key is a dichotomous or 'two - branched' key, which consists of a number of decision trees. In other words, a series of questions concerning crown appearance are posed, an affirmative means that the crown belongs to a certain species, a negative answer leads on to further descriptions, each of which branches from the previous until the correct description is reached. This form of key has been utilised for species identification (Krumpe, 1971) and the technique has been applied with some success to forest damage assessment. A good example is the dichotomous key produced by Murtha (1972) to describe damage syndromes, including air pollution effects, in Canadian forests (See Fig. 4.1). Unfortunately forest decline does not follow classical pollution damage patterns. Whilst acknowledging that air pollution is one of the primary causal factors, Cowling & Schutt (1985) pointed to the increased susceptibility to secondary root and foliar pathogens such as insects, fungi, bacteria, nematodes and viruses which this brings. Therefore, a general damage key in this case proves inadequate and the need exists for a key related to the specific symptoms of forest decline .

The present classification system used in West Germany (Table 5.2) has been supplemented by descriptive (selective) keys, of the type outlined in Sec. 5.3, which relate the trees appearence on the ground to the appearence on a CIR photograph (Masumy, 1984 and Ciesla & Hildebrandt, 1986). An air photointerpretation key has been devised as part of a multinational project known as Sanasilva, led by the Swiss (Schwarzenbach, 1986) for which the air photo keys include both narrative descriptions and photographic examples of each crown condition class. Fig. 5.2 illustrates some of the condition classes as they appear on a CIR photograph of the Black Forest. Tables 5.7 (a), (b) & (c) serve as comparisons between the narrative descriptions based on ground and airphoto observations.

The Sanasilva project is being undertaken by foresters in West Germany, Austria and Switzerland, who are attempting to define a general damage assessment key for all the major tree species in these countries (Tepasse, Pers. Comm.). The major stumbling block encountered has been the reliance on hue changes in the crown as an indicator of damage. Daels and Antrop (1978) encountered similar problems with temporal studies, where differences in film batches, processing methods and atmospheric conditions can create radically different responses from the photographic emulsion. One possible way of overcoming this problem is to place the emphasis on structural changes within the crown. By so doing, the Sanasilva project aims to minimise errors and interpretation time, whilst maximising the broad applicability.

Table 5.7 Crown condition on CIR photograph with increased damage

Fir (5.7 a)

Class	**Structure**	**Colour**	**Change**
0	Conical form, compact (no view of inner crown), branch perimeter clearly recognisable.	Uniform deep wine red.	
1	Pointed crown less distinct.	Pale red, light marbling.	Slight change texture / structure.
2	Blunted & sparse crown, storks nest recognisable.	Storks nest red, stronger marbling.	Strong change in texture/structure, deep red now grey.
3	Part of crown dead, clear storks nest.	Red storks nest, otherwise grey / green. Strong marbling.	
4	Tree skeleton visible.	Blue / grey.	

Spruce (5.7 b)

0	Conical form, full crown.	Deep purple.	
1	Disperse pointed crown, distinct star form, slight needle loss.	Pink / purple. No marbling.	Slight change in texturestructure, slight colour change.
2	Star form clear, needles hanging down, considerable needle loss.	Brown / grey - some marbling.	Strong colour change. purple - grey,
3	Part of crown dead, overall needle loss, tree skeleton visible.	Clear green / grey - blue / green.	
4	Tree skeleton visible.	Blue / grey	

Beech (5.7 c)

0	Irregular perimeter with broken edge, cannot see inner crown, branches not visible.	Even colour - deep pink.	
1	Sparse foliage in crown periphery.	Pinky red, some marbling round edges.	Slight change in texture / structure.
2	Thinning over whole crown (can see inner crown), ends of branches visible around periphery.	Light pink with grey - brown flecks, distinct marbling on inner crown.	
3	Partial dieback, sparse crown (inner clearly visible), rough crown form.	Light pink.	Increased dark grey / blue patches.
4	Tree skeleton visible	Grey to white.	

After Masumy (1984) and Schwarzenbach et al. (1986)

5.4.2 Photographic scale

When assessing vegetation damage it is important to define whether the information requireed is related to, forest area or individual crowns. Murtha (1983) compared different scale combinations for assessing low levels of defoliation and slight changes in foliar colour. A 35% loss of information was reported when the scale dropped from 1 : 1, 000 to 1 : 4, 000, so clearly there is an obvious need to correlate the damage syndrome with scale and film type. Murtha (1984) described some possible scale and film combinations for a number of damage syndromes (Tables 5.8 and 5.9).

In the acid rain category (Table 5.8), the first two columns have been left blank since Murtha states that this phenomenon rarely affects just one tree. This observation is correct in that the forest decline attributed to acid rain is occurring over vast areas of Europe and North America. Unfortunately, it fails to take into account the local decline distribution where healthy crowns sit next to severely damaged ones. This situation demands a tree - by - tree classification which is the established inventory procedure in Europe and the eastern United States. With reference to Table 5.4, in West Germany a scale of 1 : 5, 000 is considered to be the optimum in terms of cost effectiveness and accuracy. The interpretation instrument usually employed is a Wild Aviapret stereoscope which has a 30 x zoom capability thereby allowing close examination of individual trees. Experimentation with Kodak SO - 131 high definition infrared film is in progress in West Germany (Trankner, 1985 and Haenel, 1985). Trankner considers 1 : 15, 000 to be the optimum scale for damage assessment work, providing the necessary detail with large area coverage. Haenel (Pers. Comm.) however was more conservative and viewed 1 : 8,000 as the likeliest compromise between land use mapping and tree crown definition.

Suggested scale - film type combinations for the detection and assessment of various general types of vegetation damage

Table 5.8

Stress	Number of Trees Affected			
	Single	Small groups (<5)	Large groups (<100)	Extensive (<1000)
Fire	1 : 2000 (NC,CIR)	1 : 2000 (CIR)	1 : 20000 (NC,CIR)	<1 : 50000 (NC,CIR)
Wind	—	1 : 2000 (B&W)	1 : 20000 (B&W)	<1 : 50000 (B&W)
Air pollution	1 : 2000 (CIR)	1 : 2000 (CIR)	1 : 10000 (CIR)	<1 : 50000 (CIR)
Acid Rain	—	—	1 : 10000 (NC,CIR)	1 : 10000 (NC,CIR)
Nutrient deficiency	1 : 2000 (NC,CIR)	1 : 4000 (NC,CIR)	1 : 10000 (CIR)	—
Water deficiency	1 : 2000 (NC,CIR)	1 : 2000 (NC, CIR)	—	—
Water excess	—	1 : 5000 (NC,CIR)	1 : 10000 (CIR)	1 : 10000 (CIR)

Film types :B & W - Black & White panchromatic
NC - Normal colour
CIR - Colour - infrared

Ranking scales and sensor types relative to detection and interpretation to environmental stresses

Table 5.9

Stress	SCALES											
	Large			Medium			Small			Satellite		
	NC	CIR	MSS	NC	CIR	MSS	NC	CIR	MSS	NC	CIR	MSS
Abiotic - Environmental												
Water deficit	2	3	2	1	2	1	0	1	0	-	-	0
Water excess	3	3	2	1	2	1	0	1	0	-	-	0
Air pollution	2	3	2	1	2	1	1	1	0	-	-	0
Wind	3	3	2	3	3	2	1	1	0	-	-	1
Fire	3	3	2	2	2	1	2	2	1	-	-	2
Acid rain	2	3	2	1	2	1	0	1	0	-	-	0

Scales :	Large	1 : 500 to 1 : 2000
	Medium	1 : 3000 to 1 : 12000
	Small	1 : 20000 to 1 : 63000
	Satellite	1 : 250000 to 1 : 1000000 and smaller.

Sensors :	NC	Normal colour film
	CIR	Colour - infrared film
	MSS	Multispectral line scanner.

Utility : 1 = poor; 2 = fair; 3 = good; 0 = not useful.

(After Murtha, 1983)

5.5 Conclusions

The inventory systems outlined in section 5.2 are all run in conjunction with field surveys; although, certainly in West Germany there is no attempt to combine the two sets of results. In the UK, the Forestry Commission have been forced by continental and domestic pressure to undertake a field survey (see Chapter 3). However, the commission is dubious of the benefits of an aerial photographic inventory, although they are keeping their options open by experimenting with airborne scanner data (Innes, Pers. comm.). They feel that the extent of forestry in this country does not justify the expense of an aerial photographic survey. In addition, most of the UK forestry has been planted in upland areas of Scotland, and the commission feels that the problem of cloud cover in this area is an insurmountable one as far as remote sensing is concerned.

How much any Forestry Commission decision is political is open to debate. In terms of this research, it seemed clear that the UK did not contain the necessary experience or the will to undertake a small scale study of the kind envisaged. The only study of forest decline based in the UK had been undertaken by the National Remote Sensing Centre (NRSC) (Smith, 1988). They decided to study an area in West Germany; a seemingly sensible decision until it was revealed that they proposed to use a TM scene of the north Munich plain! Even if the images spatial resolution problems could be overcome, they were faced with two problems. Firstly, there are very few trees in the north Munich plain and secondly, most of the severe damage had been observed at altitudes much in excess of that under study. Smith (1988) eventually concluded that although satellite imagery should be investigated further, the only justifiable imagery was CIR photography. Additionally, Smith recommended the setting up of a feasability study of a number of UK sites, assessing forest condition using CIR photography

The NRSC's initial decision to study an area in West Germany was also pursued for this author's study because of the experience that country had in monitoring forest damage, and specifically forest decline. The photointerpretation guidelines were well established and sections 5.3 and 5.2 outline some of the techniques employed generally, and specifically in West Germany, in order to quantify tree species and their associated damage symptoms. Chapter 6 introduces the reader to the areas in West Germany that were chosen for this study.

Chapter 6 : Forest Decline in Baden - Wurttemberg

6.1 Ground Woodland Damage Inventory (GWDI) in Baden - Wurttemberg

6.1.1 Introduction

In 1986 the second West German woodland inventory was carried out; the first having been completed in 1984. For Baden - Wurttemberg this inventory (Undertaken by the state forestry service) was the third using a systematic area network created in 1983 and regionally and specifically concentrated the following year. Overall for GWDI '86 2,301 tracts with in all 47,985 test trees were catalogued.

6.1.2 Results of GWDI '86

6.1.2.1 Damage Situation

As with previous years, it was noted that all types of species of all age groups were affected to different extents by the decline. In the preceding two years the damage extended to 66% of the total area whilst in 1986 this area had declined slightly to 65%. Using average needle / leaf loss as the main identification criteria, the fir holdings were most affected with 38.8 % total damage, followed by spruce with 26.3%. Following a sharp rise in damage between 1984 and 1985 the oak damage figure had risen to 23.5%, closely followed by Scots pine with 22.9% and beech with 19.6%. As with the previous inventories the severest damage to spruce, fir and beech occured in the Schwarzwald or Black Forest. This difference between regions was also mirrored by an increase of damage with elevation, this phenomenon was particularly noticeable in the Black Forest.

6.1.2.2 Development of the Decline Syndrome

The reduction in the damage area from 66% to 65% was reflected in the tendancy of trees with needle / leaf loss between 25 - 35% (Class 2) to revitalise themselves and return to the "warning level" (10 - 25% or class 1) (Table 6.1). This improvement in health was expected because growing conditions had improved, however an unexpected reduction in the area for class 3 was also experienced. The cause of this change was due in part to regeneration phenomena and in part to clearing of class 3 trees in order to salvage timber. These values refer to a change in the needle / leaf defoliation. A corresponding measure of discolouration again showed an increase between 1984 and 1985 which was reversed between 1985 and 1986.

Results for Baden - Wurttemberg

Trees over 60 years

Class	Needle / leaf loss (%)	Spruce				Fir				Beech			
		'83	'84	'85	'86	'83	'84	'85	'86	'83	'84	'85	'86
1	0 - 10	13	7	8	8	6	4	4	4	60	28	30	27
2	11 - 25	55	48	45	52	28	25	22	21	33	53	51	53
3	26 - 60	32	44	46	39	60	62	66	65	7	19	19	19
4	61 - 100	0	1	1	1	6	9	8	10	0	0	0	1
Average needle / leaf loss		23.8	27.3	27.2	26.3	34.8	37.9	37.3	38.8	11.2	19.0	18.6	19.6
Diff. 84 - 85			- 0.1				- 0.6				- 0.4		
Diff. 85 - 86				- 0.9				+ 1.5				+ 1.0	

Table 6.1 State of health of three tree species based on needle / leaf loss
(Comparison of GWDI '83, '84, '85 and '86)

Referring to the distribution of change; one can differentiate between woodland in the Western growing areas which have worsened and those in the east that have improved. All the main tree types showed an improvement except in the Black Forest where spruce, fir and beech continued to exhibit high levels of damage. Looking at the distribution of decline with elevation the damage picture for spruce and fir was determined by two developments : an accelerated increase in decline in the already heavily damaged high level holdings; and a deceleration of the increase in damage in the mid to lower regions. The Forestry Experimental & Research Establishment report Schopfer et al. (1986) stated that :

"...the damage situation of the already structurally damaged holdings on exposed and mostly poor nutrition locations becomes steadily more threatening. The danger of a premature break - up of the larger holdings can no longer be excluded within the immediate future."

Opposed to this degradation there had been a general revitalisation of the forest condition at sites below 750m, which was dependant on the structure and density of the stands. The reason for this change, especially for spruce and fir, was undoubtedly favourable weather conditions. In 1986, optimal woodland growth conditions existed, the spring weather in the previous two years was also favourable.

In addition to the assessment of decline symptoms, test trees were also assessed for any signs of fungal or insect damage. What was noticeable was a sharp reduction (since 1984) in the area of damage for conifers and an easing of the infection situation for deciduous species. In fact since 1984, the area fraction of all trees with fungus and insect damage has halved (fir had reduced to 1/5 of the damaged area and spruce to 1/10). As noted in previous years the infection fractions were generally increasing with increasing degrees of damage.

6.2 Institute of Terrestrial Ecology (ITE) Survey

6.2.1 Aims and Objectives

The major objective of this study was the development of a predictive capability for the early diagnosis and objective quantification of forest decline (Cape et al., 1988). Within this framework, a series of predictive tests were developed which could be used to determine the status of trees and forest ecosystems in advance of the appearance of symptoms of irreversible damage; the tasks being as far as possible, indicators of specific pollutants. In practical terms the project involved the development of appropriate methods of forest survey and field sampling, based on existing recommended field techniques and the evaluation of new approaches for assessing early symptoms of pollutant stress. The main sampling strategy was devised after development of the laboratory tests, and exploratory field work in Britain during spring 1986. This programme took the form of a broad transect from the southern Germany to north - east Scotland, encompassing a variety of 'pollution climates'. Foliage samples were taken from three tree species : Norway spruce, Scots pine and beech. Experiments were conducted in the field and samples were preserved for subsequent laboratory analysis.

6.2.2 Sites sampled during 1986

The object behind using a broad 'transect' was to sample trees subject to a variety of different 'pollution climates' which had been identified as existing within western Europe. Seven areas were chosen, based on available data for air pollution, and within each area two sites were selected which differed in at least one other factor (eg. aspect). The sampling sites were located in the areas shown in Table 6.2 and the classification of these regions by pollution climate is summarised in Table 6.2, where '*', '**' and '***' should be regarded as relative terms expressing the importance of a component.

Region	Average SO_2 / NOx Concentration	Frequency of O_3 episodes	Frequency of mist	Acidity of rainfall	Amount of deposited acidity
Black Forest	*	* * *	* * *	* *	* *
Netherlands	* * *	* *	*	* * *	* *
Harz Mountains	*	* *	* * *	* * *	* * *
Fichtelgebirg	* * *	* * *	* * *	* * *	* * *
Southern England	* *	* *	*	* *	*
Western Scotland	*	*	* *	*	* * *
North - east Scotland	*	*	*	* *	*

Table 6.2 Pollution climate of sampling regions (After Cape et al., 1988)

The two sites relevant to the remote sensing study are situated in the Black Forest and Bavarian Forest (Fichtelgebirge) of West Germany. These sites were surveyed in July and August 1986 by ITE; a brief description of each site follows.

6.2.2.1 Kalbelescheuer

Situated 8 km SSW of Munstertal (Fig 6.1) at an altitude of 950m. a minor road runs through the site, which is on a steep slope (c 40°) and has a northerly aspect. Norway spruce grows below the road in a fairly even mixed stand, Douglas fir (Pseudotsuga menziesii), beech and rowan (Sorbus aucuparia) being the other species present. They formed a fairly dense canopy and the mean height of the trees was c 12m. Ground cover was < 50% and comprised grasses, mainly wavy hairgrass (Deschampsia flexuosa) and fern species, with large areas of scree over the remainder covering a freely drained thin sandy soil. Beech trees above and below the road were sampled, these stands were more open and their mean height was c 16m. The soil above the road was deeper and ground cover here was more dense, with grass, herbs and bracken (Pteridium aquilinum) being the main components of the understorey. Needle and leaf yellowing was prevalent on all tree species, together with thinning of the crowns. dead and dying trees, mostly Douglas fir, were common throughout the area.

The map was compiled in 1981 and shows the age of each stand (Lucaschewski, Pers. comm. 1987). There is a range of ages from stands greater than 120 years which lie on the mid - to upper - slopes whilst the younger trees, up to 60 years, tend to lie on the lower slopes. Appendix 1 shows the stocking levels and each of the stands in the area. The majority of stands are mixed with dense stocking levels.

The following are the main features of the climate for the station Obermunstertal for August 1984 and 1986.

	1984	1986
Temp (^oC)	29.9 (Max) 9.6 (Min)	34.1 5.0
Precip. (mm)	11 mm	13mm
Prevailing wind	E & SW	E & SW

(Source : Deutscher Wetterdeinst Wetteramt, Freiburg)

6.2.2.2 Fichtelgebirge

Situated 3 km SE of Oberwarmensteinach (See Fig. 6.1); this is a mountainous area rising to an altitude of 850m. The Norway spruce was a dense uniform stand with a mean height of 20m and was growing on level ground near the ridge with a southerly aspect. Eight Scots pine trees were located in two isolated groups on the edge of a mixed stand of Norway spruce and Douglas fir. The slope here was 10^o and the aspect was to the north. There was a similar slope at the beech stand, but the aspect was north - westerly. The age of the beech stand was variable, with heights ranging from 13m to 18m. Ground cover beneath the spruce and pine was almost complete, with wavy hair - grass, billberry, mosses and ferns present, but there was no ground flora under the beech due to the very dense canopy and thick layer of leaf litter. The trees were all planted between 30 and 40 years ago on moderately well - drained brown earth soil. Yellowing was obvious on the spruce needles and on some of the beech leaves, and, while the pine trees showed no such discolouration, they did not appear to be growing well.

Fig. 6.2 shows the stock map for the area covered by the photography. The 1 : 10, 000 map was compiled in 1982 and shows the stand age distribution. The distribution is not so elevation dependant as the Black Forest area, in fact the elevation variation for the area is not as marked. At the southern end of the area the maximum elevation is 836 m, moving north there is a gradual decrease to 630 m. Therefore, elevation factors may not be as important in determining damage distribution. The stands tend to be fairly heterogeneous with Norway spruce predominating, beech is also present and the occasional Scots pine.

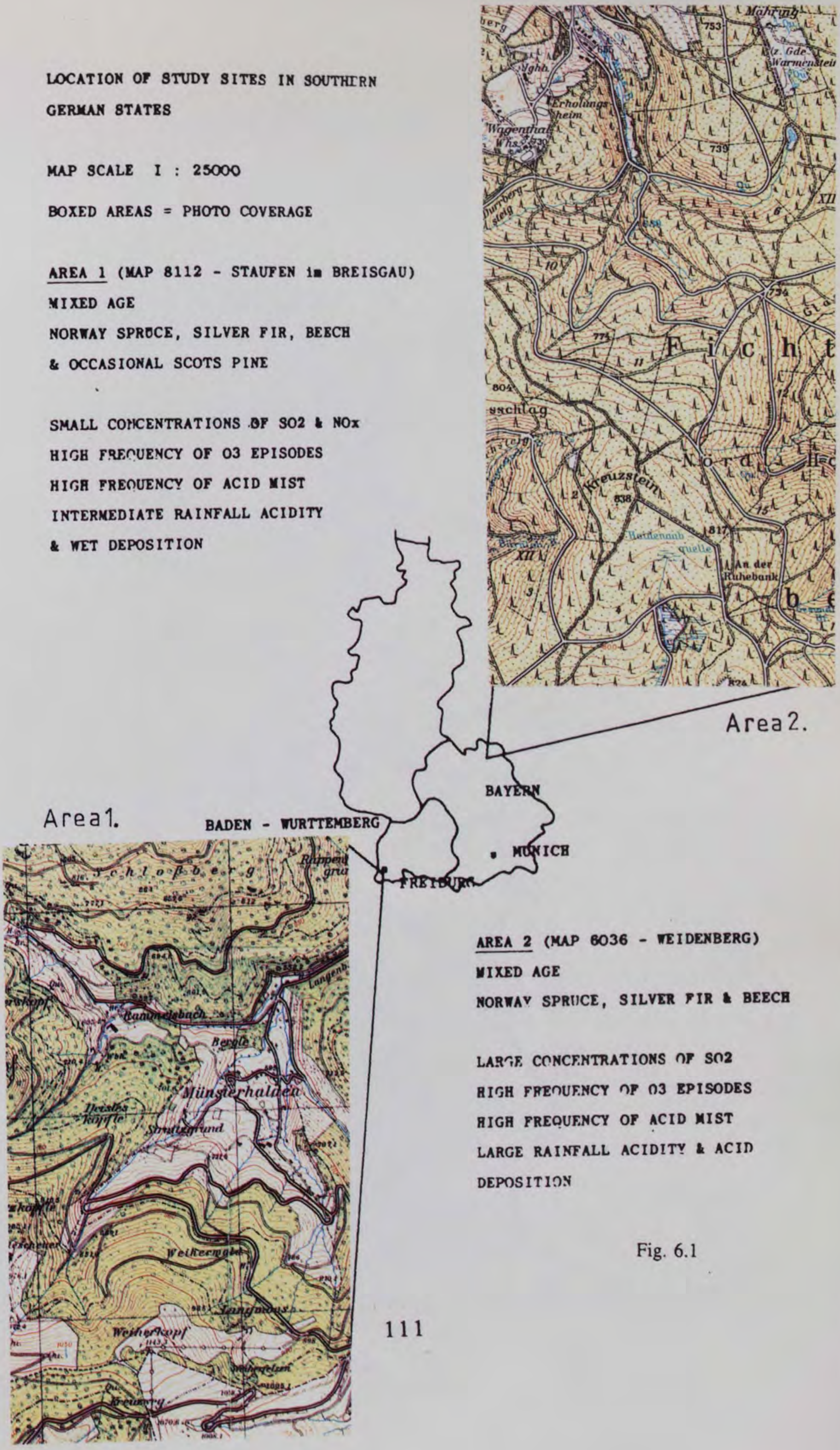
LOCATION OF STUDY SITES IN SOUTHERN GERMAN STATES

MAP SCALE I : 25000

BOXED AREAS = PHOTO COVERAGE

<u>AREA 1</u> (MAP 8112 - STAUFEN im BREISGAU)
MIXED AGE
NORWAY SPRUCE, SILVER FIR, BEECH
& OCCASIONAL SCOTS PINE

SMALL CONCENTRATIONS OF SO2 & NOx
HIGH FREQUENCY OF O3 EPISODES
HIGH FREQUENCY OF ACID MIST
INTERMEDIATE RAINFALL ACIDITY
& WET DEPOSITION



<u>AREA 2</u> (MAP 6036 - WEIDENBERG)
MIXED AGE
NORWAY SPRUCE, SILVER FIR & BEECH

LARGE CONCENTRATIONS OF SO2
HIGH FREQUENCY OF O3 EPISODES
HIGH FREQUENCY OF ACID MIST
LARGE RAINFALL ACIDITY & ACID
DEPOSITION

Fig. 6.1

Fichtelgebirge : Stand Age Map

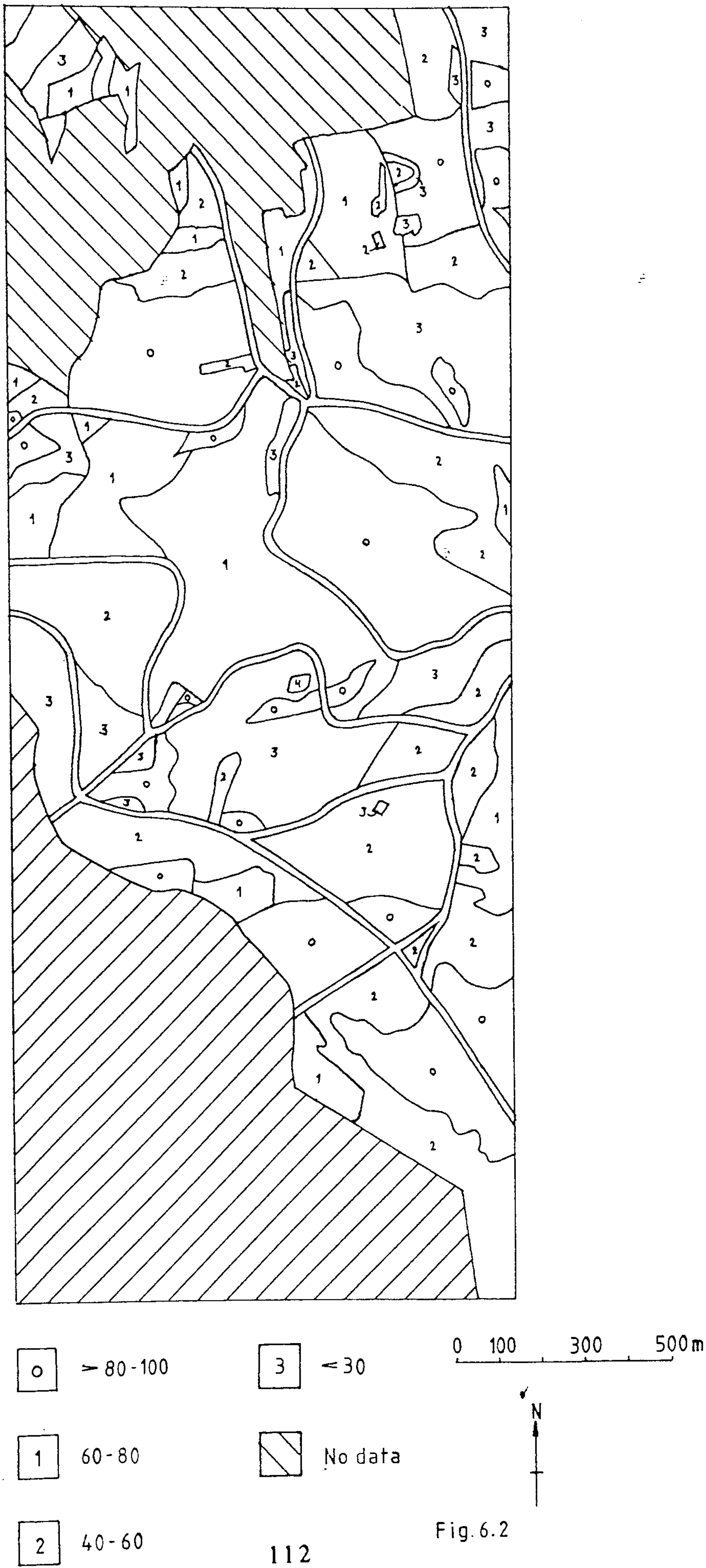


Fig. 6.2

6.3 Photographic data source

6.3.1 Black Forest

The area covered by the photography is shown in Fig. 6.2. The imagery for this area was obtained for 1984, 1985 and 1986; below is a precis of the data from these years.

Year	Film type	Scale	Material
1984	Ektachrome 2443	1 : 5000	Contact print
1985	"	1 : 5000	Transparency
1986	"	1 : 6000	Transparency

Interpretation was conducted on the 1984 and 1986 photography. Unfortunately the IR balance of the 1985 photography was distorted (See section 7.1), therefore this data was deemed uninterpretable. In addition, the 1986 photographic mission was planned as a reconnaisance survey, therefore the image quality was inferior (a wide angle lens having been employed, leading to severe vignetting). However, it was still possible to classify the condition of the majority of the trees. The major difficulty with this process was registering the sampling network due to the differential image geometry. In the absence of an "easy" option, a direct visual comparison between the two sets of photography proved to be the only effective method. Therefore, a sample tree was identified on the 1984 photography then identified and classified on the 1986 photography.

6.3.2 Fichtelgebirge

One set of CIR transparencies (Ektachrome 2443) from 22nd August 1984 was employed in this area. The area covered by this run is shown in Fig. 6.1.

6.4 Alternative data sources

6.4.1 Fluouresence Line Imager (FLI)

In addition to the acquired CIR aerial photography an attempt was made to secure other forms of imagery (other than satellite imagery), in order to augment the digital photographic data (outlined in Chapter 7) . The FLI was designed and built by a Canadian firm, Moniteq Ltd and comprises a high spatial resolution pushbroom scanner which provides imagery in either eight programmable spectral bands (spatial mode) or 288 narrow bands (spectral mode) between 4.3 and 8.0 µm.

In spatial mode, the eight imaging bands can be programmed in steps of 0.014 µm, providing narrow definition of the spectral responses under study. Whilst in spectral mode, the instrument operates as a low resolution push - broom scanner, recording only 40 pixels in the across track direction, but in 288 spectral bands. The recording mode yields a practically continuous spectral curve for the spectral pixels. Successive image lines of 40 pixels are built up by the platforms forward motion into a somewhat distorted, low spatial resolution image.

The scanner was originally developed in 1983 for the Canadian Fisheries Department to measure water quality and depth; thereby charting areas with the best fishing potential. However, its unique capabilities in the forest damage assesment role have been recognised by the forest community in Canada and central Europe. To date , FLI data have been acquired throughout Canada, Vermont, USA and a number of areas in West Germany, Switzerland and Austria.

One area flown in West Germany was the Kalbelescheuer site described in Section 6.2.2.1. Two passes of the site were made in July 1986, one in spectral and one in spatial mode. The spatial data was of more immediate interest due to the higher spatial resolution of 0.33 x 4.26m which would lend itself to the identification of tree crowns (an important consideration). The particular possibilities offered by the FLI are illustrated by the development of a technique to delineate the chlorophyll red edge between 0.68 and 0.8 µm. Referring to Chapter 4, we have seen that chlorophyll controls the absorbtion of the blue and red portions of the spectrum. As the chlorophyll cells deteriorate, the absorbing power consequently decreases and visible blue and red reflectance increases. Therefore, concentrating on the area between 0.68 and 0.8 µm allows analysis of chlorophyll absorbtion and the corresponding increase in near - infrared reflectance (the so - called chlorophyll "red edge").

In a brief assessment of the FLI's capabilities for identifying tree crown dieback in this area of the Black Forest (Buxton, pers. comm. 1987); damaged crowns (class 2) had been distinguished from severely damaged crowns (class 3/4). It was felt by the author that there was potential in merging the spectral FLI data with the structural data offerred by the aerial photography. This combined approach was thought to offer the most effective use of both data sets.

The reason for the failure to use FLI data was simply the excessive cost. One scene of 'spectral mode' data was offered at half the normal price (£1400); however, strict conditions were applied. A proposal was put to the National Remote Sensing Center (NRSC) who were involved in forest decline mapping using TM data (Smith, 1988). However, the NRSC budget for this type of work was allocated to a TM scene of the Munich area and a run of Daedelus airborne TM over a stand of extremely young conifers which had been previously exposed to ozone. It is unfortunate that both of these scenes were never used and the NRSC resorted to a review of the forest decline problem.

6.4.2 Large Format Camera (LFC) data

The LFC is a high quality metric camera taken on Space Shuttle Mission 41 - G on 4th April 1985. Five types of Kodak film (three sections of black & white, a section of aerial colour and a section of high definition colour infrared) were spliced together to fill one LFC magazine in order to evaluate the cameras optical properties at several spectral wavelengths. The image requested covers the Black Forest study area was photographed with Kodak Black and White High Definition Aerial Film (Type 3414). The cost of one transparency was not prohibitively expensive at US $100, however, the reason for non - purchase was the fact that the image was classified by NASA as having 70 % cloud cover, which was deemed unacceptable in the circumstances.

Chapter 7 : Automatic Classification Techniques

7.1 Colour - infrared photography

7.1.1 Introduction

In 1861, Maxwell discovered that adding light from three primary colour sources (red, green & blue) led to a combination of secondary colours. Therefore by varying the intensities of the primary colours it proved possible to exhibit a wide range of hues. Such a technique is termed an "additive" process and is applied to multispectral photographic techniques.

All colour photography however, makes use of a subtractive system which is the inverse of the additive process. when white light is available for viewing photographs this system allows the use of three dyes in the film emulsion; each of which controls the light of one primary region of the visible spectrum. The dyes themselves are the three products of the additive system, namely cyan, magenta and yellow. The cyan dye transmits in the blue and green primary regions but absorbs (controls by its concentration) transmission of red light. Magenta transmits in blue and red regions whilst controlling green light and yellow transmits in red and green regions whilst controlling blue light. Therefore a scene will be depicted in true colour when viewing normal colour film.

7.1.2 Characteristics of CIR film

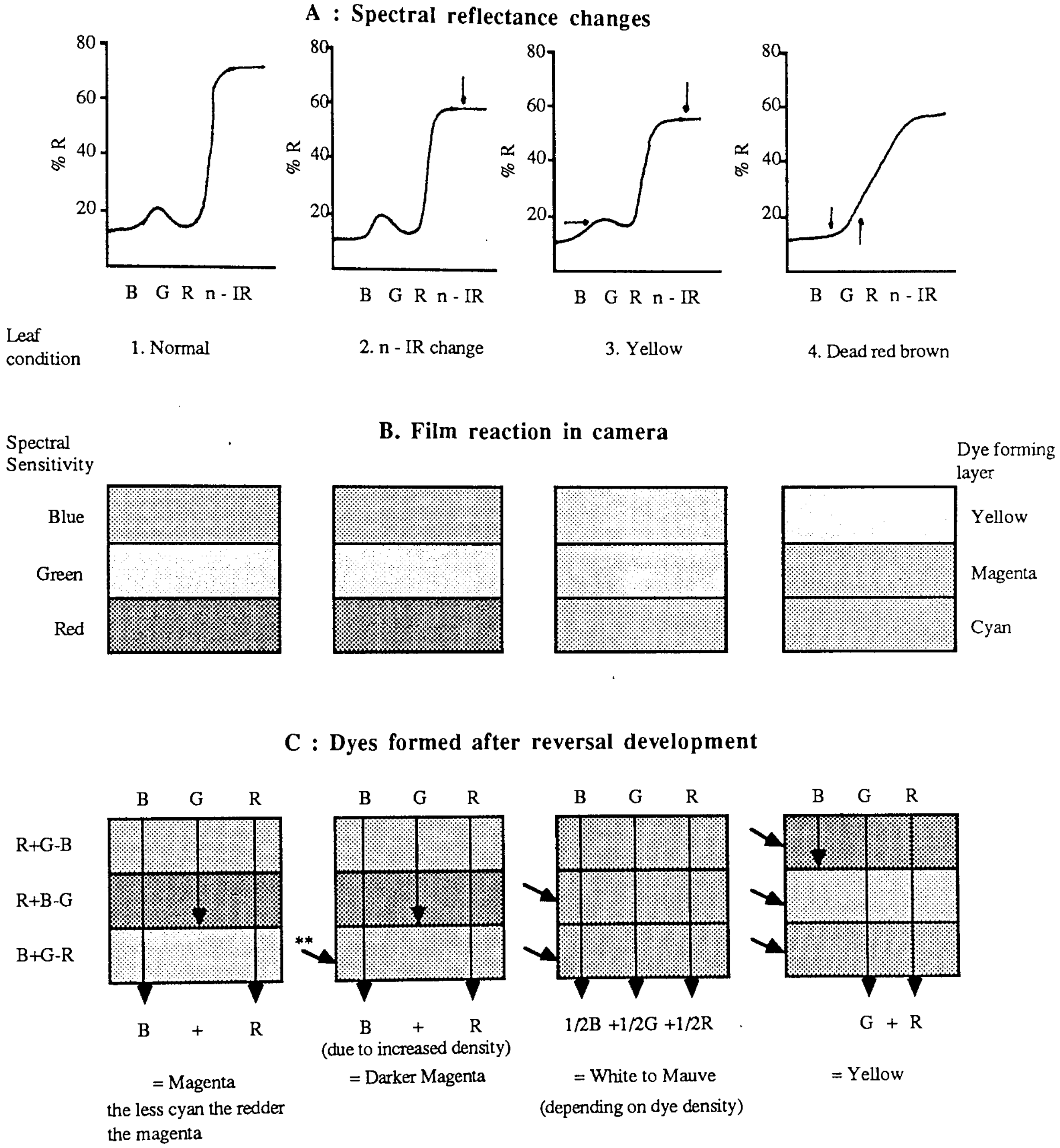
Infrared film is a material with a spectral sensitivity that extends into the near - infrared (0.7 - 0.9 μm) region of the electromagentic spectrum. CIR film was developed during the first decades of the 20th century, infrared film was first used operationally to detect camouflage during the Second World War. This ability is explained by the differential reflectance of infrared radiation between healthy vegetation and camouflage canvas. The canvas would appear darker due to the greater infrared absorbtion. In order to enhance this detection capability, a "false" colour or colour - infrared film using the colour additive process was developed by Leopold Mannes and Walter Clark in 1942 (Wells & Holz, 1985).

Within a CIR film emulsion each dye forming layer is sensitive by varying degrees to blue, green and near - infrared radiation (Marshall, 1968). The optimal photographic results occur when each layer has its peak reaction in one band of radiation. To make this possible, a yellow (minus blue) filter is placed before the camera lens to block wavelengths shorter than 0.5 µm. The dye forming layers then respond to the green, red and infrared wavelengths. The CIR emulsion produces "false" colours since the response of the dye forming layers has been shifted along the electromagnetic spectrum. Therefore, objects that predominantly reflect green light will be reproduced as blue whilst objects reflecting predominantly infrared radiation are recorded in shades of red. Blue reflecting objects appear as shades of grey or black. CIR film has several basic advantages over normal colour film. The advantages are as follows :

- CIR film responds to near - infrared reflectance which is invisible to the human eye,
- CIR film penetrates haze (but not smoke or heavy concentrations of mie particles).Haze causes light scattering at the shorter wavelengths (primarily the blue region), but since radiation in the blue is filtered haze this becomes much less of a problem with CIR film. Consequently CIR film is more effectively used from high altitudes than is normal colour film,
- CIR photography emphasizes contrast in a scene; thus photos are easier to interpret for subtle or masked colour differences.

The reccuring problem with any infrared film is the lack of an objective colour balance which one encounters with normal colour film. Subsequently, the colours must be manipulated through the use of colour compensating filters in order to attain the optimum colour balance on the final positive print. Such filters control by attenuation; this means that one colour is controlled whilst one or both of the remaining two colours are transmitted (Manual of Colour Aerial Photography, 1968). The use of the term optimum in this case must, in the opinion of Fritz (1977), depend on the mission objective rather than assuming that a "pleasing" colour balance is optimum. For example, in such applications as geology, engineering, pedology, the relative characteristics of the objects being photographed are quite different from those of normal foliage. When attempting to distinguish foliage characteristics there exists the possibility that, for maximum discrimination of reflectance differences, a seasonal modification in balance may prove beneficial.

Reaction of Colour - infrared Film to Reflectance Changes Fig. 7.1



* each of the dye forming layer is sensitive to blue light, but use of a minus blue (eg. Wratten 12 filter) prevents unwanted blue exposure of the dye layers.

** arrows indicate important changes

(After Murtha, 1983)

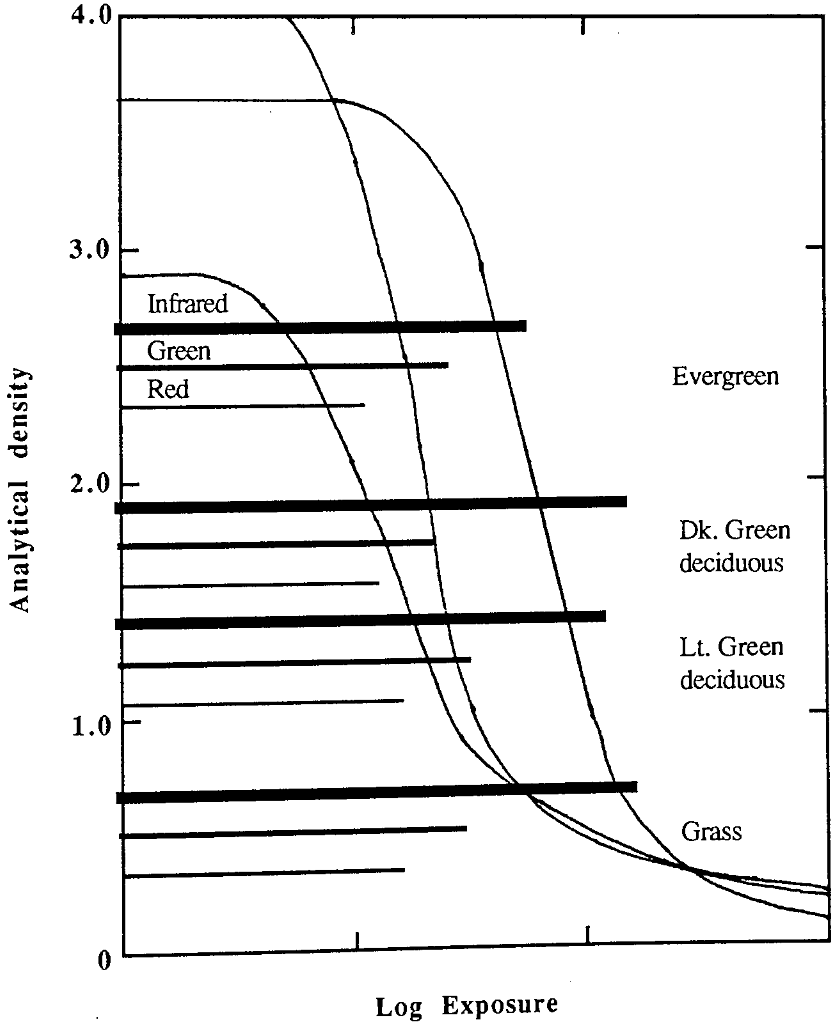
In order to allow discrimination between the infrared reflectance of different vegetation types, more exposure is required to produce a given density in the cyan - forming layer than in the remaining two layers - the cyan layer is said to be "slower" than the magenta and yellow layers (Fritz, 1977). This layer has deliberately been made slower in order to compensate for the high infrared reflectance of foliage. If the sensitivity were not so decreased, the layer would be grossly overexposed and there would be no variation in cyan density when differences in infrared reflectance occur. Fig. 7.2 illustrates this phenomenon with the relative reflectance characteristics of four vegetation types superimposed upon a CIR films sensitometric curves. By quantifying the differences in exposure between the cyan layer and the remaining two layers at Density (D) = 1.0 (See Sec.7.2.1) it is possible to achieve a measure of infrared balance allowing corrective filtration if required. The formula for infrared balance is :

$$\text{IR balance} = 100\,\Delta \log Hb$$

Where $\Delta \log Hb$ equals the shift in exposure between the centre of the green and red curves and the infrared curve at D = 1.0. The concept of a density value for a single point is the basis of densitometry. This technique can be used to quantify IR balance and digitise photographic data.

Relative Exposure superimposed on Sensitometric curves

Fig. 7.2



7.2 Digitisation of CIR Photography by Densitometric Analysis

7.2.1 Physical Principles of Densitometry

Optical densitometry is the science of quantifying the optical information contained in an object (Hills, 1986). When applied to photographic images there exist two main objectives :

- conversion of the analogue image to a data set compatible with a computer;
- preservation of the integral qualities of the data such that the original data can be digitally reproduced with no readily interpretable difference as a test of quality, (Deigan, 1981).

Since information is being quantified, an absolute unit of optical density needs to be established. For black and white imagery, density is defined by the equation :

$$D = \log 1 / T = \log (a / b)$$

where D = optical density, T = transmittance (b / a), a = the intensity of the incident light, b = the intensity of the transmitted light. Since D is logarithmic, the overall density of a series of individual samples is the sum of the individual D values of each sample. When dealing with a colour film, the individual samples are the base layer (B), cyan dye layer (C), magenta dye layer (M) and the yellow dye layer (Y). Therefore :

$$D(\ \ ) = DB(\ \ ) + DC(\ \ ) + DM(\ \ ) + DY(\ \ )$$

where D ( ) is the overall density or integral density. The component densities of B, C, M and Y are called analytical densities (Scarpace, 1978). In a mutilayer film such as CIR, one of the tasks of densitometry is to determine the analytical densities from a multitude of integral density measurements.

7.2.2 Scanning of Black Forest CIR Prints

The equipment used in this process was a Joyce - Loebl Scandig single pass colour scanner. One CIR print from the 1984 Black Forest batch was mounted on the rotating transparent drum. Since the print is opaque, the density collection optics (white light from a tungsten - halogen source) measure the reflected light. If a transparency had been used the transmittance through the emulsion would have been measured.

The white light source is mounted outside of the drum on a carriage which is free to move along the axis of the drum. The drum rotation corresponds to a scan line across the sample in the Y direction, whilst movement of the optical carriage along the drum axis corresponds to a scan in the X direction. In operation the rotating drum is mechanically coupled to a rotary encoder which can output a light pulse for every 25, 50, 100, 200, 500 and 1000 μm. For the purposes of this study, one 9 X 9" print was scanned at 100 μm whilst a 2 cm sq area in the centre of the print was scanned at 25 μm. To measure the reflectance, two high intensity light beams are projected onto the print at 45 ° from the measuring axis with the collection optics picking up the reflected light from the sample.

Full colour analysis is achieved by separating the reflected light from the three primary colours (plus a B. & W. channel), detecting and measuring each seperately. Each of these channels is linear in nature; i.e. the output is proportional to the light intensity falling on the photomultiplier. Since a measure of optical density is required, a logarithmic amplifier converts the voltage to an analogue representation of density. This voltage is then transformed by a high - speed eight - bit analogue - to - digital converter, which gives an output data resolution of one part in 256. Therefore, each pixel contains four components (red, green, blue & black and white) each 8 - bits deep.

Deigan (1981) has quantified the achievable resolution using different combinations of film scale and optical aperture. The print used in this study had a scale of 1 : 5,000; therefore given an aperture of 25 μm a ground resolution of 0.125 m was produced. An aperture of 100 μm resulted in a ground resolution of 0.5 m. The time taken to achieve a scan will not only depend upon the area to be digitised and the aperture in use but also on the speed with which the host computer can accept data. For the Scandig, maximum data output rate will be at the maximum drum speed of 10 revolutions / sec. and highest resolution of 25 μm. Each pixel gives an output of four bytes, so the data transfer rate can be up to 800 Kbytes / sec. In this case the maximum drum speed was chosen, so for an aperture of 100 μm on a 23 cm sq area the scan was completed in 3.5 minutes.

7.3 Digital photographic data for forest stress detection

The use of acquired digital data in the form of airborne multispectral scanner scenes was and still is not considered operational as a damage assessment tool (Koch & Kritikos, 1984, Kritikos et al., 1985, Kadro & Kuntz, 1986). Therefore emphasis has been placed upon CIR photographs for forest condition monitoring. As an alternative measure some workers have used digitised CIR photography in an attempt to apply digital image processing techniques.

Akca (1971) and Schneider (1978) devised automatic measures of forest tree species on digital photographic data using densograms; these are cross sections of image tone scanned across each stand. Applying discriminant analysis to the results produced excellent separation between young, middle aged and old spruce stands. The use of such textural measures was espoused by Schneider (1978) who outlined the possiblity of determining other stand parameters such as age, crown diameter and number of trees per unit area. As with manual interpretation procedures, the first stage of automated tree stress detection is tree species identification. Certainly in the homogeneous temperate forest of Europe, this initial classification does not present great problems. However, when attempting to assess crown condition one is dealing with numerous possible damaging agents, each of which have their own distinctive symptoms and methods of attack (Gaucher et al., 1978). Unfortunately the symptoms as viewed on an aerial photograph and the degree of severity of attack may only produce minor changes in crown form and spectral response.

Gaucher et al. (1978) drew up guidelines for extracting stress levels based upon measurements of reflected or emitted energy from vegetation surfaces. One important consideration is the use of a sensitometric wedge which is simply a series of known exposures on the leader or trailer of the exposed film. It is useful because any film density measurement must be corrected for exposure and then for the reflectance of the object of interest. Reliance on uncontrolled spectral density measurements was rebutted by Lillesand (1979) who stated that no single measurement would provide an overall picture of tree crown condition. Lillesand (1981) recommended the use of a red / infrared ratio which highlights objective colour differences by normalising absolute brightness variation across a scene.

Edwards & Blasquez (1985) utilised ratio images for monitoring citrus tree stress. A general rule was induced that tree ratio values for healthy trees were consistently smaller than for stressed trees. Comparing the automatic classification with a manual interpretation (acting as ground truth), a correlation coefficient of 0.85 supported the accuracy of this technique (at the 1 % confidence level).

Ratio images have also been applied to insect defoliation studies. Jackson & Wallen (1975) and Hall et al. (1983) reported on a microdensitometric analysis of CIR film for Douglas fir - beetle attack. Images of successfully attacked trees had significantly higher crown density values than images of healthy trees, indicating a decrease in infrared reflectance with damage. The ratio between red / infrared and green / red were also significantly different between healthy and damaged crowns. Discriminant analysis indicated that the best parameters to use, in order to separate healthy from damaged trees, were the green / red ratio and green response. The green / red ratio indicated important changes in the visible response, allowing for the use of normal colour film in this case.

Standard supervised classification algorithms have been applied to insect damaged crowns. McLean & Giese (1976) classified a digitised CIR transparency with a minimum distance to means classifier. As a result five distinct defoliation categories were derived and it was concluded that automatic classification techniques were superior to manual interpretation. In this case the automatic classification provided more detail, was more accurate and could be generated in a relatively short amount of time. Quantifying Douglas fir Tussock Moth defoliation, Lee & Wear (1978) could not achieve the same measure of success. Separation of healthy and damaged trees was achieved, however, further stratification into defoliation categories was not deemed possible.

Applying standard supervised classification procedures to forest decline. Meyer et al. (1985) achieved relatively low accuracies of 55 % using a maximum likelihood technique. The best results were obtained using a six band parallelpiped technique. The bands were created using a principal components (PC) transform applied to the original three band data set. This resulted in three new components; brightness, red - greenness and blue - yellowness for the spruce and pine under investigation. For subsequent analysis, all three 'spruce' components and the first 'pine' component were considered. To create band five, the PC bands were filtered using a 5 x 5 center - weighted low pass kernel which reduced the dynamic range of the data. Finally, band six was created using a 5 x 5 texture kernel from which the standard deviation of the 25 pixels was calculated.

An important aspect of this work was the post - classification imposition of tree polygons. This led to improved classification results and hence greater standardisation. The use of polygons is essential in this type of work and their applicability in training area selection has been favoured by Haenel (1985) and Pinz (1985). Haenel (pers. comm.) has developed a method of stereoscopically adjusting polygon outlines to provide an accurate determination of tree crown position. Particularly important when attempting to classify beech canopies which tend to be homogeneous with ill - defined edges.

7.4 Automatic classification

7.4.1 The minimum distance to means algorithm

The minimum distance to means decision rule is computationally simple but can result in classification accuracies comparable to other more computationally intensive algorithms (Jensen, 1986). The algorithm simply calculates the distance from an unclassified pixel to each training area class mean. This distance is usually calculated using Euclidian distance based on the pythagorean theorem. The computation of Euclidean distance relies on the equation :

$$\text{Dist} = \ (BV_{ijk} - u_{ck})^2 + (BV_{ijl} - u_{ct})^2$$

where BV_{ijk}, BV_{ijl} = unknown pixels; u_{ck}, u_{cl} = means for each class in bands k to l.

7.4.2 The maximum likelihood algorithm

The maximum likelihood decision rule assigns each pixel having pattern measurements or feature X to the class k whose units are most probable or likely to have given rise to feature vector X. It assumes the training data statistics for each class in each band are normally distributed (i.e. Gaussian in nature). The probability P(X) that a pixel vector X of P elements (a pattern defined in terms of P features) is a member of class k is given by the multivariate normal density :

$$P(X) = 2\pi^{-0.5p} [S_i]^{-0.5} \exp[-0.5(y' S_i^{-1} y)]$$

where [.] = the determinant of the specified matrix; S_i = the sample variance - covariance matrix for class i; $y = (x - x_i)$ and x_i = the multivariate mean of class i.

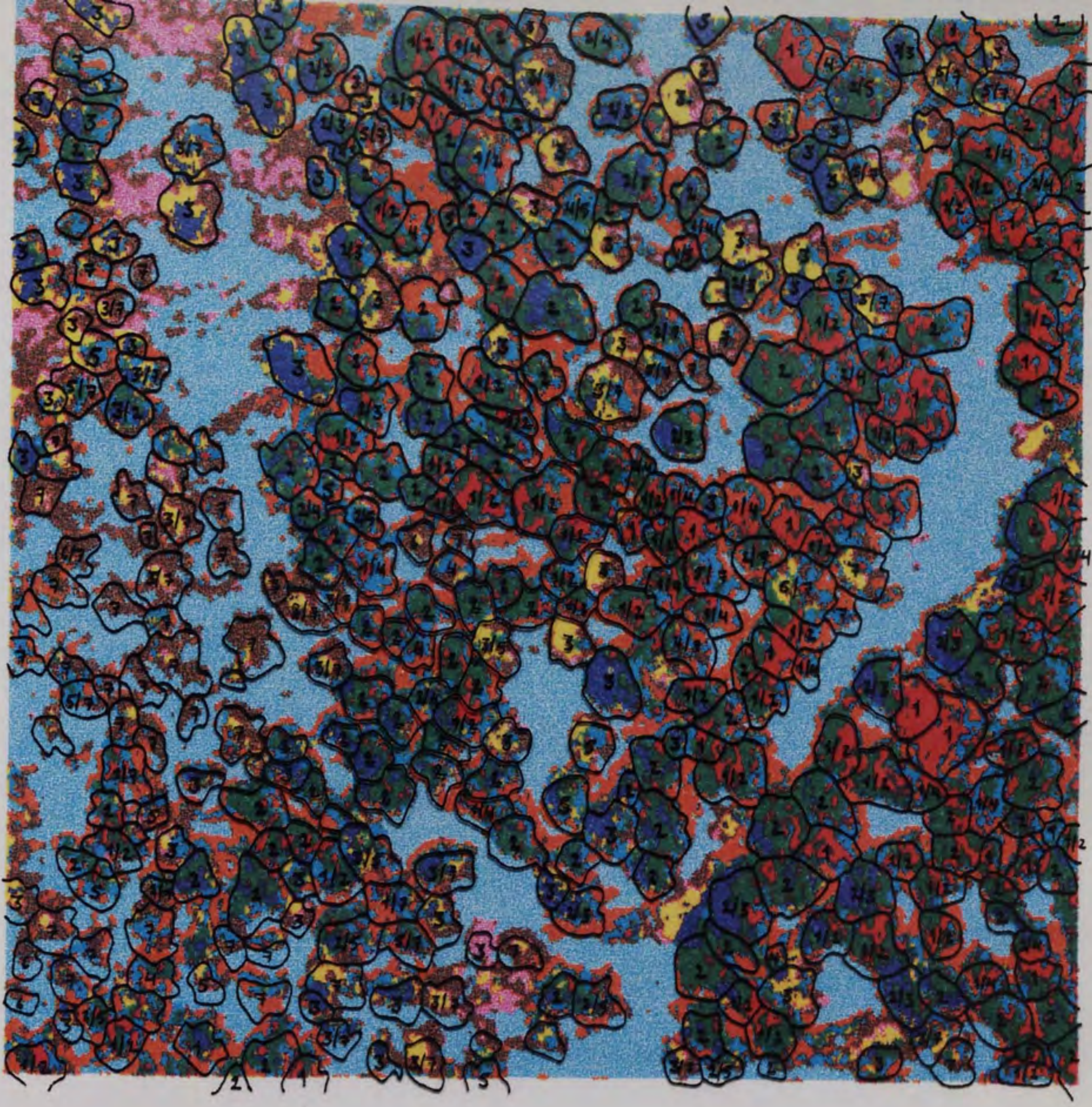
7.4.3 Manual interpretation

Rather than using training area statistics to estimate classification accuracy a decision was made to interpret the classification on a tree - by - tree basis. The reasoning behind this decision was based upon the standard manual classification rules applied to the photography in West Germany. The reason that large scale CIR photography is chosen to classify forest decline is that the interpretation attempts to assess the condition of individual tree crowns. This is done because the decline affects adjacent crowns to different degrees. Since the manual interpretation is carried out in this way it was felt that in order to gain a full assessment of the strength of the automatic classification, the accuracy of this approach must be calculated using the tree - by - tree approach. If the automatic classification could not recognise the species and its damage class then it was deemed to have failed. The assessment involved a direct comparison between the classified image and the manually classified photograph. Since no ground data was available for the classified trees , the interpretation of the aerial photography by manual means was accepted as the prime data source. This stage of the interpretation involved definition of the species types and damage class for each tree in the previously digitised area.

Species	Total number	Damage class
Beech	275	0 -45 1 - 135 2 - 72
Fir	65	0/1 - 15 2/3 - 50
Spruce	36	0/1 - 8 2/3 - 28

Table 7.1 Total number of beech, fir and spruce occuring in test scene

Fig. 7.3 and Fig. 7.4 show the extent of this area and the overlays representing species and damage class for both minimum distance and maximum likelihood classifiers. The complete interpretation process took approximately 3 man hours which is the baseline from which the automatic classification procedures are compared. Detail of the manual interpretation procedures have been outlined in Chapter 6. Tables 7.1 and 7.2 show the number and characteristics of trees in each species and the damage class identified in the image.



Minimum Distance Classification

🟥 Beech : Class 0

🟩 Beech : Class 1

🟦 Beech : Class 2/3

🟦 Fir : Class 0/1

🟨 Fir : Class 2/3

🟧 Spruce : Class 0/1

🟫 Spruce : Class 2/3

🟦 Shadow

🟪 Grass

Fig. 7.3 Minimum distance classified scene

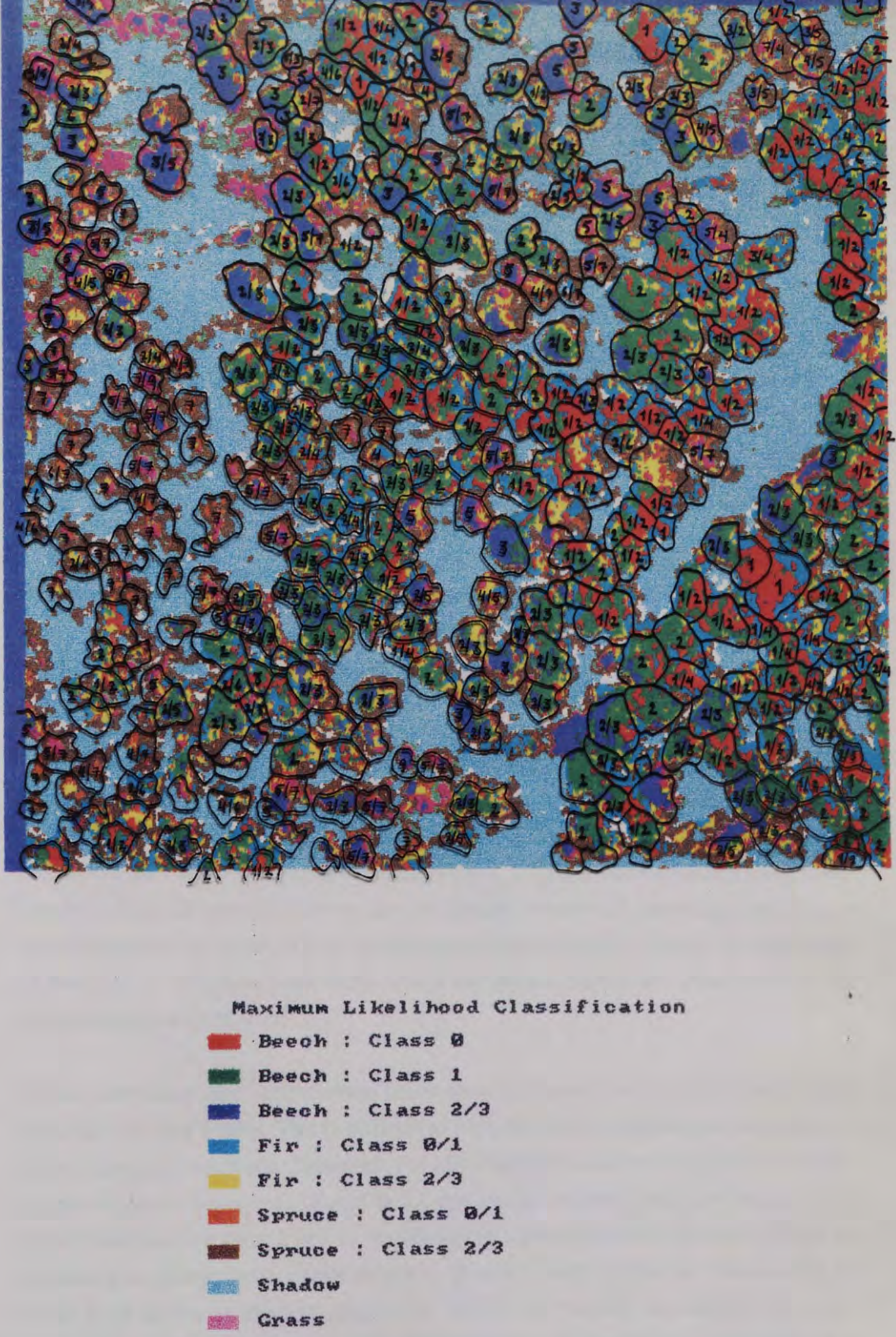


Fig. 7.4 Maximum likelihood classified scene

Species	Advantages	Disadvantages
Beech	Dense crowns. Strong spectral change as damage progresses. perimeter.	Homogeneous canopy. Variable crown size. Shadow effect around
Fir	Dense crowns. Regular crown structure.	Similar spectral response to beech. Occurs in predominantly mixed canopies (with beech). Damage manifested as strong structuralchange (Stork's nest). Shadow effect around perimeter.
Spruce	Regular crown structure. Spectrally seperate from beech and fir.	Sparse crowns induce intra - crown shadow effects.

Table 7.2 Suitability of crowns for accurate automatic classification

7.4.4 Minimum distance to means classification results

The confusion matrix (Table 7.3) shows the average accuracies for each of the identified crown classes obtained using the minimum distance to means algorithm. Immediately striking is the consistency of the results obtained for beech as compared with fir. Within the beech classes there is a certain amount of confusion between healthy beech (B 0) and slightly damaged (B 1). This is not surprising since there are only minor differences between the two groups in terms of percentage defoliation and discolouration. Again, it is worth noting that trees in class 1 should be considered as being in a transition zone from which the crown condition could improve or deteriorate (Schopfer, 1987).

Similar confusion also occurs where beech trees in classes 2 or 3 (B 2/3) have been classified as class 1 trees. This is difficult to explain since the differences here tend to be of a greater magnitude. However, the misclassification does highlight the major pattern of beech damage displayed in the test image. Namely, that the change from class 0 condition to class 2 or 3 is manifested in a predominantly spectral change as opposed to a change in the crown structure. In other words, whilst the crowns tend to retain their leaves as damage progresses, the leaves become increasingly necrotic (yellowing of the leaf surface). This phenomenon is subsequently manifested by a change in the spectral reflectance and hence on the appearence of crowns on the photograph (refer to Chapter 4). Such a spectral change will be more successfully classified using a standard spectral classifier.

With reference to the fir crowns; different damage symptoms present different problems for the classifier. According to Table 7.3 the majority of healthy fir has been classed as damaged spruce. The spectral differences between these two classes are quite marked, therefore an explanation for this anomaly can only come about with reference to the image and test site characteristics. Study of the original digital data (Fig. 5.2) shows the absence of a truly healthy fir from the scene. This category was included in the analysis by combining the healthy (0) and slightly damaged (1) classes (F 0/1). The results show that this experiment was not successful; however it does highlight the major problem faced when attempting to classify fir trees using a purely spectral approach. In Chapter 5 the major symptoms of damage as apparent on a fir crown are outlined. The most prominent feature of this progression is the development of the so called 'stork's nest' syndrome. What this represents in terms of the digital number output are low digital values occurring in the top crown with very high values occurring in the lower crown.

		Manual Classification						
		B 0	B 1	B 2/3	F 0/1	F 2/3	S 0/1	S 2/3
	B 0	66	3	---	13	---	---	---
	B 1	16	73	26	---	2	---	---
Auto - matic	B 2 / 3	---	5	59	13	60	---	11
	F 0 / 1	13	9	3	---	2	---	---
	F 2 / 3	---	4	4	13	8	---	---
	S 0 / 1	---	---	---	---	---	25	4
	S 2 / 3	5	5	7	60	28	75	86

Average classification accuracy = 53.3 %

B = beech, F = fir, S = spruce

Table 7.3 Confusion matrix for minimum - distance classifier (%)

Taking one such crown as a training area means that the values will be averaged, leading to a false impression of the trees health as well as confusion with other species. Returning to Table 7.3 , fir trees in classes 2 or 3 (F 2/3) are confused with beech and spruce in these classes. This is because invariably there will be more bare branches than healthy foliage present in a class 2 fir crown. Consequently, the average digital value for this crown corresponds to the values obtained for damaged beech and damaged spruce.

A similar problem was encountered when attempting to classify spruce into a healthy (S 0/1) or a damaged group (S 2/3). In the test image there are no completely healthy spruce crowns; the best example being a class 1 crown. Therefore a combined class 0/1 was taken as the healthy spruce group and a class 1 crown provided the training area statistics. As Table 7.3 shows however, the majority of trees in this group were classed as damaged spruce. Unlike, the true damaged spruce, of which, 86 % were correctly classified. The major reason for the confusion between healthy and damaged spruce is partly due to the lack of a truly healthy crown and the correlation with other crown training data leading to inter - species confusion. The misclassification problem is compounded in the spruce crowns by the sparse crown structure which induces a strong shadow component into the crown area, thereby masking the true reflectance properties of the crown. The infrared reflectance associated with healthy spruce is lower than that of fir of beech therefore one would expect intra - species confusion with healthy spruce crowns. As Table 7.3 indicates this phenomenon was encountered in the test image where 75 % of healthy crowns were classified as damaged.

7.4.5 Maximum likelihood classification results

Table 7.4 is the confusion matrix for the maximum likelihood classification. As with the minimum distance classification, the results for the three beech classes were more consistently accurate than those of the other two species. Echoing the results for the minimum - distance classifier the beech proved to be more consistently classified. The confusion between healthy (B 0) and slightly damaged (B 1) beech is to be expected given the interrelation between the two classes. The confusion between slightly damaged and severely damaged (B 2/3) is again prevalent in the classification process. The most successfully classified group is B 2/3, this is not surprising since, as was mentioned in section 7.4.4, the spectral properties of this class are far removed from the previous class.

		Manual Classification						
		B 0	B 1	B 2/3	F 0/1	F 2/3	S 0/1	S 2/3
	B 0	66	1	---	---	---	---	---
	B 1	22	62	4	50	7	---	---
Auto - matic	B 2 / 3	2	28	79	---	22	---	---
	F 0 / 1	9	6	1	---	2	17	3
	F 2 / 3	---	1	15	---	42	---	47
	S 0 / 1	2	2	---	33	---	---	---
	S 2 / 3	---	---	---	17	27	83	50

Average classification accuracy = 49.3 %

Table 7.4 Confusion matrix for maximum - likelihood classifier (%)

The only confusion occurs with severely damaged fir (F2/3) which is explained by the fact that the spectral response (mirrored in the digital number) of bare branches and necrotic foliage is similar for any crown. Looking at the results for the combined healthy / slightly damaged fir class the total misclassification is a product of a lack of healthy foliage on the one hand and the similar spectral response to healthy / slightly damaged beech and spruce. A similar problem was encountered with the combined damaged groups (F 2/3), which although distinct from the healthy classes are confused with the similar classes for beech and spruce. Again the problem encountered is one of a lack of possible spectral response values of bare branches and necrotic foliage. A similar misclassification pattern to fir is associated with the spruce crowns which can be explained by reference to section 5.4.4. The only difference with the minimum - distance classifier is found in the lack of success identifying severely damaged spruce (S 2/3). The overall accuracy of the maximum - likelihood classifier is lower than that of the minimum - distance classifier. No specific reason can be given for this result, however, this does tally with the experience of Meyer et al. (1985).

7.5 Evaluation of an automated interpretation approach within the inventory framework

The major problem with the Black Forest data was the fact that the digitised image was a print and not a transparency. When using a densitometer, a transparency is prefered because there is less margin for error since not only is the transparency the primary hard - copy product (a contact print was derived from the transparency) but the digitising process is less efficient when measuring the reflected light from the print as opposed to the transmittence. The training area statistics confirm this, since there is a high degree of correlation between the three bands of data. This situation can be improved by the application of principal components analysis which would find the maximum separation of the training areas (Meyer et al., 1985). However, the author must conclude that, certainly in the case of the Black Forest data, both classification procedures were unacceptable when compared with the manual interpretation.

The saving in time using the automatic procedure cannot outweigh shortcomings of the results. Any scheme which can only classify 50 % of the scene correctly cannot be accepted as an operational procedure. Meyer et al. (1985) obtained similar results using a maximum likelihood technique. However, they increased classification accuracy to 90 % using the procedures outlined in section 7.3. What must be considered here is that the digitised photography used by Meyer et al. (1985) were transparencies (unlike the Black Forest study which used second generation prints) and the classification was concentrated on one species, namely pine. Unfortunately the training classes used only included healthy and damaged crowns and could not differentiate between the standard five classes. To conclude Meyer et al. (1985) recommended investigation of textural analysis to enhance the scheme; in summarising, however, they doubted if digitised photography would ever fulfill the requirements for crown condition assessment and predicted that airborne scanner data would provide the only true competitor for manual interpretation in this field. Whatever the level of sophistication involved in this process, the final classified image will still need to be cross checked for accuracy. The only way to do this would be through field visits or the generally accepted way of manual photo - interpretation. The author is certain that the application of automated techniques to forest condition mapping should not be applied to the classification of the condition itself but could be more usefully applied to the process of digital mapping and change monitoring. In other words it is felt that an approach biased towards GIS as opposed to pattern recognition would more usefully contribute to the development of efficient and accurate inventory techniques. Chapters 8 and 9 attempt to describe such an approach based on manual interpretation of CIR photography but manipulating the results automatically in an intensive mapping exercise.

Chapter 8 : Damage Rating

8.1 Introduction

Mason et al (1981) defined damage rating as :

"an evaluation of potential risk to determine what portion of an area can be considered safe and what portion must be considered potentially dangerous."

When applied to forest pest damage appraisal, the technique is known as risk-rating and involves assessment of the susceptibilty of a tree, or stand of trees, to damage by an outside agent. In North America, as evidenced by the large amount of available literature, risk rating has been applied sucessfully in combating the impact of defoliating insects. As early as 1936 a susceptibility classification for Ponderosa pine (Pinus ponderosae), host type of western pine beetle (Dendroctonus brevicomis. Lec.), was developed (Keen, 1936). The classification was based on ground observations of foliage and crown characteristics, trees being grouped into sixteen condition classes based on age and crown vigour. This scheme involved a detailed and time consuming "timber cruise" on the ground. However, ground based systems continue to be applied for pests such as western pine beetle, Dentroctonus brevicomis (Wickman & Eaton, 1962), Mountain pine beetle (Stevens et al ,1980), Saratoga spittle bug (Heyd & Wilson, 1981), Douglas fir beetle (Furniss et al, 1981) and southern pine beetle (Zarnoch et al, 1984).

The chief difficulty encountered when applying any hazard rating system on the ground is recognising and establishing stand bounderies and determining the number of points within a stand which should be observed to adequately represent average conditions.

8.2 Risk rating

8.2.1 Aerial survey

A variety of photographic emulsions and scales are used in risk rating systems. Mason et al. (1981) identified the following combinations of scales which can be used to rate southern pine beetle (SPB) hazard. The simplest approach involved small scale aerial photographs with a supplement of black - and - white resource photography (flown each year to map the existing forest resource). The aim of this risk rating analysis was to distinguish stands which were prone to SPB attack. Unfortunately large and medium-scale photos generally revealed too much tree information, making it difficult to distinguish between stands and consequently small-scale (1 : 40,000 - 1 : 120,000) CIR photography was employed for the delineation of stands with distinctive tone and textural patterns. Medium scale photography was then used to examine each stand in more detail, extrapolating this information back into the small-scale classification to produce a stand hazard map. As an alternative to this approach, especially for small or mixed ownership forest where existing resource photography does not exist, it is possible to utilise 35mm vertical or oblique supplementary photography or ground checking to provide the necessary detail. Ground observation however, is time consuming and cannot provide the valuable aerial perspective when comparing stand detail on the ground to high- altitude photographic interpretations (Mason et al, 1981). It is believed by some that cost effective hazard rating systems can only be implemented using existing resource photography. Special flights or field survey greatly inflate the cost of insect suppression programmes, which should form part of the standard management procedures - the extra cost of photographic missions is normally deemed unacceptable (Mason, 1979).

The potential value of such an approach, where special funds or equipment are not required, was demonstrated by Heller and Sader (1980). They described a Tussock Moth risk rating system based purely on existing 1: 24, 000 black - and - white resource photography. Measurements of aspect, slope, elevation, crown diameter, crown density, topographic position, stand purity and radiation index (see Sec 8.2.9) were recorded for sample stands. This information was obtained from aerial photography or United States Geologic Survey (1 : 24, 000) topographic maps. All data were subsequently transferred manually to the final hazard maps using a Bausch & Lomb Zoom Transfer Scope (ZTS). Risk information from the map and photographic data were quantified using multiple regression techniques and an equation was produced which assessed the probabilty that a stand would show signs of damage. The general equation developed from air photos and maps as given by Heller & Sader (1980) was :

$$P = [1 + \mathrm{Exp} (- (- 0.431977 - 0.00011853 E + 0.00283975 S + 0.453617 R1 + 0.779423 R2 - 0.235660 T + 0.0217967 D + 0.0232085 CD))]^{-1}$$

where : P = the probability that a stand will be attacked, E = elevation, S = slope, R1 & R2 = Radiation index, T = topographic position, D = crown density and CD = crown diameter.

This is a good example of a relatively inexpensive but effective application of aerial photography.

Where photography has been commissioned for a particular risk assessment, the most popular emulsion has proved to be CIR. Sader & Miller (1976) had previously utilised 1: 24, 000 CIR photography for developing a SPB risk rating system in Mississippi. All old and recent infestation sites were mapped on the imagery and data were recorded on stand composition, size of dominant overstory, density of the stand, topographic position and approximate number of trees affected. Evaluation of the characteristics of 235 infestation sites showed good agreement with field data for the same sites. The percent distribution of stand size, density and topographic variables were similar in both data sets and it was concluded that a risk rating system applied through remote sensing techniques might provide a potentially valuable tool in a SPB pest management program (Sader & Miller, 1976).

8.2.2 Pollution damage rating

8.2.2.1 Introduction

Current forest decline research involves three main fields of investigation :

(i) ecophysiological studies on a micro - level,
(ii) studies in biomass, economic and environmental effects of forest decline,
(iii) macroscale monitoring of forest status.

In contrast to these rather broad fields of research, very little consideration has been given to the connection between damage and the locational situation of an individual tree or stand. Kauppi (1988) supported this view and was specific in his criticism of the lack of consideration given to the relationships between damage symptoms and altitude, age, stand density, soil characteristics, climatic variables and air pollution variables. Kuusela (1988) blamed this lack of investigation on the a priori assumption that air pollution is the principal damaging agent; he concluded that :

- the situation could be improved by defining the concepts of tree and stand vitality and the parameters that specify them;
- possible stand and site parameters should be defined as independant variables explaining the vitality;

- all of these parameters should be observed and measured as part of forest resource inventories and the results analysed by multi - parameter models;
- survey data should be combined with intensive long - term investigations on permanent sample plots having trees, other plants, pollutant loads and soils as study objects.

As Kuusela (1988) conceded the acceptance of air pollution as the prime damaging agent has led to interpretation problems because air pollution is not as stand or site specific as defoliating insects. Although the impact of airborne pollutants will be controlled to some extent by topography and prevailing winds (Bormann, 1982), the relative unpredictability of the atmosphere creates myriad problems when assessing likely attack sites. Regarding the present forest decline syndrome the ability to predict trees or stands susceptible to damage is further handicapped by the level of disagreement over the factors responsible for decline (see Chapter 2). At best the influence of locational parameters on the spatial distribution of damage levels can be assessed using aerial photography.

Taking the analysis one stage further and using locational variables in a predictive manner is, in the opinion of the author, possible but only in areas with similar pollution climates. The idea of a pollution climate (Fowler & Cape, 1986) is possibly the most important consideration when attempting to delineate and quantify forest decline. With regard to the primary pollutants, the active chemical and meteorological processes create a very different pollution climate from the same basic ingredients in different geographical areas. The climate produced depends on the distance from major sources of pollution, and the meteorology and chemistry of the atmosphere along the trajectory between the area in question and the sources (Fowler, 1985).Thus, it is the pollution climate which controls the input (of a pollutant) to a forest ecosystem and therefore ultimately dictates the level and type of response from the forest. Different soils, geology and species characteristics will be affected to varying degrees thereby confusing the general picture of decline. Despite this confusing picture the distribution of damage across major physical boundaries points to the initial damaging agent, namely air pollution, as the primary discriminating variable.

8.2.2.2 Rating methods within an inventory framework

As part of the 1983 state survey of forest decline in Schleswig - Holstein, West Germany an attempt was made to assess relationships between vitality and site / stand variables (Denstorf et al, 1984). CIR photography at a nominal scale of 1: 5, 000 was used to quantify the vitality of each sampled tree based upon a classification which corresponded to the vitality grades used on a national basis (Fig. 5.2). The grades were then related to measures of altitude, direction of slope, ground contours, soils, yield class productivity, age, degree of crown closure and stand stocking. Denstorf et al. (1984) found that throughout West Germany, the intensity of damage seemed to increase with altitude. Unfortunately, the Schleswig - Holstein study did not establish a significant relationship between vitality and altitude nor indeed with topographical features, soil characteristics or yield class productivity. The strong correlation between decline, altitude and topographic position noted elsewhere in West Germany (Hildebrandt, 1985 & Trankner, 1985) can be explained by the variation in the terrain. Where a correlation between decline level and elevation is clear, the terrain is usually mountainous, such as the Black Forest and Bavarian Alps. Schleswig - Holstein however is a relatively low lying state, much of the landscape lying at or just above sea level.

Denstorf et al., (1984) identified stronger relationships between degree of crown closure and stand stocking. Change in the latter characteristic produced vitality changes particularly in spruce stands, where mixed stands of spruce were more heavily damaged than pure stands. This was explained by the fact that spruce often forms the dominant overstory and therefore the upper part of its crown is exposed to wind and pollution. Additionally, competition from the roots of other species in the stand may intensify the damage.

Elsewhere in West Germany little work of this type has been undertaken. In Baden-Wurttemberg, as part of the state forest inventory, site and stand factors are recorded (Hildebrandt,1985). The factors studied are species, age, class, stand structure (irregular or regular plantation), stand shape, crown condition, slope, landform, position in stand and aspect. Unfortunately no attempt is made to relate these factors to vitality in anything other than a descriptive manner and there are no published results.

Within the framework of a national inventory Wastenson et al. (1988) described the Swedish forest inventory which is used as a base for investigation of the correlation between needle loss and forest stand parameters. These parameters are age, density, tree species mixture, field vegetation layer, topography, soil, bedrock, hydrography and geographical position related to open areas and local air pollution sources. Results have shown a concentration of damage in high - elevation areas with a high frequency of bedrock outcrops and lichen - rich coniferous forest. Within the forest stands, a clear concentration of damage was noted on the fringes of forest and non - forest land.

8.2.2.3 Experimental damage rating approaches

In other parts of Europe two particular studies have investigated the relationships between site / stand variables further with a good degree of success. The first was undertaken by Seger (1987) in Austria and concerned itself with an inner - alpine valley near the southeastern edge of the Alps. The cause of forest decline in this area was a coal - fired power station together with other heavy industry responsible for SO_2 and NO_x emmissions. The dominant species present was the European fir (Picea abies) which was experiencing chronic damage, although the distribution involved single dying trees as oppoosed to damaged areas. The assessment medium selected was CIR film at a scale of 1 : 8, 000, since previous work at this scale undertaken by Zirm et al. (1985) and Seger (1986) had provided a good combination of detail and ground coverage.

The first stage of the adopted methodology involved selection of interpretable and homogeneous stands older than 60 years. Within each stand 20 individual trees were selected and classified according to crown status (based upon the degree of defoliation). As with all the decline inventory methodologies in Europe the photographic classes related to the field survey classes. For each stand the percentage of trees within each of the four crown - status types was calculated, the weighted average of these percentages leading to an index of crown status (damage vitality index). The results obtained allowed for the production of a crown - status map as well as the assessment of damage intensity within individual stands.

Taking the work a stage further, certain locational parameters were selected to quantify the strength of their influence on damage. The locational parameters were divided into two groups; absolute (terrain features) and relative variables. The variables assessed were : absolute location (altitude, relief type, exposure and slope); relative location (distance and direction to main emitters; wind - and lee - side of locations in relation to main emitters); atmospheric - pollution parameter (stages of deposition of SO_2); and soil type.

Applying stepwise multiple regression rules to the data, weak relationships were established between damage, altitude and distance from the centre of emissions. Using these relationships a map was produced showing extrapolated values of forest status for areas not covered by the photography. Although the map datum were smoothed compared with the interpretation results, local foresters were able to confirm the success of the approach.

Perhaps the most conclusive work relating to pollution damage rating was the second of the two studies refered to, which was undertaken in the Rhone valley, Switzerland (Bosshard, 1981 & Scherrer, 1980). Many of the pine forest stands in this area exhibited severe damage due to the presence of pollutant emissions from nearby industrial complexes. Due to the unfavourable topography of this steep sided valley even moderate pollutant emissions can cause severe air pollution episodes. Therefore an inter - disciplinary project was initiated with the following aims:

- assessment and mapping of spatial damage patterns;
- to survey air pollution by means of chemical analysis of plant species;
- to demonstrate air pollution stress through controlled field experiments;
- to assess drought effects on annual ring formation in pine trees;
- to determine the behavior and impact of flouride originating from airborne gases and particulates;
- to evaluate long term changes of forest land use.

The first mapping project involved a combined field and aerial survey of 781 sample plots (using a 50 x 50 m grid) over a test area of 196 ha. The principle objective was the delineation and assessment of pine mortality. The aerial survey component involved 1:13, 000 CIR photography on which the 0.25 ha sample plots were rated according to the following criteria : elevation above sea level; exposure; topography; stand type; canopy coverage; age of stand; site index; pine mortality and age of dead pine trees. For each of these criteria a map was constructed indicating sampling plot distribution, but unfortunately, the spatial resolution of this procedure was inferior when compared to conventional maps. However, the information density of systematic sampling outweighed this draw back, since the frequency distributions and mutual dependance of the variables measured could be analysed. Applying a multiple linear regression model to the data it was concluded that the age of dead pine trees explained 69.9% of the observed variance in pine mortality. The authors hypothesised that natural or premature ageing was either the cause itself or a prerequisite for the observed severe forest damage. Under the influence of adverse site conditions, such as drought and / or shallow soils on steep slopes or eroded ridge tops, this trend appeared to be more pronounced.

Both of these projects have demonstrated the possiblity of quantifying relationships between damage and locational parameters. However, it is important to make a distinction between the relatively narrow aims of the projects as opposed to the broad inventory procedures undertaken on a national / regional level. The aim of a forest decline inventory is to map the distribution and intensity of the decline. Since a large area is normally covered and results must be rapidly produced there is usually little scope and resources for an intensive study, such as that required by the decline rating techniques. However, the decline rating methodology does offer an alternative approach to the total inventory techniques employed at present. The methodolgy outlined by Seger (1988) goes some way to explaining the potential of this approach since,

" The model can be used wherever selected image data, and not data covering the whole area, exist." (Seger, 1988)

In other words, the use of a multiple regression approach is applied to selected sites and the resulting equations used to gain information for the whole area. The size of the area applicable to each resulting equation will be restricted to areas of similar pollution climate which in turn are dictated by changes in topography or climate as well as the relative influences of different pollutants. The accuracy of the required damage map will influence the extent of the survey area. For example, if the accepted accuracy of the final crown condition map is low then the survey area can be increased since more pollution climates and physical conditions will come into play; which will have a generalising effect on the map output. The inclusion of a mixture of such conditions will therefore affect the purity of any predictive relationships and hence the accuracy of the final output.

In Canada attempts have been made to integrate data on vegetation, soil, water and social factors in conjunction with satellite imagery in order to better estimate the potential response of a large part of the total ecosystem to acid precipitation (Rencz et al., 1985). The project covered a region south of Ottawa and each study area was chosen to represent different recreational and agricultural land as well as a variety of bedrock, soils and forest cover types.. The data that were intregrated included laboratory seedling regenaration data, obtained under a variety of 'acid rain' conditions, a forest cover map produced from Landsat MSS data and geochemical data. By combining these data a series of sensitivity ratings were produced from which it was possible to create maps of the relative sensitivity of different areas to acid precipitation. Conclusions for the overall sensitivity rating were drawn at two levels; one detailed (10's to 100's of square metres) and the other regional (10's to 100's of square kilometres). The detailed information was required to represent environmental variability, particularly forestry. The regional information was needed to delineate large

- scale trends. In general this approach proved successful for forest management purposes.

The idea of a multi - scale / multi - variable approach to this type of analysis is the important point to appreciate here. Multi - stage sampling as discussed in Chapter 6 would fulfill the scale requirement, allowing for a regional analysis of forestry extent and condition combined with the detailed analysis of crown condition outlined in sections 8.3 and 8.4 as well as Chapter 9.

8.3 Crown condition rating

Sections 8.3.2.1 to 8.3.2.10 explain the variables used in the author's crown condition rating system and their main characteristics. Chapter 6 described the Black Forest area used for the main study as well as the Bavarian site which was used as an illustration of the problems encountered with a crown condition rating approach (refer to Section 9.5.2). The methodology outlined in this section stipulates that the independant variables should be directly measurable from either aerial photographs, topographic maps or both. There are two reasons for this; they are firstly, the paucity of data from the field and secondly, the desire to develop a rapid and cheap assessment methodology. The approach adopted by Heller and Sader (1976 & 1980) was based upon medium scale B & W aerial photography in conjunction with map and / or field data. However it was not neccessary that the field data be an intergral part of the assessment methodolgy. In this author's study the imagery utilised was large - scale CIR photography, the reasons for its selection outlined in Chapter 6. Ideally one would want to measure the variables for all the trees visible on the photography in order to maximise the information available; since this is patently unrealistic, a sampling framework must be applied.

8.3.1 Sampling technique

The Manual of Remote Sensing (1983) defines sampling as :

" the careful inspection of a small amount of representative area for characteristics or parameters which are of interest, and which can then be projected to a larger area."

The chief advantage of such an approach is the elimination of boundary definition procedures which consequently leads to an efficient methodology. When applying a sampling method the major unknown is the choice of a random or systematic sampling design. A random approach should satisfy the following two criteria; every individual

- scale trends. In general this approach proved successful for forest management purposes.

The idea of a multi - scale / multi - variable approach to this type of analysis is the important point to appreciate here. Multi - stage sampling as discussed in Chapter 6 would fulfill the scale requirement, allowing for a regional analysis of forestry extent and condition combined with the detailed analysis of crown condition outlined in section 8.3 and 8.4 as well as Chapter 9.

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The chief advantage of such an approach is the elimination of boundary definition procedures which consequently leads to an efficient methodology. When applying a sampling method the major unknown is the choice of a random or systematic sampling design. A random approach should satisfy the following two criteria; every individual must have an equal chance of inclusion in the sample throughout the sampling procedure, and selection of any particular individual should not affect the chance of selecting any other. Heller & Sader (1980) adopted a random sampling approach emphasising that the choice of sample should be based upon a knowledge of the forest to be sampled. Sayn - Wittgenstein & Aldred (1969) also recommended such a method for a timber volume inventory. The random approach was deemed most useful when the primary interest lay in the estimation of totals for large areas rather than details of the volume or location of individual stands. Therefore, it was deemed a promising pattern for a national or regional inventory. An operational inventory described by Ciesla (1984) utilised a random method to select a series of 2.5 acre photo plots for monitoring red spruce and balsam fir decline in the eastern United States.

A drawback associated with random sampling is the physical location of the sampling units, which may be inaccessible on the ground. This normally proves to be a problem with large scale photography since a number of the sampling points may be obscured on the ground (Sayn - Wittgenstein & Aldred, 1969). In fact many designs which have proved acceptable for ground surveys have to be ruled out; therefore a more practical approach such as systematic sampling (where samples are selected in a regular pattern) is required. This technique has been recommended where the chief concern is change in a continuous variable over an area, usually in response to, or in conjunction with, changes in a number of other variables. In addition, a systematic design would solve the problem of having two randomly selected photographic plots or strips fall close together. Sayn - Wittgenstein & Aldred (1969) acknowledge that such a situation in most forests represents a waste of effort, since changes in forest conditions are often gradual and one strip / plot would therefore repeat the information available from the other.

The main advantage of systematic sampling is the ease and speed with which it can be applied. The main disadvantage is the fact that once a selection is made the remainder of the population have no chance of being included. It is also possible to miss elements of a complex regular pattern if these elements occur "in - phase" with the sampling grid (Ebdon, 1977).

In the author's Black Forest study the major requirement was an overall picture of damage and its relations with the selected site / stand variables. For this reason alone a systematic approach was adopted; in addition this is the most rapid assessment method. Therefore a systematic grid was selected with a major consideration being the resolution of the cells. The resolution chosen was selected on the basis of potential inclusion in a multistage sampling methodology (see Section 5.1). The imagery that the author considers to be the most useful type at the initial stage of a forest mapping multistage sampling design, is Landsat TM data due to its good spectral resolution. Since this imagery has a nominal spatial resolution of 30m sq., the grid employed has a cell size of 0.5cm sq., which approximates to 25m sq. on the ground at a photographic scale of 1 : 5, 000. Such a stratification would allow for assessment of the TM classification accuracy over large areas whilst the aerial photography in conjunction with field plots can provide detailed stand and crown status information.

Application of the sampling grid was a relatively straightforward task. The study area consisted of three stereo - pairs of photographs; therefore the transparent grid overlay (0.5 cm sq cell size) was placed on the left hand photograph of each pair; Fig. 8.1 shows the orientation of the sampling grid in relation to the ground surface. Quite simply the tree crown occurring on or closest to each grid cell intersection was included in the analysis.

8.3.2 Variable characteristics

8.3.2.1 Species

For a summary of species identification methods employed by the author (based on the techniques employed in West Germany) the reader is referred to Chapter 5. The three species occurring in appreciable numbers within the Black Forest study area were Norway spruce, Silver fir and European beech. Small numbers of Scots pine and Common oak were also identified on the photography, however, their numbers did not justify inclusion in this example (Scots pine numbered 10, whilst oak numbered 31). Subsequent analysis was undertaken on 152 Norway spruce, 573 Silver fir and 509 European beech. Table 8.1 shows the distribution of the species identified on the dot grid.

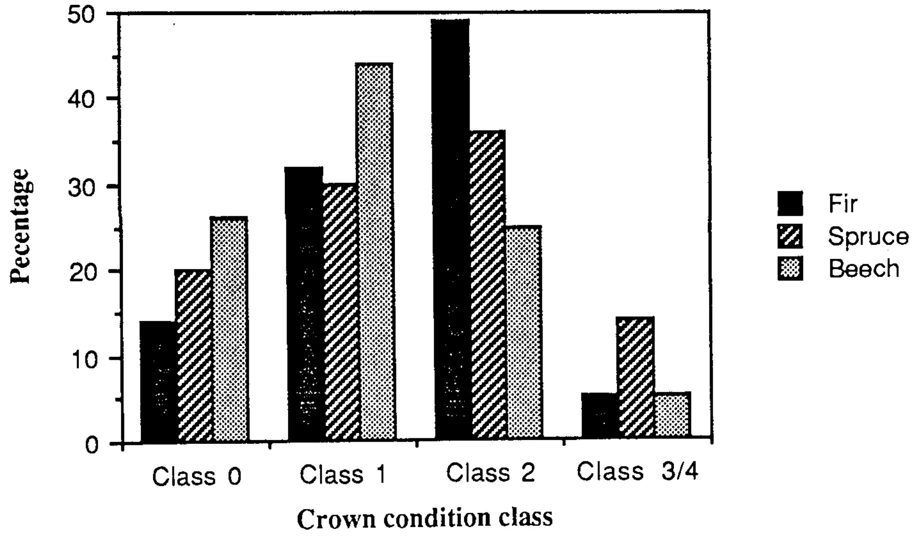
Stand Age Distribution

Fig.8.5

8.3.2.2 Damage class (CLASS)

Fig. 8.2 shows the percentage of trees for each of the three species in each damage class. Immediately striking are the high levels of conifer damage. This mirrors the general pattern of damage in 1984 for the State of Baden - Wurttemberg as well as that found in the forest districts, which are the basic survey areas within the state (Schopfer, 1986). Of the fir trees sampled, 49% were classified as badly damaged (Class 2), a pattern explained by the timescale of damage occurrence. Silver fir showed the first symptoms of damage about eighteen years ago and have experienced progressive decline ever since. Spruce began to show symptoms of decline in the mid - to late seventies, therefore damage levels are greater for these two species than for deciduous species, which began to show symptoms of decline in 1983 / 84.

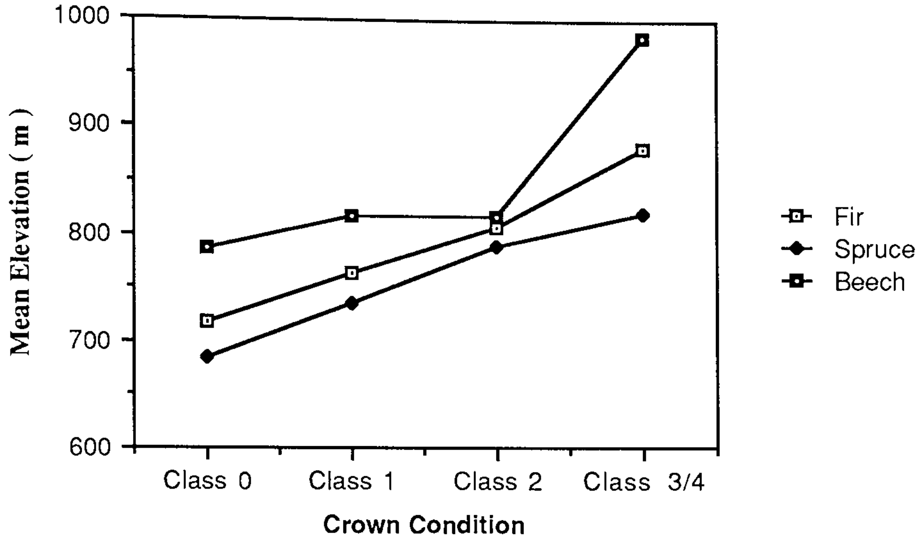
Fig. 8.2 Percentage of trees per crown condition class



8.2.2.3 Elevation (ELEV)

Elevation above mean - sea - level was assessed to within 5m using a Bausch & Lomb Zoom Transfer Scope (ZTS). This instrument allows the superimosition of two materials, such as an aerial photograph and a map, in order to accurately translate data from one to the other. In this case, the contour data from a 1 : 25,000 topographic mapwas projected onto the photographic print with the aid of a dot grid overlay. The ZTS allows for enlargement, rotation and stretching of the image, and therefore the map data could be warped to the photographic image. When the two images were superimposed it was a simple task to assign an elevation value to each of the sampled trees. Appendix 2 (a) shows the distribution of elevation values in the Black Forest study area.

Fig. 8.3 Crown condition : Mean Elevation (m)



The variation of crown condition with elevation is summed up graphically in Fig. 8.3 which shows the mean elevation for each crown condition class. Immediately striking is the degradation of crown condition with a corresponding increase in elevation for all three species. To further illustrate this relationship Fig. 8.4 (a), (b) & (c) show the percentage of trees that occur in the "healthy" crown condition classes (classes 0 & 1) as elevation increases and the corresponding percentage of trees in the damaged crown condition classes (classes 2 and 3). For all three species the percentage of damaged trees exceeds the percentage of healthy trees at a certain elevation. For fir, the change occurs at 750 - 800 m, for spruce at 801 - 850 m and for beech at 901 - 950 m. The presence of a relationship between crown condition and elevation would at first glance seem the be unquestionable. However, without a more detailed field study it is impossible to determine a possible cause for this relationship. For example, trees have their own natural elevation limits which may inhibit growth if exceeded.

Fig. 8.4 Crown condition with Elevation, (a) Fir

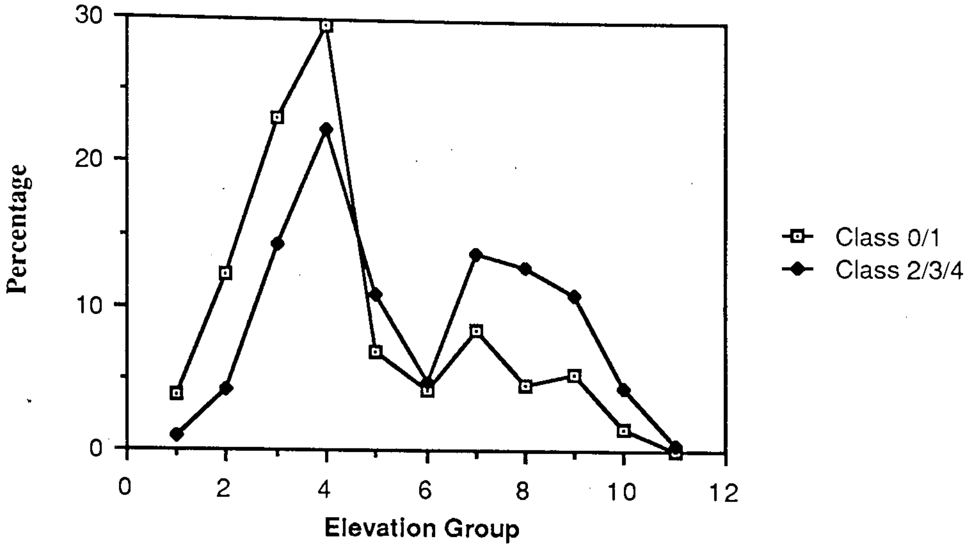


Fig. 8.4 (b) Spruce

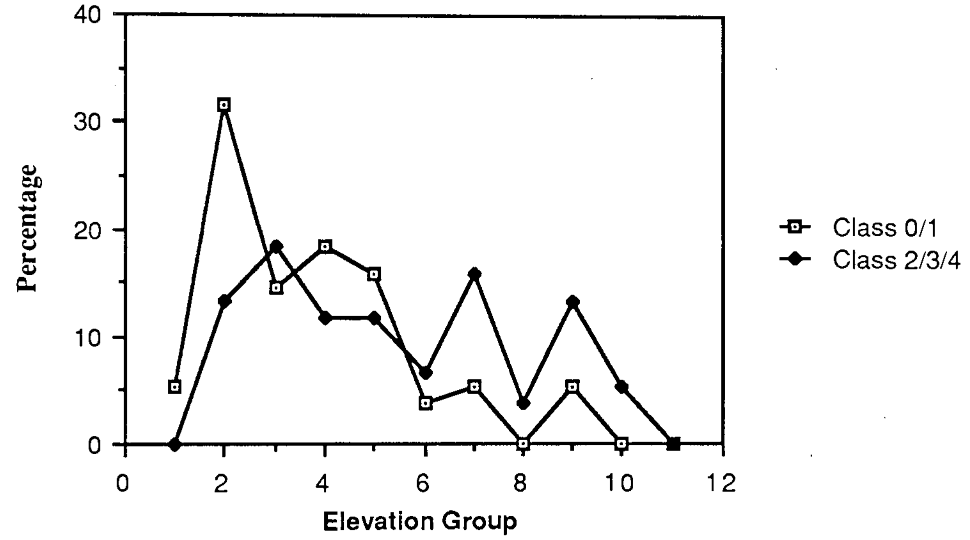
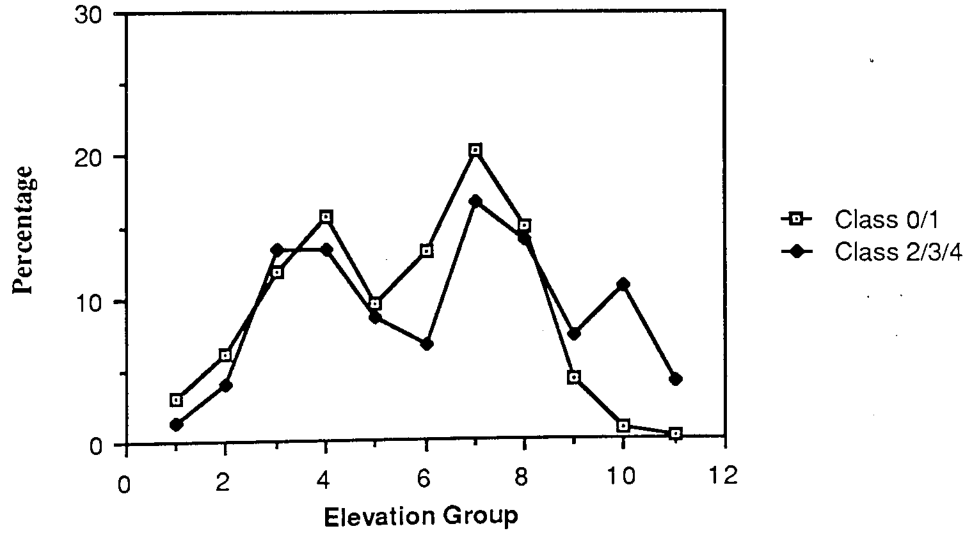


Fig. 8.4 (c) Beech



8.3.2.4 Aspect

This variable was determined from the photography with the aid of a topographic map. Heller & Sader (1980) utilised a 360 ° template graduated in 22.5 ° segments and measured aspect clockwise from the North point. It was felt that this level of detail was not adequate for the Black Forest study since the aspect values would be employed in the determination of a further variable, namely radiation index. Therefore the overlay used was graduated in 10 increments and the measurement taken by placing the centre point of the template over each sampled tree. The flight line was due North, therefore it was a simple matter to match the overlay to attain a reasonably accurate measure of aspect. Any doubtful readings from the photography were assessed independantly by reference to the 1 : 25,000 topographic map. Aspect in this case is therefore a simple measure of a trees dominant compass direction.

8.3.2.5 Age

When assessing decline in the Baden - Wurttemberg state inventory, trees of less than 60 years and those of more than 60 years are assessed seperately (Schopfer, 1986). In this case, trees younger than 60 years were extremely difficult to classify on the photography, due mainly to their underdeveloped crown form and the relatively dense stocking levels. Therefore, only the older trees could be classified with any degree of accuracy. Stand age and stock maps were obtained from the forestry department at the University of Freiburg and a stand age map was used to define those trees older than 60 years which occured within the sample. Fig. 8.5 shows that the majority of trees sampled were more than 100 years old.

8.3.2.6 Slope (SLOPE)

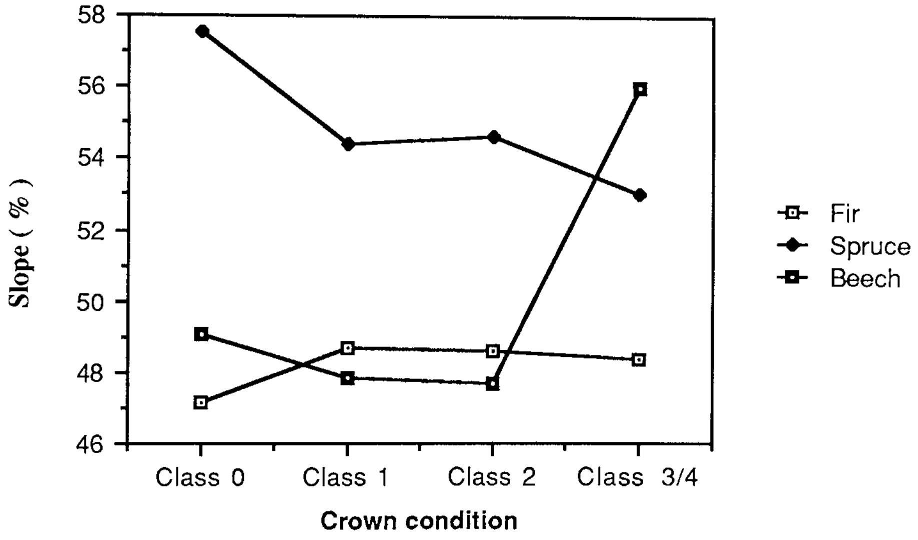
When measuring slope reference was initially made to the 1 : 25,000 topographic map sheet. Within the photo - coverage area the terrain was divided into sectors of approximately the same slope using visual discrimination. Subsequently an average slope value was obtained for each sector by simply dividing the difference in elevation (in metres) by the horizontal distance (in metres) measured from the map.

$$\text{Slope percent} = \frac{\text{change in elevation between points}}{\text{horizontal distance between points}} \times 100$$

The values so obtained were then grouped into ten percent slope classes. For an illustration of slope distribution see Appendix 2 (b). The final stage of this activity involved transferral of the slope sector from the map to the photography using the ZTS. Once completed the sample plots were assigned a raw slope value. Fig. 8.6 shows the mean slope percent for each crown condition class.

At first glance the steep rise in the average slope between beech class 2 and class 3/4 would seem significant, however, when one looks at the actual rise it is an increase of approximately 10 % from 48 to 58 %. Since these are both relatively steep slope angles it is therefore difficult to assess the relative significance of this change without recourse to more detail on the management practices and the natural slope susceptibility of beech trees. The relative stability of the mean slope with degraded crown condition for fir and spruce corresponds with observations made elsewhere in West Germany that decline has occurred under all slope conditions.

Fig. 8.6 Crown condition : Slope (%)



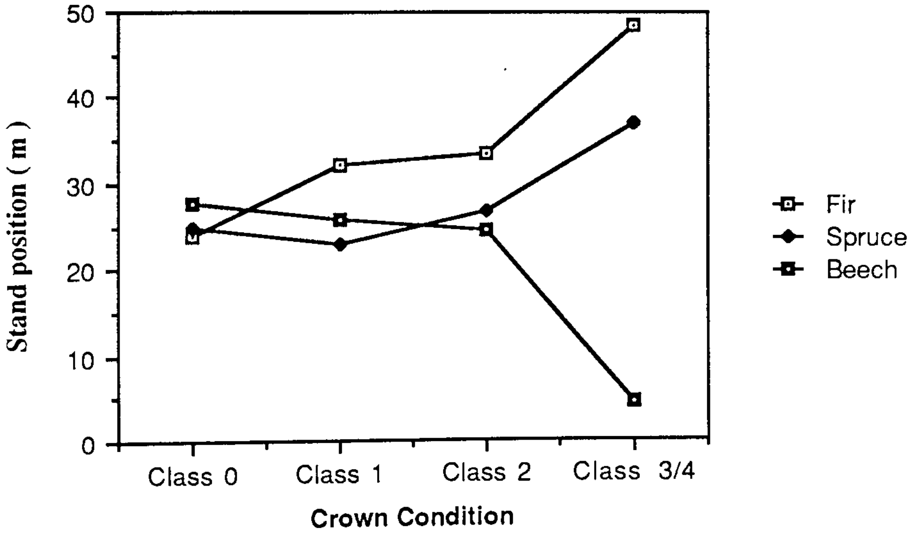
8.3.2.7 Stand position (POSIT)

Field surveys both in the UK (Innes & Boswell, 1987 & Innes, 1987) and West Germany (Hildebrandt & Kadro, 1984) have observed greater damage on trees which are in exposed positions. In fact during its 1986 forest health survey the Forestry Commission deliberately chose samples from the edges of stands in order to bias the survey towards air pollution damage effects (Innes, 1986 ; Wright & De Meyer, 1986). To test this situation in the study area the basic measure of stand position as used in the majority of decline surveys (Wright & De Meyer, 1986) was applied to sample trees. Simply, the perpendicular distance of the tree (in metres) from the nearest stand edge was measured on the photography. Fig. 8.7 serves as a pointer to the potential of stand position to affect crown condition in the study area.

A problem with this approach was deciding what constituted a stand edge. Was this, for example, the edge of a homogenous beech stand adjacent to a mixed coniferous stand or was the edge that which was exposed. Since the sampling technique was concerned with the condition of individual crowns and not whole stands the author decided that the measurement should be made from the nearest exposed edge. This decision was supported by the fact that any windborne pollutant is likely to affect such an exposed crown more so than a crown in the centre of any group of trees (whether this be one true stand or a conglomeration of stands).

The only species which showed an appreciable change in crown condition with respect to stand position was beech. The low values of the distance from the stand edge associated with the severely damaged beech crowns can be explained with reference to the photography. It is clear that at the highest elevations in the study area there are a plethora of beech crowns showing signs of severe damage. However, it is standard management practice to remove such trees when they reach this stage in order to salvage maximum timber. Therefore, the remaining damaged trees occur in isolated and exposed groups; hence the low values for stand position.

Fig. 8.7 Crown condition : Mean Stand position (m)



8.3.2.8 Topographic position (TOPO)

Topographic position was determined by reference to the the stereo - model. The categories and their numerical values were chosen at random, and these categories were :

20 - Valley bottom
40 - Lower slope
50 - Middle slope
70 - Upper slope
100 - Ridge top

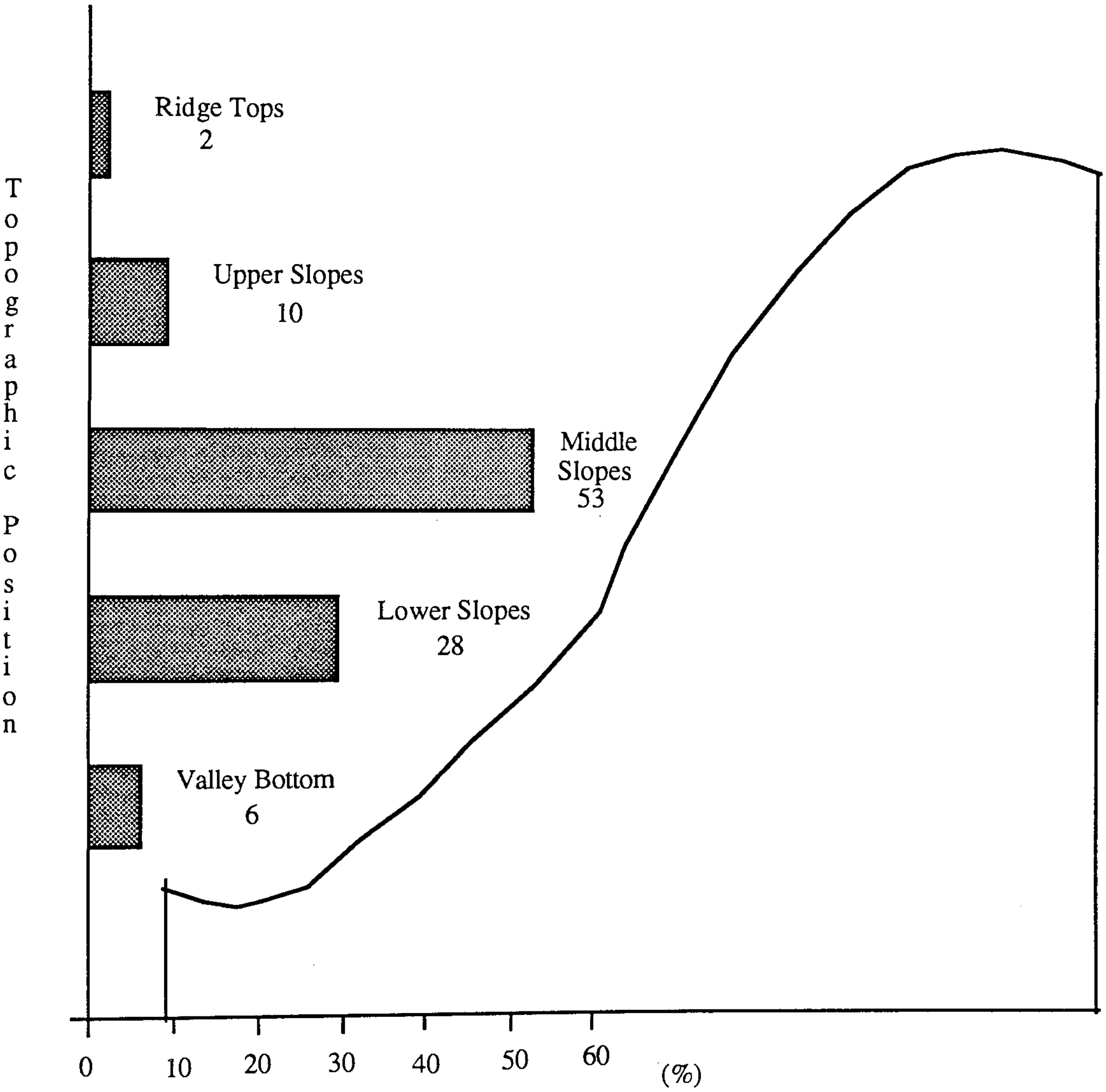


Fig. 8.8 Frequency of occurance of topographic positions

Fig. 8.9 Crown condition with Topographic position, (a) Fir

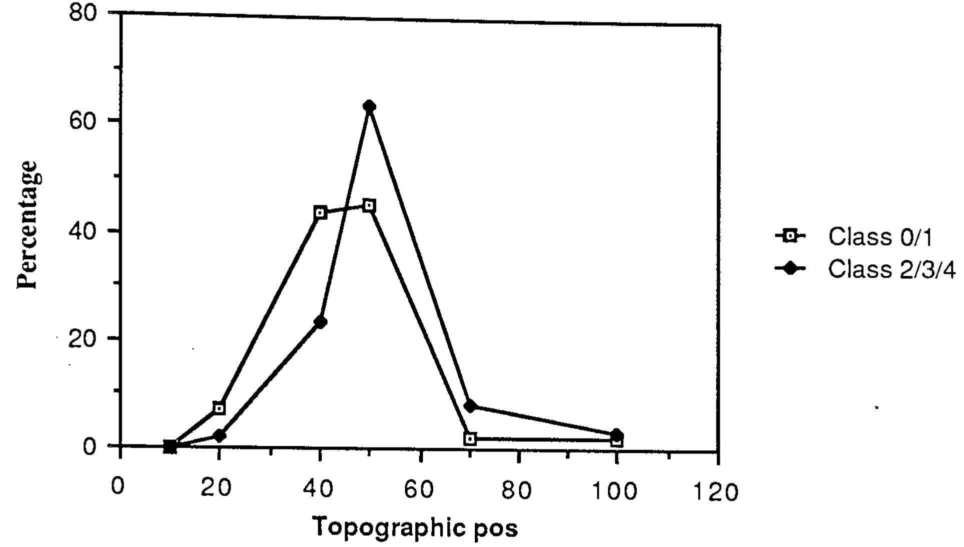


Fig. 8.9 (b) Spruce

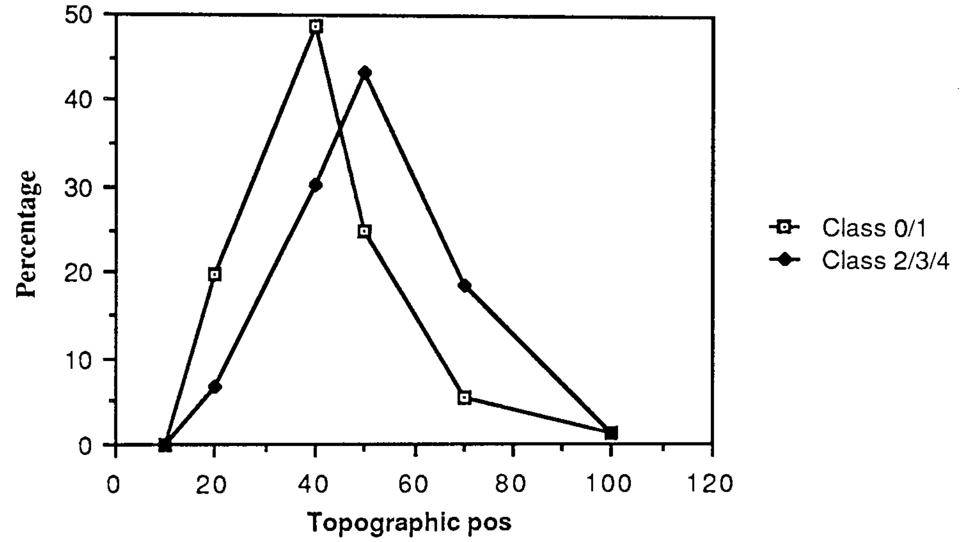
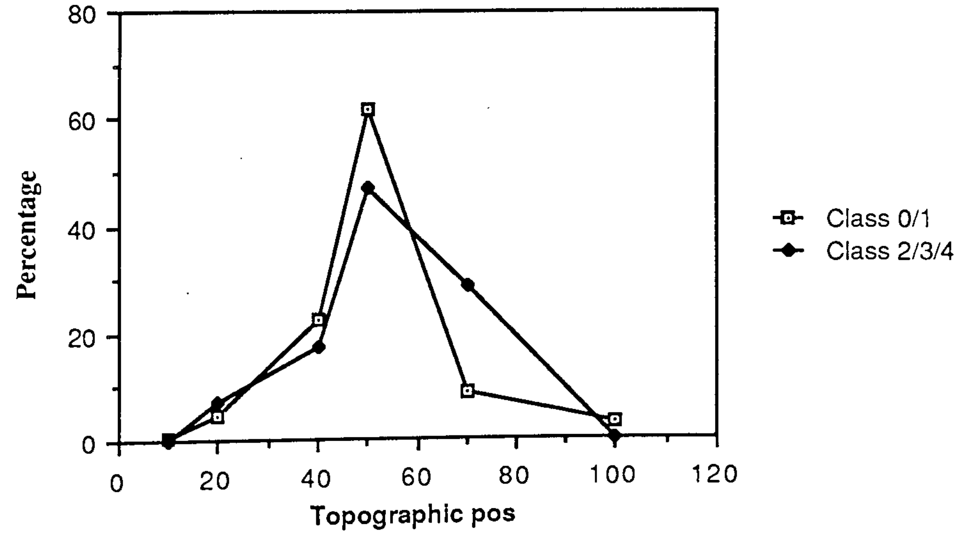


Fig. 8.9 (c) Beech



The category values were selected arbitrarily, however, the relative difference between them was chosen in order to reflect the author's assessment of the potential of each category to promote the symptoms of forest decline. Therefore, the difference between valley bottom and lower slope is twice that exhibited between lower and middle slope. This is based upon the general situation noted in West Germany where the more sheltered trees at lower elevations are showing less signs of damage. Valley bottoms offer the same protection, particularly against windborne pollution, which the lower slopes do not afford. Correspondingly, the difference between ridge tops and upper slopes is given a similar value for the reason that ridge tops are more likely to be exposed to pollution.

Fig. 8.8 shows the distribution of all tree species sampled within the study area. The majority (53%) of the trees occur on middle slopes whilst the lower slopes and valley bottoms have lower concentrations because of the prevalence of agriculture and settlement. Fig. 8.9 (a), (b) and (c) however, shows that a change in topographic position to the more exposed sites corresponds to a degradation in crown condition. Since the exposed positions are at higher elevations, this observation is not wholly unexpected.

8.3.2.9 Radiation index (RONE & RTWO)

Stage (1976) argued that optimum aspect expressions (as measured in section 8.3.2.4) should involve some measure of slope. This he justified for the simple reason that plots on level ground would supply no information on the effect of aspect on tree growth.

Therefore, the variables which best represents the effect of incoming solar radiation is the tangent of slope (percent) multiplied by the sine and cosine of the aspect. Heller & Sader (1980) utilised this technique, terming it Radiation index, as it provides a measure of the solar radiation reaching the sample point. Hence, two variables are measured, these are cosine of aspect times the tangent of slope percent (R1) and sine of aspect times the tangent of slope percent (R2). The aspect and slope values for each tree measured from the photography were used in this way to obtain a radiation index (R1 and R2) value.

Fig. 8.10 Crown condition : Mean radiation index (R1)

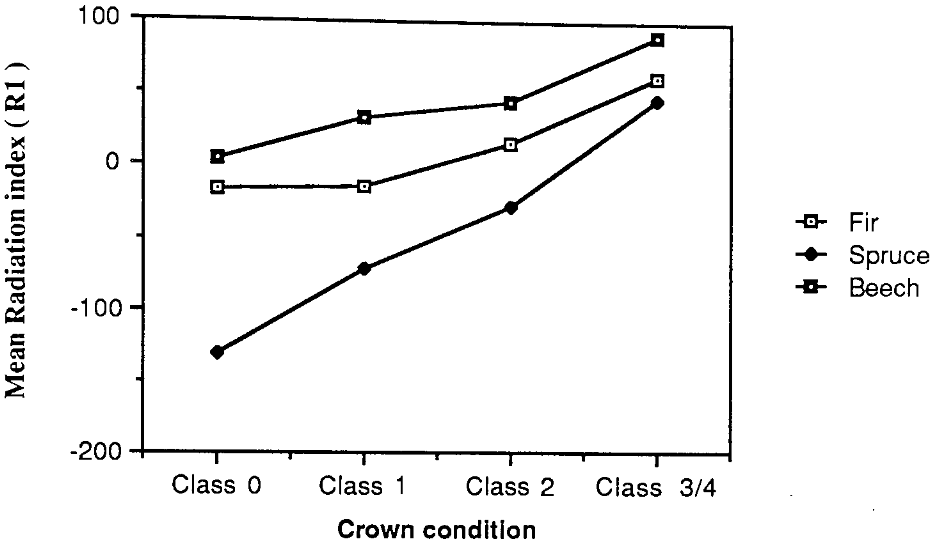


Fig. 8.11 Crown condition : Mean Radiation index (R2)

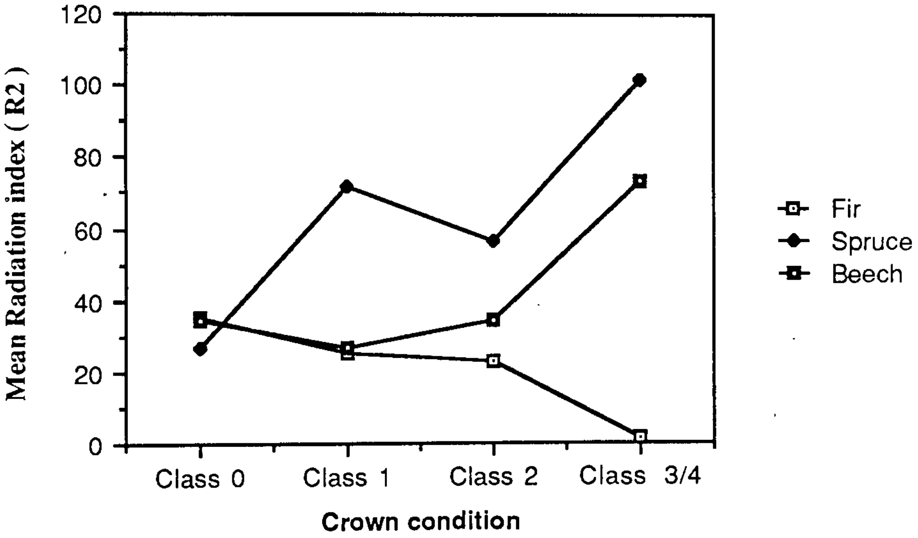


Fig. 8.10 and Fig. 8.11 point to the possibility that a relationship may exist between crown condition and radiation index (R1).

8.3.2.10 Stand composition

Denstorf (1984) described a marked difference in levels of damage between different tree mixture types. He found that the oak / spruce mixture displayed most symptoms of decline, followed by beech / spruce and pine / spruce. Stands containing Sitka spruce, larch and Douglas fir, where spruce as a rule does not dominate, were interpreted as having lighter damage when compared with pure spruce stands.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
1	F	F	F	F	F	F	B	S	S	F	F	B	F	F	B	F	B	F	S	S	F	F	B	B	F	B	B	B	B	F	F	F	F	F	F	F	F	F	F	B	F	B	B	B	B	F			B	B	B	F	F		F	F
2	F	F	F	F	F	F	F	B	F	F	F	F	F	F	F	F	B	B	S	S	S	F	F	B	F	B	F	F	F	B	B	B	F	F	F	F	SP	F	B	B	F	F	B	B	F	F	F		B	B	B	F	F	F	F	F
3		B	S	F	F	F	F	F	B	B	F	S	F	F	F	S	S	F	S	F	B	F	F	B	B	F	B	B	F	B	B	F	F	F	B	F	F	F				B	F	B	B	B	F		F		F	F	F	F	F	S
4		B	F	B	SP	F	F	F	B	B	F	B	S	F	S	S	B	F	F	B	B	B	F	F	F	B	B	F	B	B	B	B	B	F	B	B	F	F	SP	F	B	B	B	B	B	B	F	B		B	B	F	S	B	F	F
5			B	F	F	B	B	F	B	S			F	S	S	F	B	B	B	B	B	B	B	F	F	F	B	B	B	B	F	F	B	B	B	B	B	B	F	F	B	F	F	F	B	F	F	F	F	F	F	B	B	S	S	F
6				F	F	B	B	B	F	F	F			S	S	S		B	F	F	F	B	B	F	B	F	B	B	B	B	B	B	B	B	B	B	F	B	F		B	F	F	F	B	B	F	F	F	B	F	F				
7				F	F	B	B	F	B	B							S	S	SP		B	B	B	F	B	B	B	B	B	B	F	F	F	S	B	F	F	B	F		B	B	B	F	B	F	F	F	F	F	F	F	F			
8		F	B	B	B	B	F	F	F	B	F									S	F	S	F	B	F	B	B		F	B	F	F	B	B	S	B	S	B	B	F	F	B	B	F	F	F	F	F	F	B	F	F				
9	F	F	F	B	F	F	F	F	B	F	F	F				O				S	SP	S	F	F	F	B	B	B	B	F	F	F	S	F	F		B	B	F	F	B	B	B	F	F	F	S	F	S	S						
10	F	F	B	B	F	F	F	B	B	F	B	B	F							S	S	S	S	SP	F	S	B	B	B	B	F	F	B	B	F	B	B	B	F	B		B	B	F	F	F	S	B	S		B					
11	B	F	F	F	F	F	F	F	B	F		B	B	B							S	F	S	S	SP	S	B	B	B	B	B	F	F	F	B	S	B		B	B		F	F	F	F	S	B									
12	F	F	S	F	F	B	F	B	F	B	F	F	B	B	F				S	O		S	F	F	S		F	B	B	B			F	B	B	B	B	B	F	F		F	F	B	S	S										
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15	F	B	B	F	F	B	B	F	F	F	F	F	B	B	B	B	F					O	S	F	F	F	F	S		O	S			F	B	F	F	B	F	F	F		B													
16	B	B	F	F	F	F	B	F	F	B	B	F	B	F	SP		B	S						S	F	F	F	F	B	F		S	S	S	F	B	F	F	F	F	SP	F														
17					B	B	F	F	B	B	B	F	B	B	B		B	F				F	S	S	S	S	S	S	F	F	B	F	S	B	S	F	F	F	F			F	B													
18					B	B	B	F	F	F	B	B	B	B	B	B	B	F	F				F		S	F	B	F	F	F	F	F	F	F	F		F	F	S	S								S	B					F		
19	B			F	B	B	B	B	F	F	F	B	B	B	B	F	B	F	F				F		O	S	F	F	F	F	F	F	F	B	S	F	F	F	S	F	F	B					O	S	S	S						
20	B	B	B			B	B	B	B	B	B	B			B	F	B	F	B			S		F		B	F	F	F	SP	SP	F		S	F	F		F	S	F	F			B			B	S	S	B	F	F				
21			B	B	B	S	F	B	F	F	B	B			B	B	B	B	F			O					B	F	F			B	F	S	S	S	F	F	F	F							B	S	S	S	F					
22	B	B	B	B	F	B	B	B	B																		B	B	F		F	B	F	S	S	B	B	S							F		S	S	S	B	F					
23	B	B	S	S	S	S	B	B	B	B	B											S	F		F		F	B			F		B	S	F	F	S	S								B	S	S	S	F	F	S				
24	B	S	S	B	S	B	B	B	B	B	B	B																					B	F													B	F	S	S	S	F				
25	B	S	S	S	S	S	F	B	F	B	B	B	B											O			O	O				O		F	F					S	S	F	F		F	F	S	S	S	S		F				
26	F	S	S	S	B	S	S	F	S	B	B	B	B														O								F					F	S	F	B		F	F	F	F	S	S	F	B	B	F	B	
27	B	F	F	B	F	F	B	F	F	S	B	B	B	F	B											S		S							F	S	S	S	F			B		S	S	F	F	S	S	B	B	F	B	F	B	B
28	B		F	B	F	B	B	F	B	F		B	B	B	B									B								B	B			F	S	S	B	S		B		F	F	F	S	F	F	F	F	F	B	S		F
29	B		B	F	B	B	B	B	B	B	B	B	S												S												F	S	B				F	F	F	S	B	F	B	F	B	B				
30				B	B	B	B	B	B	B	B	F													B																	B	B	F	F	S	B	B	B	B	B	F				
31				B	B	B	B	B	F		F	F	F																									B	B				F	F	S	B	F	F	F	F	F	B	B	B	B	B
32	B	B	B	B	B	B	B	B	F		B																															B	F	S	B	F	F	F	F	F	F	B	F	B	B	B
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36	F	B	B	B	F	F	B	B															B										B						O	F	F	F	B	F	F	B	F	B	B	F	F	B	F	F	B	B
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38																			S		O		O										O				O	O	O	F	F		B	B	B	F	F	F	F	F	F	F	F	B	F	
39																		B															O	O						F	F			B	B	F	F	B	F	F	S	B	F	B	B	F

Table 8.1 Distribution of sampled species

Stands used to measure Stand Composition

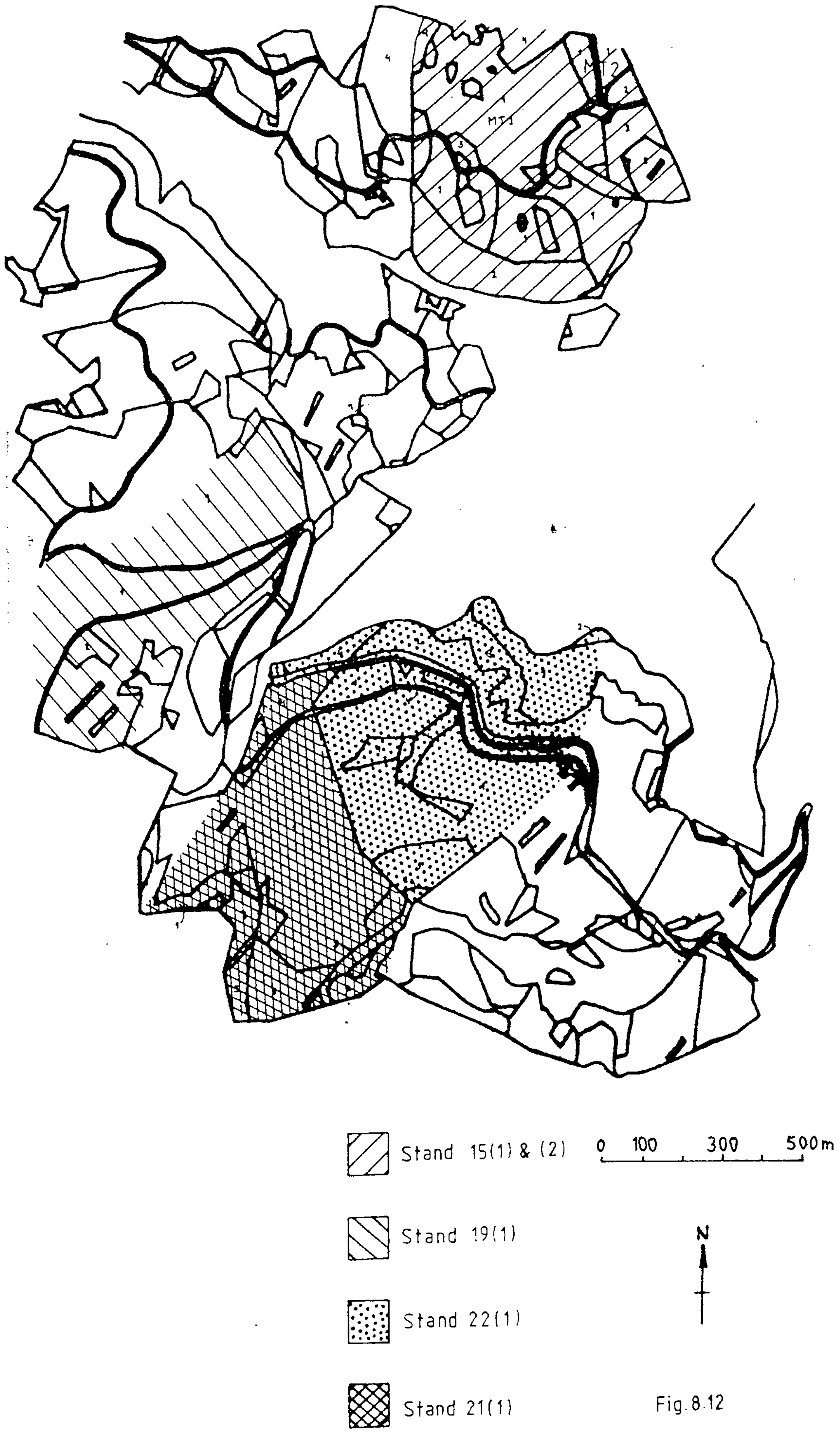


Fig.8.12

In the Black Forest study area it was hypothesised that no one mixture of species would prove more likely to exhibit damage intensity than any other. Fig. 8.12 illustrates the distribution of stands that were tested to assess this hypothesis. Whilst Table 8.2 shows the results obtained when calculating a mean damage class for these sample areas. The species combinations so asessed were fir / beech, spruce / fir and beech / fir / spruce mixtures. With reference to Table 8.2; immediately striking is the lack of any obvious correlation between different mixtures and mean damage class. Of more immediate interest is the variation between individual stands. Stand 15 (1) has an overall mean damage class of 0.32 which is close enough to zero to be classed as generally healthy. Meanwhile stand 21 (1) which is another fir / beech combination has a mean damage class of 1.3. Therefore the stand classification as a whole lies somewhere between slightly damaged and damaged (classes 1 and 2). Since both stands are fir / beech mixtures, stand composition does not immediately explain this difference. There are approximately equal proportions of each specie in the stands as witnessed by the stand volume estimates (Appendix 1) and the presence of other species, particularly spruce, is negligible. It would seem that "within" stand variation alone is not affecting the observed difference in damage class. Looking to obvious differences between the two stands, one must first refer to Fig. 8.5 and Appendix 1 These two stands lie at opposite ends of the sampling grid and Table 8.2 illustrates the change in elevation between these positions. In fact, Stand 15 (1) has a mean elevation of 695 m whilst stand 21 (1) has a mean elevation of 970 m. How this might affect damage severity in terms of damaging agents is discussed in Chapter 4.

The stand data provided by the Baden - Wurttemberg Forestry Service did not include all of the sampled individuals. The figures for percentage species composition referred to the total stand, and this unfortunately could not take account of the relative concentration of stand species. Therefore, a simple methodology was devised to measure stand composition. For each sampled tree, the eight sampled crowns in immediate contact were counted by species and an approximate percentage ratio of fir, spruce and beech was produced. The selection did not go beyond the eight adjacent crowns because the furthest of these crowns were in reality 25 m from the central sample point. Any extension of the matrix might have included crowns that were in a different stand, since the distance would have been approximately 50 m from the centre. The possible combinations of species can be seen in Fig. 8.13 for Norway Spruce. The histograms give some indication of the mixture of species which experienced highest damage levels. Fig. 8.13 indicates that Norway spruce crown condition deteriorates when it occurs in small numbers with high concentrations of European beech. Where spruce is the dominant species the opposite occurs and damage levels are generally lower. It is evident that the relative percentages vary for each mixture, however it is the inter - mixture ratio of healthy to damaged trees that is of interest. For the example of Norway spruce the relationships established in this study do not agree with the observations made by Densdorf (1984), as part of the Schleswig - Holstein state inventory, who observed that the heavier damage was experienced in pure spruce stands. The advantage of the author's methodology is that it provides a more detailed picture of the influences (if any) of surrounding species on the individual.

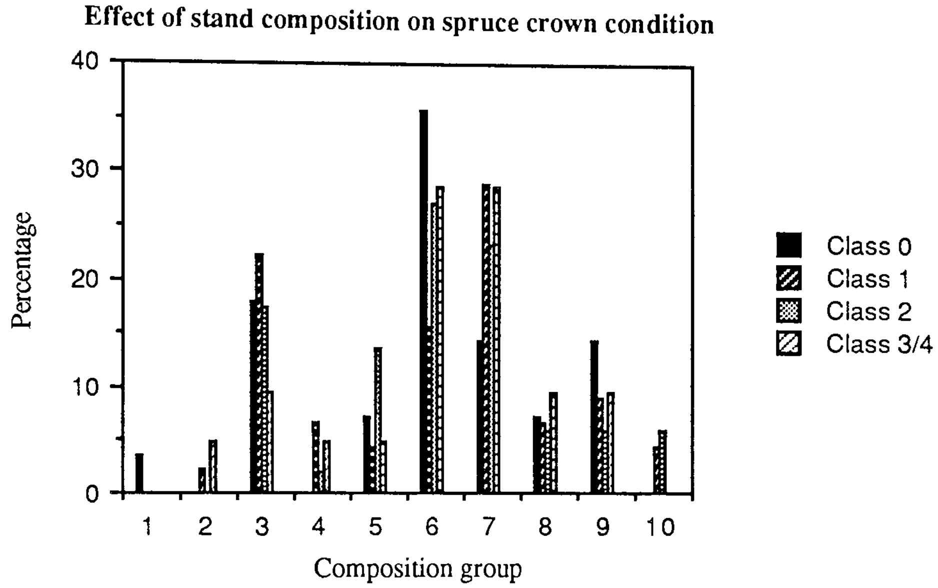


Fig. 8.13

Key to groups (Fir, Beech, Spruce) : (1) >90, <10, <10 (2) <10, >90, <10 (3) <10, <10, >90 (4) 10 - 40, 60 - 90, <10 (5) 60 - 90, 10 - 40, <10 (6) 10 - 40, < 10, 60 - 90 (7) 60 - 90, <10, 10 - 40 (8) <10, 10 - 40, 60 - 90 (9) <10, 60 - 90, 10 - 40 (10) Equal

The figures refer to the percentages of fir, beech and spruce surrounding each spruce crown sampled on the photography.

Stand No.	Area (ha)	Age	Substand Area (ha)	Species	Area (ha)	Class	Overall Damage
15 (1)	24.1	4	18.1	Fir	10.0	0.43	0.32
				Beech	6.8	0.16	
				Spruce	0.4		
				Oak	1.1		
15 (2)	8.6	2	5.0	Spruce	2.8	0.5	0.52
				Fir	2.0	0.61	
				Beech	0.2		
		2	2.0	Fir	1.0	1.67	0.75
				Spruce	0.2	0.8	
				Beech	0.2		
				Dgl. Fir	0.6	0.1	
		1	1.6	Fir	0.8	0.17	0.5
				Spruce	0.2	0.62	
				Dgl. Fir	0.1		
				Beech	0.5	0.33	
19 (1)	27.3	3	27.3	Beech	17.2	0.77	0.95
				Fir	8.5	1.27	
				Spruce	1.1		
				Dgl. Fir	0.5		
21 (1)	20.8	3	17.4	Fir	9.6	1.38	1.30
				Beech	7.0	1.04	
				Spruce	0.8		
Remaining substand not covered by the photography							
22 (1)	17.5	4	17.5	Beech	11.4	1.0	1.28
				Fir	4.4	2.04	
				Spruce	1.7	1.82	

Table 8.2 Characteristics of stands used to assess a variation in stand composition

8.4 Damage Pattern Recognition

8.4.1 Methodology

The damage rating methodology proposed in section 8.3 interpreted the pattern of damage in relation to site and stand factors; however it did not attempt to delineate any pattern existing within the stands themselves (other than the localised stand composition). Bird et al. (1978) proposed a method for assessing such patterns of forest decline based upon photointerpretation of colour and CIR transparencies. The basic data required are the occurrences of runs of healthy and diseased trees along narrow belt transects laid down through an infected forest, or as in this case, along line transects placed upon aerial photographs of a forest area.

A run consists of a series of continuous trees along the transect that are either all healthy or all damaged; any such run can be as small as a single tree. The applied stochastic model assumes that the forest is made up of a series of 'patches' and 'gaps' - the patches representing areas of damage in which there is assumed to be a constant probability that a patch tree will be diseased. Gaps are, by definition, damage - free areas and therefore the forest consists of patches containing both damaged and healthy trees and of gaps which contain only healthy trees.

The transects selected for this study were chosen in order to represent the overall decline situation for all three major tree species represented. Crown condition was interpreted using the German classification system. Unfortunately a transect of appreciable length could not be identified, therefore the section chosen consisted of a series of smaller sub - transects.

8.4.2 Results

The results of the analysis are shown in Table 8.3. The average patch and gap size is five or less crowns length, which according to Bird et al. (1978) could be truly representative of the distribution of damage or the entire forest is a patch with the probability of a tree being damaged equal to the overall fraction of the forest that is damaged. Both situations are by no means incompatible, representing a situation in which damaged trees are scattered throughout the forest in which large runs of contigious diseased trees do not occur. Such a situation would correspond with the expected pattern of forest decline experienced in West Germany where healthy trees are found next to damaged trees.

Bird et al. (1978) found that when the stochastic model is applied to this type of patterning, it did not provide significant agreement between the estimated and predicted models. Therefore a computationally simpler technique was recommended by Vithayasai (1971).

Application of Vithayasai's method, initially involved the compilation of a table summarising the observed and expected frequencies of healthy and damaged trees (Table 8.4). The 'Run length' column refers to the relative sizes of the patches and gaps, therefore the observed frequency indicates the frquencies of patches and gaps of a certain size.

	Av. Patch	Av. Gap
1	2.28	3.08
2	1.76	2.47
3	1.81	1.71
4	1.78	3.11
5	2.44	2.06
6	2.35	1.55
7	3.62	1.83
8	5.00	2.50
9	2.83	2.80
10	2.83	2.00
11	2.60	1.67
12	2.00	2.29
Total	2.20	2.32

Fraction of total area covered by patches : 0.487

Table 8.3 Average patch and gap size for each sub - transect

To calculate the probability that a tree will be healthy or damaged involved a simple calculation :

$$\text{Probability of being healthy} = \frac{258}{258 + 286} = 0.47426$$

$$\text{Probability of being damaged} = \frac{286}{286 + 258} = 0.52573$$

Correspondingly :

Probability of occurrence of a run of r damaged trees =

$$d (r) = (0.52573)^{r - 1} (0.47426)$$

Probability of occurrence of a run of healthy trees =

$$d (r) = (0.52573) (0.47426)^{r - 1}$$

The above probabilities were used to calculate the 'expected' values for the frequency of runs of length r. In order to test the significance of the calculated values, a chi - square test of goodness - of - fit was applied to the observed vs. expected frequencies (after pooling runs of low frequency). The result , which equalled 17.898 was 99.61 % significant with 6 degrees of freedom, therefore the probability values can be accepted.

Run Length	Healthy Trees Frequency		Damaged Trees Frequency	
	Observed	Expected	Observed	Expected
1	59	61.51	58	58.33
2	21	29.17	27	30.67
3	16	13.84	10	16.12
4	10	6.56	12	8.48
5	3	5.92	7	4.94
6	2		2	
>7	6		7	
Total runs	117		123	
Total trees	258		286	

Table 8.4 Application of the Bernoulli trial model

The probability that a crown will be damaged or healthy (according to the model) are approximately equal. The fraction of the total area covered by the damaged patches was 0.487 whilst the probability that a tree will be damaged was 0.526. These figures confirm the conclusion drawn by Bird et al. (1978) that such results reflect a scatter of diseased trees throughout the forest as opposed to a coarse pattern of clearly defined patches and gaps, with trees in the patches possessing a high probability of being infected. As the observations made in Chapter 5 have shown, forest decline displays the former type of pattern. In the study area chosen it is difficult to define a relationship between damage and site / stand factors; the only identifiable relationship existing between damage and elevation for trees over 60 years. However, any interpretation of this relationship must display caution, since in general a high elevation site will always be the most vulnerable from climatic extremes with or without the input from airborne pollutants. Leaving this variable out of the equation; every tree must stand an equal chance of showing the symptoms of forest decline. This has been the general experience throughout West Germany and the rest of central Europe which has experienced such a 'new kind of forest damage.' By applying quantitative methods to the decline distribution (admittedly over a small study area), these observations can be confirmed.

8.5 Conclusions

Section 8.3 defined the variables that were used in the Black Forest study to assess the distribution of crown condition. The measurement technique applied in each case was formulated on the premise that each variable could be measured on maps and aerial photography in order to simplify the methodology as much as possible.

Each of the variables presented their own problems during the measurement phase, although some were simpler than others. The problems encountered when assessing tree species and crown condition have been considered in Chapter 5. Suffice it to say here that once both variables can be assessed confidently, the measurement process is relatively straightforward. Elevation proved more difficult because of the need to transfer the grid to a topographic map, however once this had been done on the ZTS the measurment process was again straightforward.

The measurment approach for aspect was documented by Heller & Sader (1980), therefore little refinement was needed. The problem with the age assesssment was the same as for elevation namely the transferral of the grid to a map, however the measurement was a precise one. Slope on the other hand was more subjective since it was dependant on the visual discrimation of slope sectors which were then transferred to the map and the photography.

The major problem with the measurment of stand position was considered in section 8.3.2.7., however, this variable is considered by the author to be important, especially so in areas which are prone to wind borne pollutants. Topographic position was like slope a subjective discrimination from the maps and photography. Although inextricably linked to elevation in this case (as seen in Chapter 9), it could come into its own where a number of areas of differing topography at similar elevations (or vice versa) are considered.

Radiation index is not physically measured but utilises combinations of two other variables. These are straightforward calculations, therefore radiation index is simple to apply in this context. Finally, stand composition which proved to be the most difficult to apply because of the complexity of the stands themselves. The decision of what measure constituted stand composition was the crux of this technique. The basic approach adopted had been used both by Denstorf (1984) and Scherrer et al. (1980) and involved a simple percentage ratio. This ratio as applied by Scherrer et al. (1980) was divided into three, therefore the approximate percentages used for the Black Forest study were of the same magnitude.

To conclude, the measurement techniques employed in this case were considered to be satisfactory regarding their ease of application. The qualitative data obtained in section 8.3 and 8.4 provided an insight into the possible relationships existing between crown condition and all variables. In Chapter 9 the success of the sampling strategy and a detailed assessment of the relationships will be considered.

Chapter 9 : Statistical Approaches to Crown Condition Monitoring

9.1 Previous Approaches

9.1.1 The ideal approach ?

Previous statistical approaches to the assessment of the distribution of tree crown / stand condition have involved linear techniques. Hamilton & Edwards (1976), however, predicted that a linear model cannot ensure that probability estimates will lie within the interval (0,1), where 0 indicates zero probability and 1 indicates 100 % probability. The interval scale consists of allocating a number to an individual to indicate its precise position along a continuous scale. In Hamilton & Edwards' case the interval categories were bounded by 0 and 1 which are the limits of probability that a tree will / will not die. They concluded that the logistic function, which limits estimates of probability to the interval (0,1) is the statistically preferred model for expressing the relationships between a 0,1 dependant variable and a set of independant variables.

Hamilton & Edwards recommended a non - linear approach for tree mortality prediction, however, when applied to classical risk rating methods, both linear and non - linear statistical techniques have been employed to successfully predict biotic damage. However, the application of these techniques to forest decline has been limited (see Section 8.2.2) although, its potential to provide further insights into the causes of decline has recently been recognised.

Kauppi (1987) noted that the European inventories only obtained information on the regional variability of individual damage symptoms. Although procurement of this information is the primary aim of an inventory, Kauppi along with Kuusela (1987) claimed that a lack of studies on the relationships between crown condition and stand site parameters was hindering the investigations of possible decline causes. Kuusela (1987) blamed this dearth of investigation on the a priori assumption that atmospheric pollutants are the sole or principle cause. Kuusela reached the following conclusions :

(i) the situation could be improved by defining the concepts of tree and stand vitality and the parameters that separate them;

(ii) possible stand and site parameters should be defined as independant variables explaining the vitality;

(iii) all of these parameters should be observed and measured as part of forest resource inventories and the results analysed by multi - parameter models;

(iv) survey data should be combined with intensive long - term investigations on permanent sample plots having trees, other plants, pollutant loads, soils, etc. as the study objects.

The problems of incorporating such an approach into the main regional and national inventories have been discussed in Section 8.2.2. The methods discussed in sections 9.1.2 onwards have all been incorporated into specific regional / experimental projects and do not form part of the main national inventories.

9.1.2 Descriptive methods

Within the confines of forest decline inventory procedures the approach most commonly adopted has been a basic descriptive one. Denstorf et al. (1984), Wastenson et al. (1987) and Kuhl (1989) made observations concerning the seeming increase of damage with increasing elevation. In fact Wastenson et al. (1987) produced a digital elevation model (DEM) overlayed with crown condition information in order to graphically illustrate this relationship. Denstorf et al. (1984) identified other possible relationships between crown condition, tree age and degree of crown closure, however, no quantitative evidence was produced. Where such relationships have been assessed statistically the work has gone beyond the remit of the standard inventory procedures. The chief aim of the forest decline inventories is to produce accurate measures of crown condition over large areas, in a timely manner. However, this approach does ignore the potential of additional statistical analysis, which if applied properly could extend the influence of the inventory.

The studies outlined in section 8.2.2 all involved a certain level of analysis beyond the merely observational. The descriptive methods employed varied from basic observation to graphical representations similar to those introduced by Scherrer et al. (1980) and Seger (1987). Scherrer et al. (1980) in fact stratified sample plots according to one variable; i.e. 'damaged' vs. 'undamaged'. The application of this technique to the elevation classes therefore provided insight into the mutual interdependance of this variable. The resulting graph showed that at varying elevations the maxima and minima of the two distributions (damaged / undamaged) were complements of each other. Seger (1987) on the other hand adopted a more basic approach by cross - tabulating mean stand condition with elevation. Both techniques, however, are effective methods of graphically representing the dependance of crown condition on elevation.

9.1.3 Regression analysis

Seger (1987) found that the connection of forest status with 'locational' parameters such as slope, exposure and soil type offered no indication of possible relationships. The conclusion subsequently drawn was that relationships could only be measured for the dominating 'spatial' parameters and recommended that such a multi - parameter problem should be solved with multivariate methods. Kuhl (1989) opted for a statistically simple approach, using the chi - square test to assess the significance of the relationships between crown condition and the single variables assessed (age, crown density, social position in the stand, stand structure, sample position in stand and thinning grade). However, Kuhl readily acknowledged that the chi - square test is only a test of independance and does not measure the scale of dependancy between the two populations, i.e. crown condition and any one of the variables.

Seger (1987) opted for stepwise multiple regression analysis involving the variables crown status, altitude level, distance to emitters and SO_2 deposition (each variable could be measured on an interval scale). The variable included in the first step was 'distance to emitters,' since this had the highest correlation with crown status, with elevation as the second step. Whilst distance to emitters explained 13 % of the total variance of crown status, inclusion of elevation only explained a further 4 % of the variance since the two variables were highly correlated. For this reason the third variable SO_2 deposition was excluded from the analysis. Seger (1987) concluded that such weak results could be attributed to :

(i) the partially unsystematic pattern of different damage values;
(ii) absence of nominal locational variables;
(iii) complexity of the landscape structure;
(iv) absence of other parameters expressing the actual forest status.

Scherrer et al. (1980) also adopted a multiple regression approach, however, like Seger (1987) a high degree of autocorrelation was present. In order to obtain truly independant variables the observations Xij (variable j, plot i) were normalised, Xij = (Xij - x) / sXj (s = total number of variables) and then transformed by means of a principal components (PC) analysis and this yielded the orthogonal, uncorrelated variables. Using all of the adjusted variables, the regression analysis explained 69.9 %

of the variance. Those variables with coefficients significantly different from zero still accounted for 69.9 % of the variance, in fact, the variable " age of dead pine trees " alone accounted for 67.7 % of the variance. Scherrer et al. (1980) were able to conclude from their analysis that natural or premature ageing was either the cause itself or a prerequisite for the observed forest damage.

9.1.4 Further multivariate methods

Faced with this complex problem described above; Seger (1987) attempted cluster analysis in order to try and combine the dominant locational variables with the index values of the forest stands observed. The variables included in this analysis were crown status, elevation and level of SO_2 deposition. The results indicated that healthy trees occurred at higher elevations, where they were little affected by SO_2 emissions. Damaged trees on the other hand were found at lower elevations which experienced high SO_2 emissions.

9.1.5 Discussion of approaches

Both the approaches adopted by Scherrer at al. (1980) and Seger (1987) place a different emphasis on the utility of regression techniques for crown condition monitoring. The studies are similar in that the areas under investigation were both alpine valleys influenced by emissions from industrial plants, although Scherrer et al. (1980) studied Scots pine (Pinus sylvestris) whilst Seger (1987) studied European fir (Picea abies). The fundamental differences between the two approaches stem from the choice of variables. Seger (1987) included a wider range of "geo - ecological" parameters (data relating to pollutants and climate) whilst Scherrer et al. (1980) only included spatial parameters (stand / site characteristics). The major problem encountered in both studies was the strong interdependance between the chosen variables. For this reason Scherrer at al. (1980) transformed the data (see Section 9.1.3) before attempting regression analysis. The eventual success of this approach was due to the choice of an "age" class which on its own accounted for most of the variance in crown condition. It was interesting to note that after taking this class out of the analysis the remaining variables only accounted for 42 % of the observed variance. Seger (1987) on the other hand, only studied trees older than 60 years, therefore, an age class was not used. This might explain the lack of success with the regression approach, which in turn lead to the adoption of a more sophisticated analytical technique.

The overriding conclusion which can be drawn from studying from both approaches is the difficulty found when attempting to apply statistical rules to such complex data sets. The dependant variable (crown condition) consists of four or five nominal measurements whilst the independant variables are a mixture of interval and ordinal measures. Therefore, prior to analysis the data must be converted into a common ordering system - simply a matter of grouping the interval data; e.g. creating 100 metre elevation groups, each one numbered in ascending order. The analysis must involve a regression measure, however, it is felt by the author that a further test would be required since regression analysis makes too many aasumptions about the data. Therefore a combined regression and discriminant analysis was deemed suitable for this project. Before embarking on this approach it is worth assessing the degree of difference between the populations of each variable using the descriptive statistics outlined in the next section.

9.2 Crosstabulation and the Chi - square statistic

9.2.1 Crosstabulation

The original data from the photography was transferred to a grid of the type shown in Fig.8.1 (the technique is described in Section 8.3.1). In order to manipulate this data statistically the first stage of the analysis involved transfer of the grid information to Supercalc 4 spreadsheet files. In this format the data could be manipulated in order to assess the relative amounts of each independant variable occurring in each damage class. The spreadsheet tables provide a description of the interdependance between the variables, however, in order to quantify these relationships the data was translated into SPSS PC format. This package accepts data in Lotus 123 spreadsheet format, therefore the Supercalc 4 files were initially converted into Lotus 123 files. The final stage of this process involved translation of the files into SPSS format from within SPSS PC. The software avilable for SPSS PC allows for simple statistical analysis. Therefore, in order to establish a basic measure of correlation between the measured variables and damage class, a series of crosstabulations were run.

In order for the crosstabulation to have any meaning the variables that had been measured on an interval scale had to be sorted into ranked classes (nominal data). With reference to Section 8.3.2 the variables that needed conversion were slope, elevation, stand position and radiation index (1 and 2). The following is a list of the groups eventually chosen for crosstabulation and the chi - square test :

(1) Elevation - 5 groups (550 - 650 m, 651 - 750 m, 751 - 850m, 851 - 950m, > 951m).

(2) Slope - 4 groups (0 - 20 %, 21 - 40 %, 41 - 60 %, > 60 %).

(3) Topographic position - 4 groups (Valley bottom (20), lower slope (40), middle slope (50), upper slope / ridge top (70)).

(4) Stand position - 5 groups (edge of stand, 1 - 20 m, 21 - 40 m, 41 - 60 m, > 60 m).

(5) Radiation index - varied by species. Fir (R1 = 7 groups, R2 = 7 groups), Spruce (R1 = 6 groups, R2 = 7 groups), Beech (R1 = 7 groups, R2 = 6 groups).

(6) Stand composition - 4 groups

The crown condition classes used to crosstabulate with the independant variables were a modified form of the standard German classes. The modification simply involved combining the class 3 and class 4 results since the number of dead (class 4) trees was not deemed adequate for inclusion in the chi - square test, which was the main aim of this stage of analysis.

9.2.2 The Chi - square test

The chi - square (X_2) test is a very flexible test which can be applied in one - sample, two - sample and more than two - sample situations. The test is restricted to nominal (frequency) data and is nonparametric (Ebdon, 1977). A large value of X_2 indicates that there is a large amount of difference between the observed and the expected frequencies, and would suggest that the null hypothesis can be rejected - in this case the null hypothesis states that there is no relationship between the frequencies of crown condition and those of the independant variables.

There are a number of restricions applying to the Chi - square test. Firstly, the data must be in the form of frequencies, i.e. the number of discrete objects occurring in different categories. In addition, the categories must be mutually exclusive, so that one individual cannot possibly be counted in more than one category. Both of these conditions are met by the data under review, the only problem was the number of categories with a small number of frequencies. There is a rule of thumb which applies in this case, that is : if the number of categories is greater than 2, no more than 1 / 5 of the expected frequencies should be less than 5, and certainly none should be less than 1. The only way to remedy a breach of this rule is to combine the groups until the required minimum has been reached. In this case such a route was followed for the elevation groups, which were reduced from 10 to 5 and the slope groups which were reduced from 6 to 4. Crosstabulation showed that in the case of spruce even this did not meet the requirement (see Table 9.1 (b)) and certainly for Radiation index applied to all species, this condition was not met (see Tables 9.1 (a), (b) and (c)). The data was not rationalised further, however, for two reasons : firstly, it was felt that further reduction of the number of groups would have wiped away any traces of interdependance, thereby making a nonsense of the underlying research hypothesis (Ebdon, 1977), and secondly, when dealing with a complex data set, the chi - square test is a reconnaissance measure, therefore, further refinement of the data was needless.

Tables 9.1 (a), (b) & (c) Results of the Chi - square test

Table 9.1 (a) Fir

Variable	X2	D.F.	Sig.	Min E.F.	Cells with E.F < 5
Elev	83.295	12	.0000	3.239	3 / 20 (15.0 %)
Slope	10.658	9	.2999	5.808	0 / 20
Posit	19.552	12	.0761	3.909	3 / 20 (15.0 %)
Topo	80.242	12	.0000	0.056	7 / 20 (35.0 %)
Rone	37.440	18	.0042	0.299	11 / 28 (39.3 %)
Rtwo	29.494	18	.0427	0.112	11 / 28 (39.3 %)
Comp	19.749	9	.0195	1.426	2 / 16 (12.5 %)

According to Table 9.1 (a) the variables Topo, Rone and Rtwo (refer to Section 8.3 for explanation of variables) do not meet the frequency requirement (E.F. = Expected Frequency). The variables Elev, Posit and Comp meet this requirement and are significant. Therefore it is permissable to reject the null hypothesis for these three variables. In other words, the frequency distributions of Posit and Comp correspond with that of the dependant variable crown condition.

Table 9.1 (b) Spruce

Variable	X2	D.F.	Sig.	Min E.F.	Cells with E.F < 5
Elev	31.176	12	.0019	2.605	5 / 20 (25.0 %)
Slope	6.395	9	.6990	2.316	5 / 16 (31.3 %)
Posit	5.295	9	.8078	1.882	5 / 16 (31.3 %)
Topo	27.726	9	.0011	2.895	4 / 16 (25.0 %)
Rone	33. 477	15	.0040	1.882	11 / 24 (45.8 %)
Rtwo	22.880	18	.1953	0.579	16 / 28 (57.1 %)
Comp	7.851	9	.5492	2.392	3 / 16 (18.8 %)

Table 9.1 (c) Beech

Variable	X2	D.F.	Sig.	Min E.F.	Cells with E.F < 5
Elev	153.93	12	.0000	1.175	3 / 20 (15.0 %)
Slope	17.712	9	.0387	3.299	2 / 16 (12.5 %)
Posit	46.767	9	.0000	1.853	2 / 16 (12.5 %)
Topo	27. 726	9	.0000	1.310	3 / 16 (18.8 %)
Rone	43.258	18	.0007	0.181	13 / 28 (46.4 %)
Rtwo	23.390	15	.0762	0.045	13 / 24 (54.2 %)
Comp	5.700	9	.7695	1.435	2 / 16 (12.5 %)

Only the variable Comp meets the frequency requirement in Table 9.1 (b), however, it is not significant. Of the remaining variables, Elev, Topo and Rone are significantly related to crown condition, although none of them meet the frequency requirement. However, only 25 % of the frequency groups for Elev and Topo are less than five, which only falls just outside the 20 % level, therefore, it would seem that a potential link between crown condition and elevation / topographic position does exist for Spruce. Section 9.3 illustrates the strong correlation between these two variables for all species.

Table 9.1 (c) shows a different set of relationships existing for Beech. Interestingly, only two of the variables do not meet the frequency requirement, those of Rone and Rtwo. However, the variables Elev, Slope, Posit, Topo and Comp frequencies are significantly related to those of crown condition. Comparing these results with those of fir and spruce, the only common denominator is the variable Elev. However, the frequency limit has precluded the use of radiation index and therefore the chi - square test does not provide a full picture of the possible relationships. In addition the chi - square test is only a check of independance and not of dependance (Kuhl, 1989). In order to test for the levels of dependance it is necessary to apply analysis of variance approach. The chi - square test has therefore provided a useful indicator that the sampling scheme is not affecting the results which are in fact a function of the true data.

9.2.3 Analysis of Variance

The simplest method of testing the assumption that crown condition is directly affected by site / stand variables is to compare group means for different variable classes. Genuine differences might exist, however, one cannot be sure whether these differences are simply random variations occurring by chance, or if they really do represent systematic differences between the means. Analysis of variance allows these two hypothesese to be tested and therefore confirm or deny the conclusion that observed variation is a product of the sampling procedure.

The rationale of analysis of variance is to find out whether there is more variation between the samples than from within them. If the samples are taken at random from a common population (the null hypothesis) it is reasonable to expect the variation within the samples to be about the same as the variation between the samples, since both are reflections of the overall variation in the population. Any difference in these two measures is merely due to chance in the sampling process. If the samples are taken from different populations (the alternative hypothesis) the variation within each sample is a reflection of the variation within the particular population from which it has come. Variation between samples in this case is a reflection of the difference between the populations.

In order to demonstrate the steps of the analysis undertaken, a series of worked examples will be considered. The data used in these examples are drawn from the observations made in Section 8.3.2, which served as a graphic illustration of the possible relationships present within the data. The two variables selected for analysis are elevation and radiation index (R1). Taking the example of European fir, Table 9.2 (a) & (b) shows the mean crown condition class and standard deviations for the goups of both variables. Noticeable for elevation is the fact that the original ten groups have been chosen, since there is no minimum frequency limit for each group, unlike the chi - square test.

An increase in the values of both variables corresponds to an increase in the mean crown condition class. In order to test the significance of this change the first step in the analysis is to calculate the total sum of squares. The total sum of squares for both variables are shown in Table 9.3 (a) and (b). To compute the F - ratio, the variation components (between and within groups sum of squares) must be standardised according to the degrees of freedom involved in their estimation. For the total variation, based on the total mean, one degree of freedom is lost in calculating the mean, so TDF = N - 1 (N = total number of observations).

Table 9.2 (a) & (b) Mean crown condition classes for elevation and radiation index (R1) groups

Table 9.2 (a) Elevation

Group (metres)	Count	Mean	Standard deviation
1 (550 - 600)	13	0.6923	0.8549
2 (601 - 650)	45	1.0000	0.8257
3 (651 - 700)	105	1.3143	0.7883
4 (701 - 750)	148	1.3514	0.7725
5 (751 - 800)	52	1.5577	0.7775
6 (801 - 850)	26	1.4615	0.9047
7 (851 - 900)	65	1.6154	0.6776
8 (901 - 950)	52	1.8462	0.6682
9 (951 - 1000)	48	1.8958	0.7784
10 (1001 - 1050)	18	1.9444	0.6391
TOTAL	N = 572	1.4650	0.8096

Table 9.2 (b) Radiation Index (R1)

Group	Count	Mean	Standard deviation
1	5	1.0000	0.7071
2	26	1.0769	0.7442
3	58	1.3103	0.7993
4	158	1.3987	0.7369
5	164	1.4695	0.8394
6	152	1.6776	0.8347
7	10	1.4000	0.5164
TOTAL	N = 573	1.4660	0.8092

For between groups variation, the degrees of freedom are the number of groups less one for the calculation of the total mean from them, so if the number of groups is K, DFB = K - 1. Finally, for within groups variation one degree of freedom is lost in the calculation of each group mean, so DFW = N - K.

The F - ratio is calculated by dividing the between groups variance estimate by the within groups variance estimate. A value of 1.00 would indicate that the variation in the group means is only random variation occurring between samples. Alternatively an F - ratio considerably larger than 1.00 suggests that the variation in the group means is more than could be expected from a chance difference, and the means of the two populations are therefore different. Refering to Table 9.3 (a) and (b) the two F - ratio values are 8.384 and 3.661.

Table 9.3 (a) and (b) Analysis of Variance results for variables Elev and R1

Table 9.3 (a) Elevation

Source	D.F	Sum of sq's	Mean sq's	F ratio	Signif.
Between Gps.	9	44.3072	4.9230	8.384	.0000
Within Gps.	562	329.9935	0.5872		
Total	571	374.3007			

Table 9.3 (b) Radiation index (R1)

Source	D.F	Sum of sq's	Mean sq's	F ratio	Signif.
Between Gps.	6	13.9952	2.3325	3.661	.0014
Within Gps.	566	360.5912	0.6371		
Total	572	374.5864			

From a table of the F distribution, the elevation score is significant at the 100% confidence level whilst R1 is significant at the 99% confidence level (Tables 9.3 (a) & (b)). Therefore for these two groups it can be concluded that the differences did not occur merely because of sampling error and that the two means are almost certainly not equal in the parent population.

In general the results from the analysis of variance, in addition to the degree of error associated with the sampling procedure (Section 8.3.1), indicate that sampling inadequacies cannot be responsible for the variation in group means. Therefore, having established a certain level of dependency between crown condition and the measured variables, the next procedure to follow should logically be an assessment of the strength of this dependency between the variables themselves and with crown condition. As described in section 9.1 a multiple regression analysis is the best initial approach.

9.3 Regression Analysis

9.3.1 Correlation

Section 9.2 dealt with techniques that measure the strength and direction of the relationship between the site / stand variables and crown condition. This section describes a method for measuring the form of a relationship between two variables, or, more importantly, of measuring the dependance of one variable on another.

Multiple correlation coefficients describe such relationships, since the square of a multiple correlation coefficient (the multiple coefficient of determination), indicates the proportion of the variance in the dependant variable associated with all of the independant variables. Tables 9.4 (a), (b) & (c) are the correlation matrices for fir, spruce and beech.

The correlation matrices provide an insight into the levels of correlation between the independant variables based on the Pearson's correlation coefficient scores. In this case it is clear that there is quite a high level of correlation between certain of these variables. For all three species the variables Elev, Topo and Rone display such correlation, however, it is these three variables that display the greatest correlation with crown condition class.

What the correlation matrix does not indicate however, is the degree to which each variable accounts for the variation in crown condition. The matrix does show that Elev, Topo and Rone are the variables most likely to account for the majority of the variance. What is required is a measure of the significance of each of these variables and hence its ability to explain the variation observed. The usual way of testing the significance of a correlation coefficient employs the F - ratio encountered in Section 9.2. Standard multiple regression techniques are aimed at isolating the independant variables that have critical causal effects on the dependant variable and should be retained in an equation required either to describe the variance or to predict other values of the dependant variable.

Table 9.4 (a), (b) & (c) Correlation matrices for fir, spruce and beech

Table 9.4 (a) Fir

	Class	Elev	Slope	Posit	Topo	Rone	Rtwo	Comp
Class	1.000	.324	.028	.069	.237	.182	-.061	-.121
Elev	.324	1.000	.152	-.079	.430	.534	-.197	-.082
Slope	.028	.152	1.000	.016	.129	-.153	-.151	-.121
Posit	.069	-.079	.016	1.000	.217	-.092	.112	-.062
Topo	.237	.430	.129	.217	1.000	.280	.188	-.130
Rone	.182	.534	-.153	-.092	.280	1.000	-.133	.041
Rtwo	-.061	-.197	-.151	.112	.188	-.133	1.000	-.006
Comp	-.121	-.082	-.121	-.062	-.130	.041	-.006	1.000

Table 9.4 (b) Spruce

	Class	Elev	Slope	Posit	Topo	Rone	Rtwo	Comp
Class	1.000	.384	-.093	.118	.350	.377	.164	.112
Elev	.384	1.000	.036	.202	.683	.648	.383	-.102
Slope	-.093	.036	1.000	.111	.106	-.507	.047	-.254
Posit	.118	.202	.111	1.000	.383	-.027	.143	-.067
Topo	.350	.683	.106	.383	1.000	.446	.446	-.160
Rone	.377	.648	-.507	-.027	.446	1.000	.239	.140
Rtwo	.164	.383	.047	.143	.466	.239	1.000	-.074
Comp	.112	-.102	-.254	-.067	-.160	.140	-.074	1.000

Table 9.4 (c) Beech

	Class	Elev	Slope	Posit	Topo	Rone	Rtwo	Comp
Class	1.000	.248	.039	-.135	.166	.187	.056	-.007
Elev	.248	1.000	.101	-.122	.490	.568	-.059	-.080
Slope	.039	.101	1.000	-.017	.152	-.133	.082	.043
Posit	-.135	-.122	-.017	1.000	.004	-.177	.023	-.042
Topo	.166	.490	.152	.004	1.000	.436	.017	-.016
Rone	.187	.568	-.133	-.177	.436	1.000	-.089	-.012
Rtwo	.056	-.059	.082	.023	.017	-.089	1.000	.056
Comp	-.007	-.080	.043	-.042	-.016	-.012	.056	1.000

9.3.2 Stepwise multiple regression methodology applied to the fir data

One of the most frequently used methods of isolating the critical variables is that of stepwise multiple regression (Johnson, 1980). This approach does not feed all of the independant variables in at once, but instead builds up the equation one variable at a time. The procedure used to order the entry of the variables into the equation is based on their importance in reducing the variance of crown condition (the most important first).

The variable entered in the first step was Elev. A corresponding analysis of variance of this relationship produced an F - ratio value of 66.99431 (1 and 571 degrees of freedom). Reference to the tables of F - distribution indicated that the F - ratio value would occur in less than one random sample in a thousand. Therefore it is extremely likely that there is a positive correlation between Elev and crown condition (Class), since it is highly unlikely that the observed correlation will occur in a random pairing of any two values from each of the populations. The null hypothesis of no correlation can therefore be rejected in favour of the research hypothesis of a positive correlation. The resulting regression equation takes the form of :

$$Y_0 = -0.291 + 2.242\mathrm{E}-03(X_0) \quad (\text{Eqn. } 9.1)$$

where : Y_0 = crown condition class, X_0 = nearest integer part of elevation value

If the data being studied comprises a properly taken sample from a specified population, then we want to know if the observed parameters of the regression equation are likely to have the same sign and magnitude in the population. The validity of such an inference is usually assessed by the Student's t - test which expresses the difference between the observed value of the elevation constant, b and an assumed value of b at zero, as a ratio of its standard error. The t - value computed for Elev was 8.185, which, with reference to the t - table, was deemed significant at 99 % confidence level. Therefore the positive relationship established between elevation and crown condition almost certainly occurs in the population.

The first step accounts for the most significant variable, the second step in this case included the variable Topo in the equation. Reference to the R^2 value indicated that the inclusion of Topo only explained a further 1 % of the variation ($R^2 = 0.11671$) in crown condition. This is not surprising since the variables Elev and Topo are correlated ($R = 0.43$). Finally the variable Comp was entered into the equation, however, this only accounted for a further 0.5 % ($R^2 = 0.12368$) of the variation in crown condition. The final regression equation produced took the form :

$$Y_0 = - 0.319 + 1.867E - 03 (X_1) + 7.308E - 03 (X_2) + - 5.585E - 03 (X_3) +/- 0.221$$

(Eqn. 9.2)

where : Y_0 = crown condition class, X_1 = Elevation term, X_2 = Topographic position term, X_3 = Stand composition term.

The corresponding results and equations for spruce and beech can be found in Appendix 3. The same criteria were used and similar conclusions can be drawn about the limitations of the approach and the results obtained, as will be discussed in the next section.

9.3.3 Discussion of the Stepwise multiple regression approach

The results of this analysis suggest that of the variables measured, elevation / topographic position and stand composition are the factors that most affect fir crown condition. However, before drawing conclusions it is worth putting the analysis into some sort of perspective. Firstly, the study area is only 2 sq km., therefore the results may not be directly applicable to other areas.

A more basic drawback associated with the regression approach is the choice of variables. As Section 9.1.5 showed, Scherrer et al. (1980) found that by neglecting age from the analysis, 42 % of the variance in pine mortality was explained by the remaining variables. Seger (1987) on the other hand found that only 17 % of fir crown condition could be explained by the variables he selected. Herein lies the major problem associated with the whole approach of damage rating: the selection of the variables exerts an extremely strong influence on the outcome of the analysis. How then does one decide which variables to use ? The only answer is to use every available variable, thereby giving the approach as much chance as possible to identify possible relationships. In this particular case the variables selected do not by any means provide us with a picture of the potential for decline to occur. Referring to the results of Scherrer et al. (1980), a deliberate decision was made not to include age as an independant variable for a number of reasons, these are :

(1) the Baden - Wurttemberg state inventory discriminates between trees older than 60 years and those younger than 60 years due to the different levels of damage in each group;

(2) the photo - sampling strategy only included trees older than 60 years because a crown condition class could not be assigned to each tree with any degree of confidence;

(3) the desire to identify a factor other than age that would explain the distribution of crown condition.

As outlined in Section 8.1 the variables were selected using two criteria; firstly they had to be measurable from aerial photographs or topographic maps, and secondly they had to be measurable on an interval scale (or to allow conversion to this scale) for inclusion in the statistical analysis. Therefore the choice was automatically limited, however, for the model to work it is recommended that parameters such as climatic and pollution data are included in any such analysis. Even then, as Seger (1987) discovered, the complexity of the environment and the data handling / conversion problems will lead to generalised results which are not robust. In order to reach a point where confidence could be placed in the results, Seger (1987) used cluster analysis (see Section 9.1.4). In the author's study a discriminant analysis was used, which unlike regression analysis is applied to nominally - measured dependant variables. Crown condition classes come under this category, therefore, the approach should furnish more reliable results.

9.4 Discriminant analysis

> "Discriminant analysis is a statistical technique which allows the researcher to study the differences between two or more groups of objects with respect to several variables simultaneously" (Klecka, 1980)

The basic prerequisites for analysis are that two or more groups of variables exist (crown condition classes 0 - 4), which is assumed to differ according to several independant variables and that those variables can be measured at the interval or ratio level. Discriminant analysis will then help to analyse the differences between the groups and / or provide a means to assign (classify) any case into the group which it most closely resembles. The basic equation is :

$$X_0 = f (D_I, D_{II}, \ldots\ldots\ldots, D_m) \quad (\text{Eqn. } 9.3)$$

where D_I ...... D_m are the discriminant functions;

X_0 is the dependant variable - the categories into which the observations are divided (n);

m is the number of categories into which the dependant variable is divided, less one, i.e. (n - 1).

In the case of the Black Forest data the dependant variable, crown condition, is divided into crown condition classes, and these serve as the dependant variables. The individual observations are assigned scores within the discriminant functions which are derived in standardised form , and a mean score is computed for each group of observations (this mean is usually referred to as the group centroid). Analysis of variance can be conducted on these scores, the aim being to maximise the F - ratio of the between - groups to within - groups variance estimates such that the classes of interest have maximum separation.

Discriminant analysis has been used to examine vegetation - environmental relationships using a field survey approach. Norris & Barkham (1970) applied this technique to an investigation of differences between ground flora from a series of Cotswold beechwoods. The discriminating factors measured included aspect, slope, exposure and tree categories such as age class and date of thinning. The authors postulated that differences in the flora between woods may be due to differences inherent in phyical site conditions. However, if these are similar for two or more woods, the differences in flora may be accounted for by variation in management practices.

Most of the variation found could be explained using three axes, in decreasing order of importance. The first component of variation (discriminant function) corresponded to a general moisture gradient which was in turn related most strongly to exposure and soil. The second component was related to soil properties, and the third was attributed to a management factor.

9.4.1 Discriminant analysis of tree crown data

9.4.1.1 Data preparation

Before the analysis could be undertaken the tree crown data had to be converted into a form that could be handled by SPSSx. Up to this point the PC version of SPSS had been utilised to analyse this data. The first step involved conversion of the Supercalc spreadsheet files into comma separated data files (undertaken within Supercalc).

These files were then transferred onto a mainframe DEC VAX 8650 where they could be edited. The final stage of the process involved input of the variable data into the SAP package, which provides an interface to the SPSSx package. Once in this format the files could be called from SAP into SPSSx for subsequent analysis.

9.4.1.2 Evaluating the importance of variables : The discriminant function coefficients

A method of assessing the importance of a particular variable is to study its discriminant function coefficient. Discriminant analysis produces discriminant function coefficients for each predicting variable. For each case the score on a variable is multiplied by that variables discriminant function coefficient. The resulting sum is the case's discriminant function score. The discriminant function coefficients are calculated in order to maximise the differences between the groups in discriminant function scores. In other words, the ratio of between - groups variance to within - groups variance is maximised. The set of standardised discriminant function coefficients for the predicting variables in the fir data is shown in Table 9.5.

Table 9.5 Fir data : Standardised canonical discriminant function coefficients

	Function 1	Function 2	Function 3	Function 4
Elev	0.76611	0.40755	- 0.04848	0.42839
Slope	- 0.19291	0.19643	0.13018	0.15770
Posit	0.17065	0.57096	0.78990	- 0.22847
Topo	0.33293	- 0.11637	- 0.45282	- 0.59338
Rone	- 0.00827	- 0.34709	0.32261	0.50604
Rtwo	- 0.17570	- 0.02316	0.43749	0.77506
Comp	- 0.23098	0.67432	- 0.49933	0.42591

The term standardised indicates that each variable score is standardised before it is multiplied by the coefficient. The method of standardising a variable score involves subtracting the mean of that variable from the score; this difference is then divided by the standard deviation of the variable. Standardised coefficients are used to remove the effects of differing means and differing standard deviations in the predicting variables, otherwise, variables with smaller standard deviations would tend to have larger coefficients, making it difficult to assess the relative importance of the predicting variables. The Function 1 column (which explains most of the variation within the data) in Table 9.6 indicates that an elevation / topographic position factor exerts the strongest influence on crown condition, thereby confirming the multiple regression results. It is worth noting that because the dependant variable is treated as a nominal measure there are no positive or negative associations, therefore, the signs of the discriminant function coefficients have no significance.

9.4.2 Relative importance of discriminant functions

Table 9.5 does not furnish an estimate of the statistical significance of each predictor variable, for this information reference must be made to the Wilks' Lambda statistic displayed in Table 9.6 (a), (b) and (c).

Table 9.6 (a) Canonical discriminant functions for fir data

FCN	Eigenvalue	% variance	Cum %	Can. corr.	DF	W Lambda	Chi - Sq.	DF	Sig
1	0.1500	78.50	78.50	0.3612	0	0.8351	99.860	28	0.00
2	0.0342	17.90	96.40	0.181	1	0.9603	22.433	18	0.21
3	0.0059	3.10	99.50	0.0767	2	0.9932	3.803	10	0.95
4	0.0010	0.50	100.00	0.0310	3	0.9990	0.532	4	0.97

One measure of the success of the discriminant analysis is a comparison of the between - groups variance and the within - groups variance. The Eigenvalues represent such a comparison since the values are derived from the between - groups variance divided by the within - groups variance. An eigenvalue of 0 means that the discriminant analysis had no discriminating value, whilst an eigenvalue greater than 0.4 is considered significant. (The discriminant analysis eigenvalue has no upper limit .) Referring to Table 9.6 it is clear that the first canonical discriminant function is the only one with any significance, according to the associated eigenvalue of 1.500. The three remaining functions are all approaching zero, therefore, their value for predicting crown condition variance is minimal. In this case, four functions are the maximum, since the total number is decided by subtracting one from the total number of groups. Since the crown condition classes range from zero to four, then the number of functions equals four.

The spruce and beech datum feature only three functions since the crown condition class '4' (dead crown) is not existant. Table 9.6 (b) and (c) confirm the importance of only three functions for both species as well as confirming the strong influence of the first canonical discriminant function.

Table 9.6 (b) Canonical discriminant functions for spruce data

FCN	Eigenvalue	% variance	Cum %	Can. corr.	DF	W Lambda	Chi - Sq.	DF	Sig.
1	0.2679	81.93	81.93	0.4579	0	0.7441	40.350	21	0.00
2	0.0360	11.02	92.95	0.1865	1	0.9435	7.945	12	0.78
3	0.0231	7.05	100.00	0.1501	2	0.9775	3.111	5	0.68

Table 9.8 (c) Canonical discriminant functions for beech data

FCN	Eigenvalue	% variance	Cum %	Can. corr.	DF	W Lambda	Chi - Sq.	DF	Sig.
1	0.2157	87.98	87.98	0.4212	0	0.7989	109.447	21	0.00
2	0.0223	9.11	97.08	0.1478	1	0.9712	14.239	12	0.28
3	0.0072	2.92	100.00	0.0843	2	0.9929	3.474	5	0.62

Table 9.6 (a), (b) and (c) all show that the first canonical discriminant functions explain the majority of the variance in crown condition. This is not surprising since the functions are derived such that the first function separates the groups as much as possible. The second function separates them as much as possible in an orthogonal direction given the first separation, whilst the third function provides maximal separation in another orthogonal direction. The end result is that the groups are as distinct as possible given the original discriminating variables.

A further aid in judging the importance of a discriminant function is its associated canonical correlation. The canonical correlation explains how closely the function and the 'group variable' are related, which is another measure of the function's ability to discriminate among the groups. Table 9.6 confirms that for all three species, the first function is moderately correlated with the crown condition groups, whilst the remaining functions are insignificant.

A second criteria for eliminating discriminant functions is to test for the statistical significance of discriminating information not already accounted for by the earlier functions. As each function is derived, starting with no (zero) functions, Wilks' Lambda is calculated. Lambda is an inverse measure of the discriminating power in the original variables which has not yet been removed by the discriminant functions - the larger the lambda, the less information remaining. Taking Table 9.6 (a) as an example, the Wilks' Lambda value was 0.9603 after one function had been derived. This corresponded to a chi - square of 22.433 with a significance level of 0.2133. This means that a lambda of this magnitude or smaller has a 21.33 % chance of occurring due to the sampling strategy even if there was no further information to be accounted for by the remaining three functions. In fact the chi - square after two functions have been derived has a significance value of 0.9558. Clearly anything beyond the first function will be statistically insignificant, even though the first function has a one in five chance of being insignificant.

A similar conclusion can be drawn for the beech data, however the chi - square values for the spruce data indicate something different. This difference is exemplified by the fact that the inclusion of a second function increases the significance of the Wilks' Lambda statistic. The chance of Lambda deriving from a random sampling error is reduced from 79 % to 68 % by inclusion of the second function. Since this function accounts for 11 % of the group variance for spruce, then the variables that have high second function values must be taken into account when considering the factors influencing spruce condition.

According to the standardised canonical discriminant function coefficients for spruce, the variables Elev, Topo and Rone in function one, exert the greatest influence on crown condition (refer to Appendix 4). Referring to function two, the high value of Rtwo indicates that this variable may also explain some of the variation in crown condition. The beech data indicates an elevation / topographic position factor in conjunction with stand position influences crown condition.

As a confirmatory measure the Pearson correlation coefficients were calculated in order to examine each variables association with a discriminant function. For all three species the first function takes precedence, therefore the results for this function were analysed. Table 9.7 (a), (b) and (c) illustrate the relative importance of each variable in each function. Since the first function is most important in explaining the variation in crown condition it must be concluded that the variables taking precedence within this function are the factors exerting most influence on crown condition.

Table 9.7 (a) indicates that for fir elevation, topographic position and radiation index (Rone) have the strongest correlation with function 1. Therefore, one must conclude that for fir trees these factors influence the distribution of crown condition. Table 9.7 (b) indicates that for spruce the influencing factors are elevation, topographic position, radiation index (Rone) and stand composition. Further, taking function 2 into account, radiation index (Rtwo) must be added to this list. Table 9.7 (c) indicates that for beech, elevation, topographic position and stand position influence crown condition.

Table 9.7 (a), (b) and (c) Pooled within - groups correlations between discriminating variables and canonical discriminant functions (variables ordered by size of correlation within function)

Table 9.7 (a) Fir

	Function 1	Function 2	Function 3	Function 4
Elev	0.89633	0.09492	- 0.15016	0.32603
Topo	0.62165	0.01794	- 0.06647	-0.20973
Rone	0.52346	- 0.29857	0.07566	0.44297
Comp	- 0.27780	0.70461	- 0.44383	0.30177
Slope	0.02577	0.19501	0.02941	- 0.10769
Posit	0.11706	0.60282	0.67066	-0.30827
Rtwo	- 0.17933	- 0.09297	0.41832	0.42545

Table 9.7 (b) Spruce

	Function 1	Function 2	Function 3
Elev	0.86089	- 0.32981	- 0.08965
Topo	0.77620	0.10871	0.24619
Rone	0.77292	0.00123	- 0.17465
Comp	- 0.21177	- 0.06555	0.13902
Rtwo	0.42388	0.69854	- 0.13902
Slope	- 0.15271	- 0.09492	0.61709
Posit	0.25367	0.07081	0.55799

Table 9.7 (c) Beech

	Function 1	Function 2	Function3
Elev	0.77066	0.40069	- 0.10168
Topo	0.56051	0.18575	- 0.54248
Posit	- 0.43569	- 0.10070	- 0.21877
Rone	0.33973	0.83906	0.13318
Slope	0.32111	- 0.61166	0.22413
Comp	0.09982	0.39538	0.16904
Rtwo	0.22808	- 0.23732	0.57519

9.4.3 Prediction of group membership

The aim of discriminant analysis is to predict group membership, therefore an obvious measure of success is the percentage of cases that are classified correctly. The results of the classification procedure are presented in Table 9.8 (a), (b) and (c) which are the confusion matrices for the three species under analysis.

The simplest summary statistic is the percent of cases correctly classified; immediately striking is the lack of success measured with this criterion. Only 49 % of fir, 40 % of spruce and 46 % of beech were correctly classified using discriminant analysis.

9.8 (a), (b) and (c) Confusion matrices for group classifications of fir, spruce and beech.

9.8 (a) Fir

Actual group	No. of cases	Predicted group membership			
		0	1	2	3/4
Group 0	73	4	24	45	--
Group 1	175	2	46	127	--
Group 2	274	2	43	228	1
Group 3/4	30	--	3	27	--

Table 9.8 (b) Spruce

Actual group	No. of cases	Predicted group membership			
		0	1	2	3/4
Group 0	29	10	14	5	--
Group 1	44	7	21	13	3
Group 2	52	8	14	27	3
Group 3	17	--	3	11	3

Table 9.8 (c) Beech

Actual group	No. of cases	Predicted group membership			
		0	1	2	3/4
Group 0	130	24	106	--	--
Group 1	217	16	198	--	3
Group 2	115	5	107	1	2
Group 3	23	--	12	--	11

With two groups of equal size, one would expect 50 % of the classifications to be correct by chance. However, when the groups are not of equal size and when each group is randomly assigned the number of cases equal to its size, the expected percentage of correct classifications is found by squaring the proportion in each group and then summing the squares. The results for fir, spruce and beech are 36 %, 28 % and 33 % respectively. Using the fir data, the model can be evaluated by comparing its proportion of errors (1 - 0.49 = 0.51) with the proportion of errors that would occur if cases were classified randomly (1 - 0.28 = 0.72). The model therefore enables a reduction in the proportion of errors of [(0.72 - 0.60) / 0.72] x 100 = 17 %. (This amount is the random - error proportion minus the model - error proportion, and then divided by the random - error proportion so that the reduction in error is expressed as a proportion of the original - error proportion). The corresponding results for spruce and beech are 17% and 18 %. Appendix 5 serves to graphically illustrate the spread of the classified points around each group centroid.

9.5 Utility of a crown condition rating approach

9.5.1 General remarks

The classification results further illustrate the problems of applying statistical rules to such complex data sets. The accuracies of the three classifications are all greater than those expected by a random assignment of cases, therefore one can hypothesise that a certain level of correlation between the independant variables and crown condition does exist. It seems clear that the variation in crown condition for each species is influenced by a number of different factors. However, in order to make a rational assessment of the situation it is worth looking at each of the first discriminant functions for each species since it this function that exerts most control over crown condition. Klecka (1980) indicated that the coefficients can be used to 'name' the functions by identifying the dominant characteristics they measure.

Referring to Table 9.7, the first function is clearly dominated by the elevation and topographic position variables. Since the first function is the only significant function for all three species it is safe to assume that for the site studied, the elevation and topographic position of any tree influences the condition of its crown. This factor has been observed in West Germany and other continental states as exerting some influence on the degree of crown discolouration / defoliation, although few attempts have been made to quantify this relationship. Admittedly this particular study has its drawbacks, particularly in the sample size and area, however, the predictive quality of the approach using the multiple regression equation allows for the construction of thematic maps predicting trees or stands which will exhibit certain crown condition classes under a similar pollution climate. However, the problems are manifold since the factors influencing crown condition will vary spatially. In order to test this hypothesis a study area in the state of Bayern was assessed using the same variables and methodology as for the Black Forest (refer to Chapter 6).

9.5.2 Discriminant analysis of Bayern data

Applying discriminant analysis techniques to the Bayern data, (which includes Norway spruce, Douglas fir and beech) a similar pattern emerged in the discriminant functions. Three functions were identified, however of these, it was the first function that was deemed significant. Referring to the standardised discriminant function coefficients for function 1in Table 9.9, the slope and radiation index variables dominate.

Table 9.9 Discriminant function coefficients (Function 1)

	Function 1
Elev	- 0.05431
Slope	0.53852
Topo	0.02802
Posit	0.15030
Rone	0.48271
Rtwo	0.62757

The lack of influence from the elevation and topographic position variables is probably due to the fact that the change in elevation over the study area was no more than 200 m. This is compounded by the fact that the maximum elevation is 836 m which falls far short of the 1300 m encountered in the Black Forest. In addition, the other major difference between these two areas occurs in the pollution climate. This difference is illustrated in Table 6.2 where the average SO_2 / NO_x concentration for the Bayern site is shown to be approximately three times that of the Black Forest - but just how this affects the crown condition distribution is a matter for more intense field study.

9.6 Discussion of statistical methods

The discriminant analysis of the Bayern data serves to indicate the major problem with the crown condition rating approach. For the predictive qualities of the methodology to be of any use there should be two main criteria applied. These are :

(1) the area under investigation should be topographically homogenous with the area for which the model was devised - i.e. mountainous, rolling, flat etc.;

(2) the pollution climate for the area under investigation should be similar to that of the area for which the model was devised.

If these rules are followed and the variables assessed include climatic and pollution factors, in addition to the site stand factors, then it should be possible to successfully predict which sites are likely to be susceptible to forest decline - if not already exhibiting the symptoms of forest decline. However, as has already been shown the symptoms of classical forest decline can disguise a number of causes. If for instance, a defoliating insect is known to be the cause of a specific pattern of crown dieback then this will hide any possible pollution effects. Therefore, the crown rating methodology must take this into account and variables that specifically relate to the pattern of insect damage should be included in the analysis (refer to Section 8.1 for details of risk - rating approaches).

Chapter 10 : Creation of a Crown Condition Surface

10.1 Introduction

Sections 9.1 to 9.5 describe the second stage of analysis of the manually derived crown condition data. The final stage of analysis involves the production of :

(1) maps representing the distribution of crown condition classes within the study area;
(2) maps representing the distribution of the independant variables;
(3) maps representing the relationship between the crown condition and the independant variables.

The first stage involved conversion of the crown condition data from the spreadsheet file in which it was stored into an image file which could be used as the basis for a crown condition map.

10.2 Crown Condition Surface

10.2.1 Image creation from a spreadsheet file

The basic spreadsheet data were stored in Supercalc 4 files with the position of each crown and its corresponding crown condition class stored as the original analog grids shown in Appendix 2. The spreadsheet contained the classes 0 - 4 representing all possible crown states. The spreadsheet also contained missing values where no trees existed on the photography, these were therefore assigned a value of 5.

A program was written that converted each spreadsheet value into a grey - scale image value between 0 - 255. Class 0 (healthy) was assigned a value of 255 (white) whilst class 5 (missing) was assigned a value of 0 (black). Once converted into this format the grey - scale values were assigned to a pixel on the image monitor, thereby creating a 39 x 52 pixel array. Since such a small array forms only a corner of the screen, and the screen and array aspect ratios differed, a 10 x zoom and a geometric correction were applied to the image. The geometric correction ensured that the long axis was in the x - direction (as opposed to the y - direction caused by screen geometry), therefore the image was correct for eventual combination with a digital elevation model (see Section 10.3).

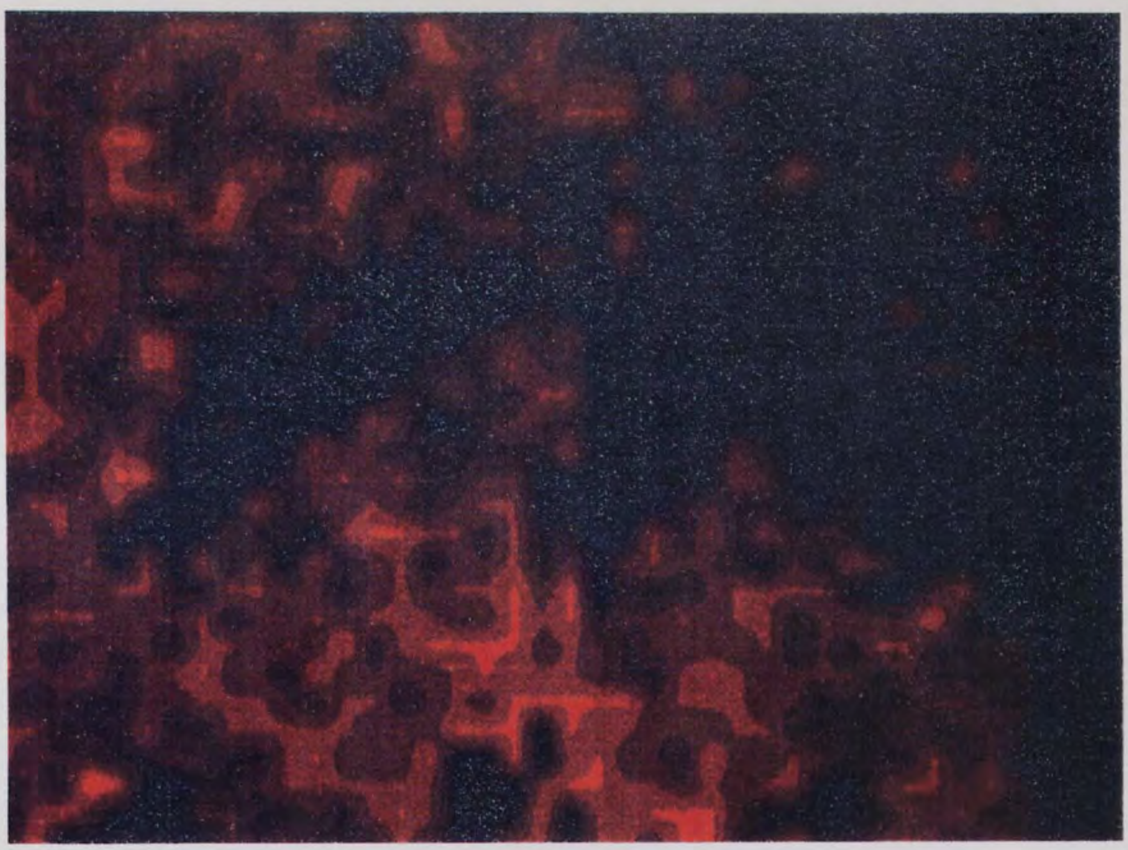


Fig. 10.1 Two - dimensional block image of spreadsheet data

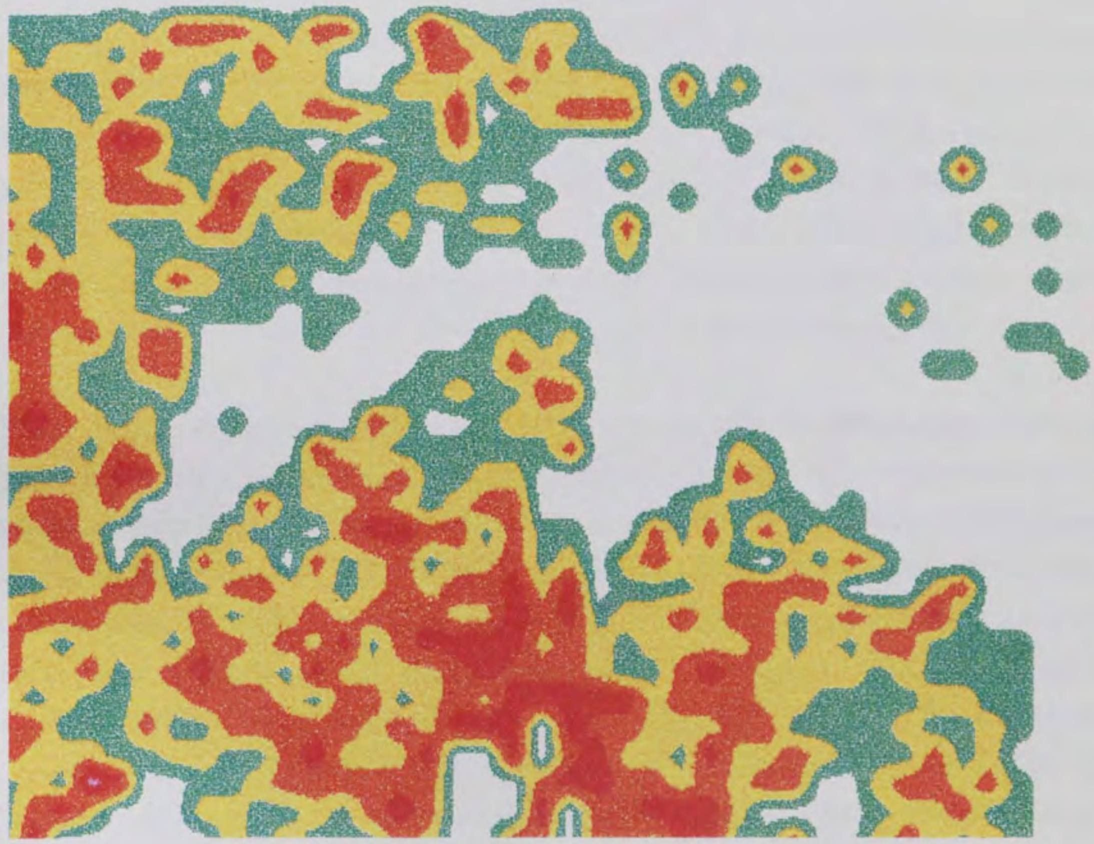


Fig. 10.2 Two dimensional block image of spreadsheet data - density sliced
White = missing data, Green = Class 0, Yellow = Class 1, Orange = Class 2, Red = Class 3, Purple = Class 4

Once the image had been modified in this way it consisted of a 39 x 52 array of 10 x 10 pixel blocks. This arrangement was not deemed suitable for the production of a crown condition surface, therefore a low - pass filter was applied in order to smooth the blocky image - the result for all three species is shown by Fig. 10.1. This pattern of grey scales, however, did not provide the necessary level of differentiation between the crown condition classes, therefore a density slice was applied. The resulting colour image Fig. 10.2 only shows five classes due to the loss of the class 4 detail. This is caused by the fact that only five isolated crowns (of all species) fall into this category and the class has been lost during the smoothing operation. This final image represents the crown condition surface. However, in this state the image only represents the distribution of crown condition within the screen co - ordinates. In order to give this distribution some meaning it was necessary to relate the surface to topographic map co - ordinates.

10.2.2 Creation of a three - dimensional surface

The first stage in the creation of a three - dimensional surface model based upon map contours, otherwise known as a digital elevation model (DEM), involved video grabbing the 1 : 25, 000 map sheet of the study area. The video grab is a low cost alternative to a scanning densitometer for digitising an image. The process involved mounting a colour vidicon camera perpendicular to the map sheet. Using an appropriate lens attachment on the camera, the area covered by the sampling grid filled the frame and use of the appropriate software and hardware allowed a colour image of the map to be saved to the hard disk of the image processing workstation.

When displayed on the monitor it was possible to vectorise the 50m contour lines with judicious use of a mouse driven cursor. The resulting vector data were converted to a digital surface using the GINOSURF routines, which are a set of FORTRAN routines on the Aston University VAX 8650. When displayed the image represented a shaded contour map for which the shading was produced by calculating the brightness of each individual element of the polygons surface (polygons are formed by the interconnection of each individual vector point). The usual notation is for the polygons facing towards the light source to be brighter than those that face away. The light source is taken to be the sun which is usually directed from a north - westerly direction.

The DEM has been created from map co - ordinates converted to image co - ordinates, therefore the final stage of analysis involves merging the two data sets (crown condition surface and DEM) in order to represent the relationship between crown condition and elevation / topographic position.

10.2.3 Creation of a perspective view

A 'projection' is a representation of a three - dimensional object on a two - dimensional surface. Thus a projection can be represented by a 4 x 3 matrix which will, when applied to a three - dimensional point described in homogeneous co - ordinates, produce a two - dimensional point similarly represented.

The projection most commonly used to add realism to a picture is the perspective projection. For simplicity one can assume that the object to be viewed is entirely behind the view - plane $z = 0$. This means that every co - ordinate has a negative value for its z - component. One can also assume that the view - point is the centre of projection and lies on the positive z - axis (see Fig. 10.3). If one takes the centre of projection to be a point that is not the same as the view - point the general perspective projection matrix can be obtained.

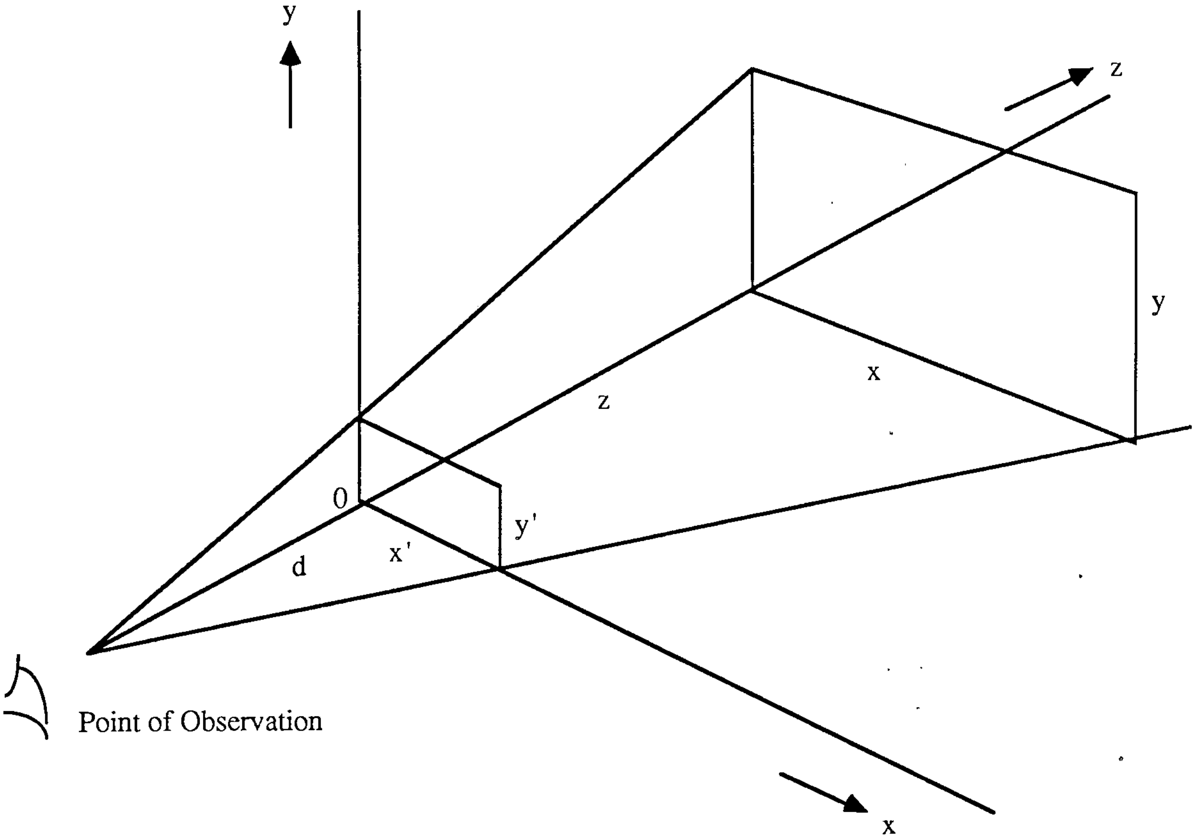


Fig. 10.3 Perspective projection

Applying these rules to the DEM and the crown condition surface, a perspective view of the distribution of crown condition in relation to elevation topographic position was produced. Fig. 10.4 shows the result for the 1984 photography. The section of 1 : 25, 000 topographic map that represents this area is shown in Fig. 6.1 from which it can be seen that the area in the foreground is the highest elevation and the most exposed.

10.3 Temporal variation of crown condition

In general the areas of worst crown condition are distributed around these upper elevations, however, small pockets do occur in the lower elevation areas. In order to assess the development of decline over a number of years the same procedure was followed for the 1986 photography. The accuracy of the photo - interpretation for this imagery is called into question in Chapter 5, however, since the emphasis is on relative differences between the two dates of photography (rather than absolute values) the approach was deemed useful.

The resulting crown condition surface (Fig. 10.5) showed intensification of the previously poor crown condition classes in the high elevation areas in addition to a spread of these classes to the lower elevation areas. This distribution tallies with the observed distribution of decline noted by the Baden - Wurrtemberg forest authorities (Schopfer, 1986); namely a decline in crown condition at lower elevations. One would expect the magnitude of the changes to be greater in the low elevation areas since trees in 1984 were relatively healthy, therefore to test this hypothesis the 1984 surface was subtracted from the 1986 surface. The resulting difference surface (Fig. 10.6) confirmed the prediction and the changes at higher elevations were within one group or two at most, whilst the lower elevation crowns had changed in most cases by two groups (if change had taken place at all). Only a negative change was considered, i.e. a decrease in crown condition (increase in crown condition class number), and any positive changes were ignored since these only occurred in isolated crowns which would be difficult to represent and additionally the study was only concerned in monitoring the general trend over time. Where important changes in crown condition occured the sample block was marked as a missing value. Such values in certain areas acted as a measure of the amount of clearfelling (on the 1986 surface) whether as a result of damage or for management purposes. Such clearance had occurred at higher elevations and is clearly visible on the 1986 surface.

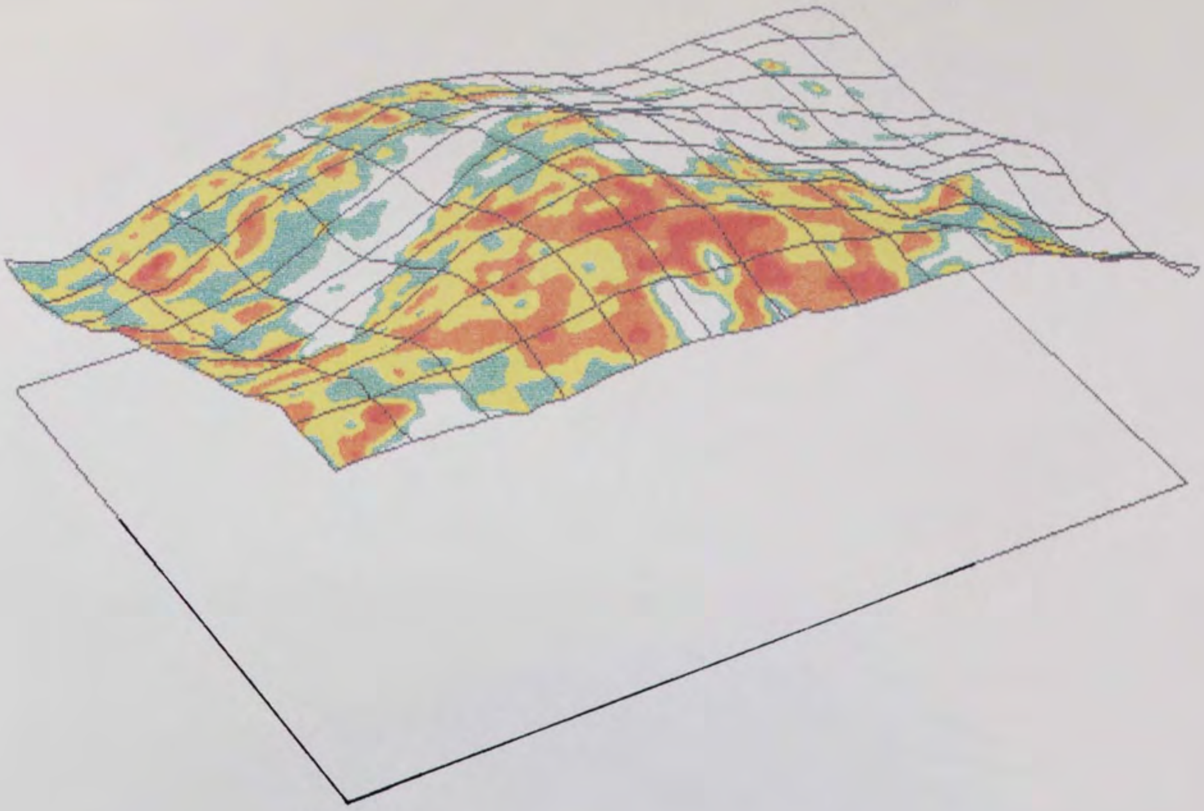


Fig. 10.4 Crown condition surface - 1984

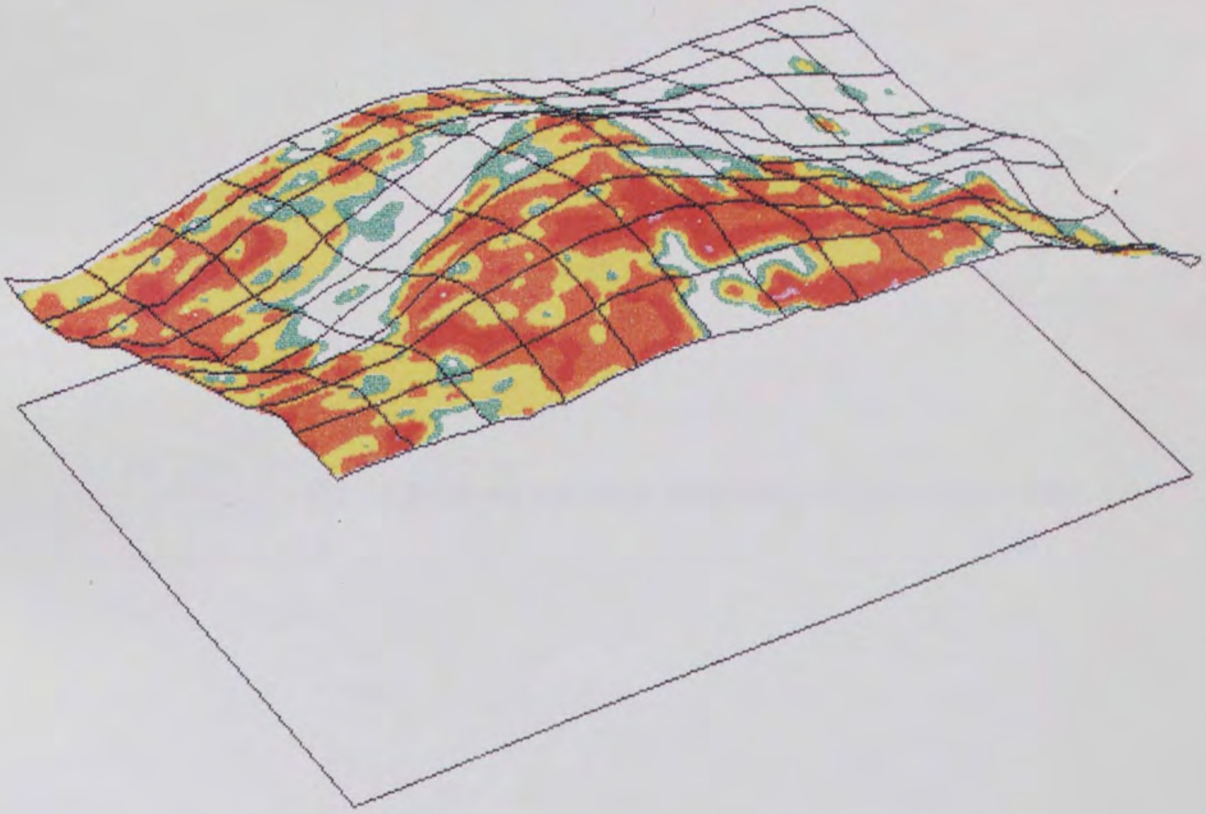


Fig. 10.5 Crown condition surface - 1986

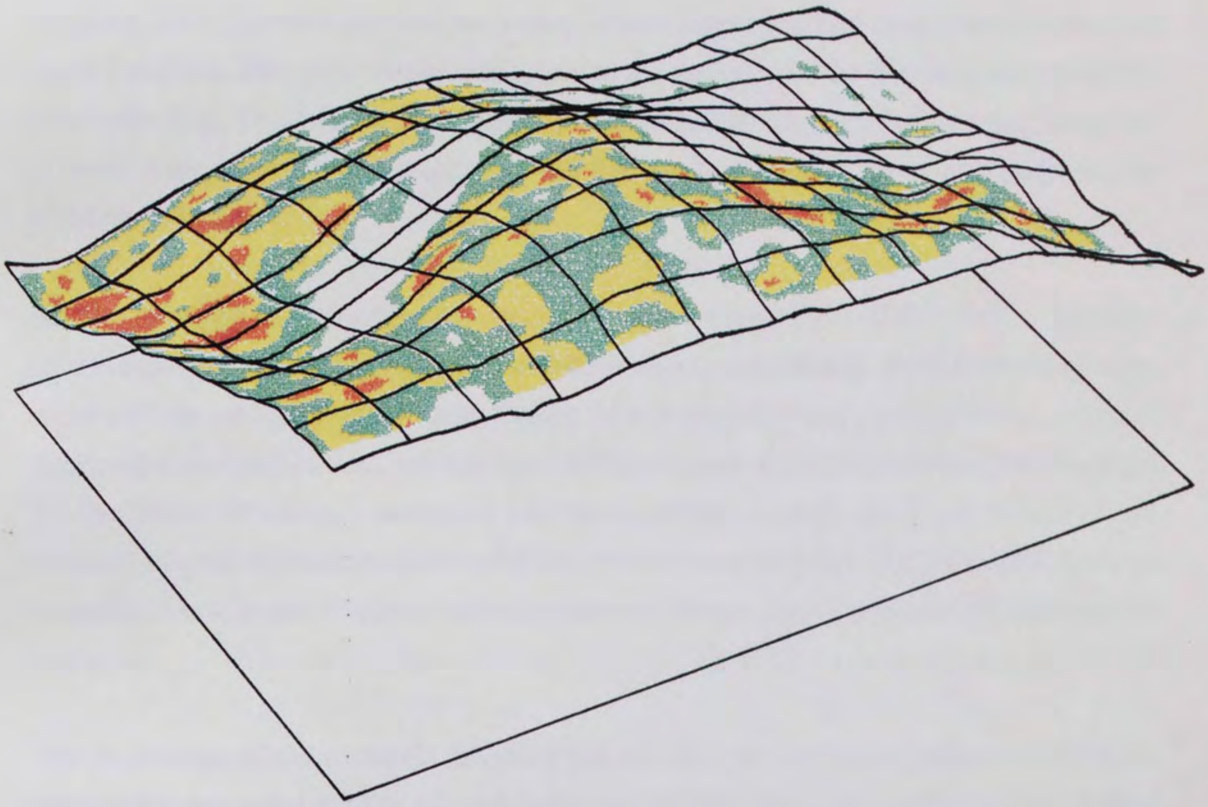


Fig. 10.6 Crown condition difference surface - 1984 - 1986

Chapter 11 : Discussion and Recommendations for Future Research

Within the main body of the thesis consideration has been given to specific points of interest and importance. The discussion presented in this chapter will, therefore, be more general in nature and directed towards the requirement for future work.

11.1 The Research Programme

The primary aim of this research was to develop a technique for assessing and mapping the relationships between a trees crown condition and its associated site and stand variables. The term automated refers to the analysis of the data as opposed to the data collection. This means that the initial assessment of crown condition was based on manual interpretation techniques which the author deemed most suitable for the problem in hand.

Having established a raw data set consisting of the manually derived crown condition information and the individual variable information, a number of spreadsheet packages were used to manipulate the data; sorting by species, age and crown condition class. Each separate species data set was then analysed with the SPSS (Statistical Package for the Social Sciences) statistical package in order to establish if any relationships existed between the independant variables and crown condition. The statistical analysis is outlined in Chapter 9 which also summarises the problems inherent in this form of analysis.

The final stage of the research involved the creation of a crown condition surface for each of the two years of data. Combining these with a DEM (Digital Elevation Model) allowed for a visual inspection of the influence of elevation and topographic position on crown condition. Finally, one surface was subtracted from the other, the resulting surface showing the positions where crown condition had deteriorated. This is of more use than a single map, since the temporal distribution of decline will deny or confirm any predictive model of decline.

The 'total' analysis of the manually interpreted data was accomplished in the way described above. The three phases of analysis were :

- manual interpretation of species and crown condition;
- statistical manipulation of resulting data from spreadsheet to multivariate analysis;

-- creation of final crown condition surfaces, based on the assessed relationships.

11.2 Forest decline assessment in the UK

The initial intention of this project was to study an area in the UK, however, problems arose in finding an area of forestry that could be classed as suffering from the decline extant on the continent. The Forestry Commission insist that any visible signs of damage present in this country are caused by natural factors. The commission's latest published survey results (Innes, 1988) indicate crown density and needle discolouration levels consistent with those in West Germany. The only difference, however, seems to be in the interpretation of these results. The Forestry Commission state that low crown densities of stands in Cumbria, the west coast of Scotland and to some extent the east coast of Scotland, can be attributed to climatic phenomena such as severe frost following a mild winter (Smith, 1988). Further, the Commission states that, it must also be recognised that trees are in a constant state of flux during their life cycles, therefore it is to be expected that at some point certain trees will experience relatively low crown densities. The influence of these factors cannot be disputed; what is disputed is the presence of pollution levels sufficient to weaken the trees and leave them susceptible to such secondary damaging agents. As shown in Chapters 2 and 3, the ambient levels of SO_2, NO_x and O_3 in parts of rural Britain are approaching the threshold concentrations at which effects are likely to be visible on the more sensitive tree species. In addition to the presence of pollution, the trees planted in certain areas of the UK are immediately disadvantaged by the unsuitability of the plantation area. The presence of large tracts of failed plantation in upland peat bog areas and the fact that windthrow is a major problem, well illustrate this point. Since it is the stated aim of the Commission to increase the total forested area of the UK, and hence timber availability, the area of trees planted in unsuitable areas is likely to increase.

How can remote sensing play a part in the British forestry sector if there is no forest decline ? Firstly, the low crown density levels presently found in the UK have never been experienced before, so whether they are resulting naturally or as a result of pollution, the phenomenon is still of the "new kind" as recognised in West Germany. It is merely a difference in political priorities which has led to the difference when interpreting the data. Since the area of British forestry is on the increase, the potential for further abnormal patterns in growth is consequently greater. Whether these patterns exist as a result of pollution or as a result of ground conditions, the requirement still exists for a quick and efficient monitoring method. To date the Forestry Commission have relied on a field survey approach, however, an aerial survey would provide the information of overall distribution of crown condition not otherwise provided by field sampling.

Having established a need for a remote sensing approach in order to develop a suitable technique; as already applied in Europe and North America, a decision was made to study an area in West Germany where a library of imagery already existed and the problem of forest decline was acknowledged. The area subsequently analysed was chosen to coincide with a study undertaken by the Institute of Terrestrial Ecology in 1986. The details of the imagery used and the areas studied are outlined in Chapter 5.

11.3 The potential of remote sensing in forest decline inventory

To satisfy the requirements for information relating to forest decline, Smith (1988) stated that there was a need for information on the distribution and status of decline which is comparable over large areas. Chapter 6 reviewed the problems encountered when attempting to compare the inventory results for the European nations undertaking crown condition surveys. To date, these surveys have been field based with some input from CIR aerial photography. Attempts to obtain this information from airborne and satellite scanner data have thus far been experimental. An extensive research effort in Europe has been mounted into the potential of satellite imagery for monitoring forest decline (Duinker & Nilsson, 1987), and views on its utility have been mixed. It is believed by some that despite the need for continued efforts to overcome technical obstacles, this should proceed in conjunction with a Europewide survey of forest decline. Others think that these obstacles are of such profound importance that a survey should not proceed until further research is undertaken. The problems identified vary from general terrain and continuity of satellite imagery to specific problems in identifying healthy pine stands from damaged spruce, and detecting light to moderate defoliation in spruce, in addition to registering the defoliation in deciduous stands.

Smith (1988) recognised that the potential use of any branch of remote sensing would depend upon the information required and the ability of the various technologies to meet them. The review of remote sensing techniques outlined in Chapters 4 and 5 of this thesis, explain the view that in an operational scenario CIR photography will continue to be the mainstay of forest decline assessment, as both a tool for mapping and for analysis. In the inventory role it is envisaged that a combination of satellite imagery, CIR photography and field survey in a multistage sampling framework would provide the best overall methodology. Whilst the best analytical tool remains CIR aerial photography.

The importance of the integrated approach cannot be overstated. The term integration can be applied in two ways. Firstly, integration of imagery types (spaceborne or airborne) and secondly integration of other sources of information in order to analyse the relationship between crown condition and variables likely to affect this condition. Kauppi (1987) defined the latter as one of the main objectives of any forest inventory, however, he recognised that in the 1980's much progress had been made in measuring and collecting data on forest damage whilst little was achieved in the analyis of this data. Kauppi (1987) made a distinction between regional variability and a temporal analysis of the change in decline severity and classed them as two seperate objectives. However, according to Chapter 8 a combination of these two approaches provides the best chance of increasing our understanding of forest decline (or any other forest damage syndrome).

The first part of this combined spatial / temporal approach involves the assessment of crown condition, which is the primary indicator of the damage syndrome as far as remote sensing is concerned. The very fact that a remote sensing interpretation relies on visible crown condition is perhaps the primary weakness in the use of the proposed crown condition rating methodology. Duinker & Nilsson (1987) have clearly shown that any change in canopy density or colour provide only the coarsest indicators of tree health, and therefore any system monitoring these symptoms will correspondingly provide a coarse measure of decline. In reality, however, the crown condition assessment approach is the only practicable means of monitoring large areas of decline. Any laboratory based measurements of stress effects in plant cells would be costly and time consuming and would not give a clear indication of the distribution of condition. A remote sensing approach provides a map of the distribution of crown condition, thereby identifying areas which are worth investigating in more detail.

11.3.1 Crown condition rating

11.3.1.1 Assessment of independant variables

The assessment of independant variables is the first step in the intergrated approach recommended by Kauppi (1987). The selection of the independant variables is an extremely important step since it dictates the degree of success in identifying the presence of any potential relationships. The methodology adopted in this project was chosen on the basis of information obtainable from either photographic or map sources. This was undoubtedly a hinderance and affected the final outcome, in that no information on local climate or pollution characteristics was included in the analysis. This was due to the paucity of such detailed data allied with the desire to develop a methodology applicable primarily from a remote sensing source.

The initial step involved devising a sampling scheme that could be easily applied. The sampling strategy adopted was a systematic strategy, which was suitable for two reasons. Firstly, it is the most easily applicable sampling method, and secondly it provided information on the distribution of crown condition over the sampling area. The second consideration was most important, since it was establishing a relationship between the distribution of crown condition and that of the measured variables that was the main aim of the research. Having devised the sampling approach the next stage involved the measurement of the independant rating variables. Two types of variable were chosen; those that related to the site and those relating to the stand. The former were described by Seger (1987) as absolute features, in that they related to the elevation, topographic position, aspect and slope. The latter were intended to identify any possible variation resulting from the composition of a stand or a trees position within it.

All the variables were measured from the photography using a sampling grid overlayed on a stereo - pair and a 1 : 25, 000 topographic map and the data transferred to the same sampling grid . The resulting framework, shown in Table 8.1 represented an instant picture of the distribution of the variables, however, it was also the source of all the quantitative information eventually derived. In order to establish the presence of any links between crown condition and the variables the layers of data in the form of the grids were incorporated into computer spreadsheet files (a separate file for each species). The analysis was than ready for initiation, in the form of intregration of the data sets and the application of statistical manipulation techniques.

11.4 Crown condition rating : a critique

The process outlined in Chapters 8 and 9 is designed to gain the maximum amount of information from a source of data that remains one of the premier remote sensing tools - CIR photography. The continuing development of satellite, video and high spectral resolution airborne techniques have potential in forest condition assessment; however they have not proven operationally viable in this role.

Duinker and Nilsson (1987) identified a number of deficiencies in satellite systems for identifying forest decline. These deficiencies ranged from detecting light to moderate defoliation in spruce stands to problems in registering defoliation in stands of deciduous trees. The overriding conclusion was that satellite systems on their own cannot be used for monitoring decline and according to Duinker & Nilsson (1987) must be viewed,

"as a tool for providing data in the context of an overall problem - solving network."

This view is one that is now being put into practice with the rapid development of GIS technology, whereby an array of information systems are combined in the same co - ordinate system to try and solve, or at least monitor, a problem. With regard to forest decline, the airborne sources of imagery offer greater potential in the monitoring role because they are more flexible (important in cloudy northern hemisphere regions) and can offer greater spatial and spectral resolution - but at a price. The costs of large - scale airborne scanner and CIR missions can only be met by central government (Murtha, 1976), which in the case of widespread forest decline is not an unreasonable situation since the potential costs are likely to have a major impact on national economies. A cheaper alternative is offered by airborne video which has much potential in the reconnaisance role; the question of how much qualitative information can be gained however, must be considered. Airborne video is still in its infancy and the analysis techniques have not been refined to a sufficient degree to justify its use in a national inventory of tree crown condition.

The choice of airborne imagery for decline assessment is therefore realistically restricted to scanner and CIR imagery. The crown condition rating technique described in Chapter 8 made use of CIR photography, for the reason that it remains the primary source of remote sensing information in forest decline assessment and it was therefore reasonable to make use of an existing store of information. Hildebrandt (1984) identified the value of CIR in this role since, if nothing else, photography forms a readily accessible and manipulated source of data.

Procedure for the creation of a crown condition rating model based on photographic and map sources

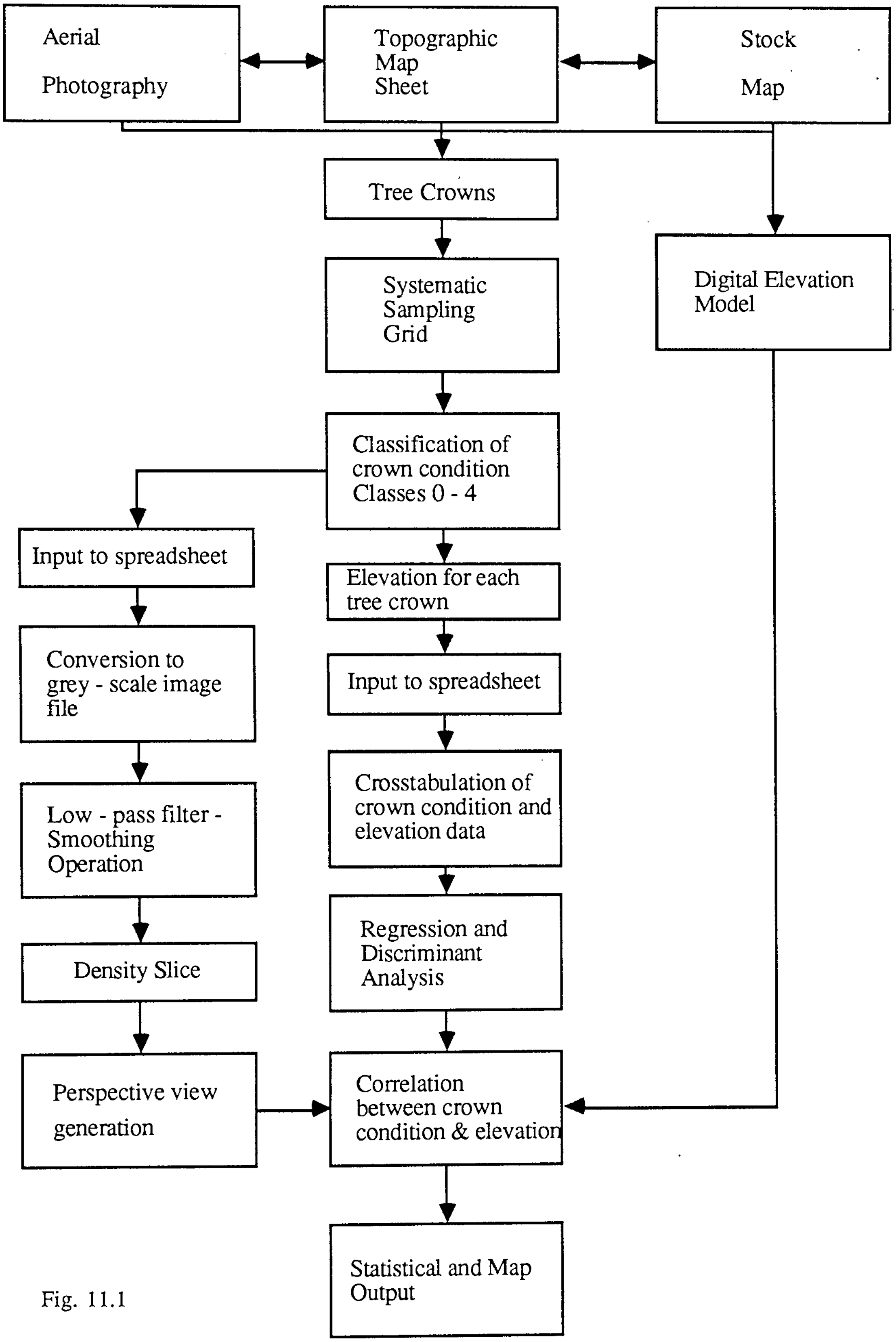


Fig. 11.1

The variables measured in this study were chosen primarily for the ease with which they could be measured from the photography or topographic maps (see section 8.3). However, the beauty of the approach is the flexibility which allows for any number or type of variables, which might affect crown condition, to be chosen. As the results of this analysis showed neglect of field data on pollution levels, local biotic damage syndromes and weather patterns proved to be the biggest restraint on the determination of the dominant variable or variables affecting crown condition at the study site. However, the technique enabled the strength of a relationship between elevation / topographic position and crown condition to be quantified. This relationship had previously been qualitatively identified throughout West Germany, but as section 8.2.2 showed, there had been very few attempts to define a quantitative measure.

The statistical analysis itself is undertaken rapidly on the VAX 8650 and immediately with SPSSPC. Most of the time however was allocated for the task of collecting and preparing the data within the spreadsheet environment prior to the statistical analysis. In this case, point sampling allied with standard spreadsheet packages were intended to simplify this stage of the analysis.

To summarise, the crown condition rating methodology outlined in Fig. 11.1 represents a flexible mapping / monitoring model which can be applied to any type of forest damage problem. An understanding of the problem is required before choice of the independant variables can be logically made, however, the amount of information to be gained outweighs the problems of data collection. In the case of forest decline, the major task of objectively assessing defoliation and discolouration is facilitated by the choice of existing good quality photography. Other damage syndromes might dictate other forms of imagery but in any situation where the identification of individual tree crowns is required the use of large - to medium scale photography will probably the be the best if not the only choice. Development of high resolution CIR film now means that medium - scale photography can now cover a larger area than was previously the case, with no loss in visible detail.

11.5 Recommendations

The crown condition rating technique outlined in Chapters 8, 9, 10 and 11 was developed from earlier work which attempted to assess the condition of a tree crown in relation to factors which might influence this condition. The methodology was originally intended to be applicable to any areas where forest decline was in evidence, however, it was recognised that the technique had wider application to any areas exhibiting crown damage. Due to the relative lack of resources and information available (certainly ground data) the approach adopted for this study was based on aerial photographic and map sources. However, the methodology is flexible and does allow for the input of field survey data on specific damage syndromes, soils, climate and pollution levels etc.

The flexibility of the crown condition rating approach also extends to the potential for monitoring disparate geographical locations on an intensive or general level. At the general level one would be looking at perhaps a state or country. Where the usefulness of the approach is hindered by the "woolly" nature of the various information sources. However, this has not stopped the Foresty Commission from undertaking a field - study of this kind over mainland Britain.

The chief problem encountered by the Commission, the interpretation of relationships between crown condition and independant factors, is difficult because of the inter - correlations between the independant variables. For pine, beech and oak, crown density decreased towards the north and west of the country. This distribution was thought to reflect climatic variation, although local pollution levels could well be having an effect. In general the levels and distribution of airborne pollutants is well documented in the UK, however, there is a scarcity of data on trends in background ozone levels. The Forestry Commission have admitted that inclusion of such data could well affect their forest health survey. The results of the author's Black Forest study must support this argument since it would seem from the results of the crown condition rating approach that atmospheric ozone is the strongest candidate for primary damaging agent in this area (see Chapter 2). Applying the results of such a narrow study to the UK (which was one of the original intentions of the research) would seem foolhardy, however, the author feels that the German experience could be a pointer to a forest decline situation in the UK. In other words, if atmospheric ozone is a primary cause of decline in the UK it is likely to follow a similar pattern to that in West Germany.

11.5.1 Recommendation 1 : Studies of selected sites in the UK using CIR photography in conjunction with intensive field work

Since the Black Forest study could only identify a significant relationship with elevation it seems reasonable to make two major recommendations in relation to the UK. Smith (1988) recommended the setting up of pilot projects to study forest decline using aerial photographs, therefore, this author recommends that these projects be concentrated in :

(1) areas above 500m elevation;
(2) areas which exhibit high levels of atmospheric ozone based on present knowledge.

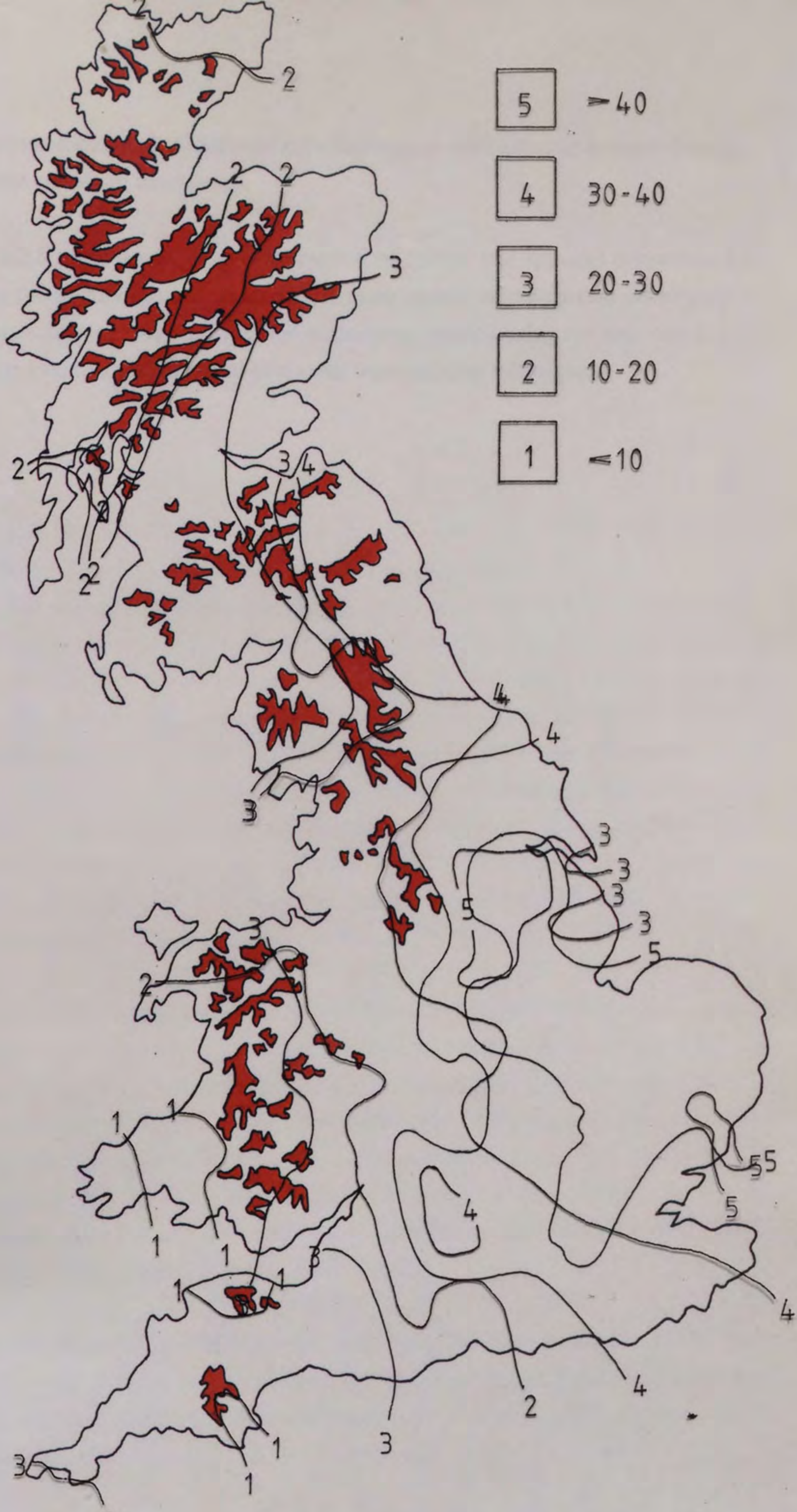
Fig. 11.2 shows land in the UK above 400m which is overlaid by information on ambient sulphate and nitrate levels. The data on ozone levels is still rather patchy, and the main body of work has involved study of the diurnal and seasonal variation in ozone levels on a regional level. However, the development of ozone is partly dependant on the nitrate levels in the troposphere combined with the amount of solar radiation. Therefore, this author feels that an examination of the distribution of nitrates would correspond with that of ozone.

11.5.2 Recommendation 2 : Continued improvements in variable selection and sampling procedure for a crown condition rating model

The constraints placed on the author's study in terms of time and money have shaped the development of the outlined methodology. However, this was deemed no bad thing since one intention was to cut down on the time spent collecting and and analysing data. This recommendation is therefore aimed at expansion in terms of the number and complexity variables measured, and streamlining in terms of the sampling procedure.

11.5.3 Recommendation 3 : Identification of European pollution climates accompanied by a crown condition rating program on selected sites

If we are to presume the continued influence of airborne pollutants on ecosystem development it is important to identify areas where particular climatic and pollution dynamics exist. Within each of these areas it is recommended that a series of sites should be subjected to the crown condition rating technique. In this way, a signature of decline distribution for each pollution climate could be produced; leading eventually to a predictive model for any change in severity of decline .



Precipitation weighted annual mean Areas above 600m nitrate concentration (ueq l⁻¹) 1986

sulphate concentration (ueq l⁻¹), 1986

Areas above 400m

nitrate concentration (ueq 1^{-1}), 1986

Areas above 400m

11.5.4 Recommendation 4 : Continued experimentation with airborne scanner data for forest condition monitoring.

Airborne MSS provides the best combination of spatial and spectral properties for monitoring forest condition. In conjunction, there should be concurrent development of image classification and segmentation techniques, perhaps using context, which will allow for the eventual displacement of manual interpretation techniques.

Chapter 12 : Conclusions

The primary aim of the project was to develop a technique for assessing the relationship between the condition of a tree crown in relation to the physical situation of that crown. Within the bounds of the study, this aim has been achieved, however, as part of this process a number of ancillery objectives have been pursued; these objectives are documented in Section 12.1.

12.1 Objectives

12.1.1 Consideration of the forest decline situation in the UK in order to assess the potential for a remote sensing inventory of forest decline.

Chapter 2 attempted to illustrate the uncertainty surrounding forest decline in the UK. This uncertainty is created by the lack of hard scientific evidence which is available to explain the causes of forest decline. Therefore, the government is loathe to accept responsibility for something that cannot be proven; namely the detrimental effect of pollutant emissions on forest areas. Opposing this view are the environmental groups; however, their attitude towards forestry has traditionally been ambivalent. This is in part due to the idea of new coniferous plantation ruining the landscape as well as the difficulty in assessing the symptoms of forest decline. Therefore, these groups have concentrated on deterioration in water bodies and associated wildlife, in their campaigns against acidification of the environment.

The latter find themselves trying to defend a resource whilst at the same time attacking its continued growth. When defending forestry by pointing to emissions from coal fired power stations the environmental groups are plagued with assurances that this will not be a problem in a nuclear powered Britain. When attacking the continued planting of conifers in environmentally sensitive areas the reply to the environmentalists becomes, "what do you really want ?" Meanwhile however, the government continues to allow unacceptable emissions, build nuclear power stations and plant trees in environmentally sensitive areas!

As to the question, "Does forest decline exist in the UK ?" The answer must be yes in that large scale changes in crown condition have been documented. The problem is simply a matter of interpreting these observations; a problem indeed, also faced by the West Germans.

management tool. The image interpretation should be undertaken by a non - government organisation in order to remove any doubt about results. In this way a national image archive of this type would provide useful measures of change in general land use in addition to forest condition.

12.1.2 Assessment of the optimal method for interpreting crown condition on the imagery selected for the analysis

The received wisdom is that manual interpretation of CIR photography is the best method of classifying tree crown condition (see section 5.2). Accepting that CIR photography remains the primary remote sensing source for this work there are only two possible ways of undertaking the classification process. Manual - photointerpretation is one; the other is a digital classification of the photography.

The procedures which were adopted in order to digitise the photography are outlined in Chapter 7. The image so produced was manipulated on a PC-based image processing system and a number of standard spectral classification algorithms applied. The accuracy of the approach was based upon the number of crowns correctly classified (using manual interpretation for reference) - since the automatic classification accuracies were in the order of 50 % this approach was deemed unacceptable. It was envisaged that application of more sophisticated classification algorithms based upon the texture and structure of tree crowns would improve the accuracy of interpretation. Once it becomes possible to identify four or even five defoliation / discolouration classes, the comparison of the two methods will be based upon ease of application, speed and cost. Considerable research effort would be required in order to improve the classification and even if this were achieved it would be worth acquiring high resolution airborne multispectral scanner data, thereby eliminating the digitisation stage necessary with aerial photography.

The cost of a digital aerial - photographic approach would not only involve acquisition of expensive CIR photography but would include the added cost of analogue to digital conversion and the acquisition of image analysis equipment in addition to operator time. Admittedly, manual interpretation is costly, however, the analysis equipment costs are low and the classification accuracies can be achieved swiftly by a trained interpreter. A comparison of the automatic and manual interpretation approaches has been made in Chapter 7.

The overriding conclusion of this chapter is that manual interpretation of CIR aerial photography remains the best method of assessing crown condition. This term "crown condition" is used here, because when studying forest decline, which is selective in its attack, one must consider a tree - by - tree classification.

12.1.3 Definition of the most appropriate method of quantifying the relationship between crown condition and the site / stand variables eventually chosen

The chief drawback of the attempt to establish a relationship is inherent in any system which attempts to integrate information from the natural world. This is the case, since the natural world does not follow strict statistical model parameters. In the Black Forest study, an attempt was made to relate a dependant variable, crown condition, with independant variables consisting of a large number of interval scores. Crown condition was, however, measured on a nominal scale and consisted of five classes representing a combination of defoliation and discolouration.

The initial approach was purely a descriptive one of calculating the mean of each variable for each crown within the individual crown condition classes. Although a coarse approach, possible relationships were identified between crown condition and elevation, topographic position and radiation index. However, at this stage it was not possible to say whether this distribution resulted from a true relationship or as a result of sampling error. In order to check the validity of the relationships, the chi - square test and analysis of variance were applied to the data. These tests did confirm that the observed relationships were a product of the true situation not of the sampling strategy.

The next stage of analysis involved testing the strength of these relationships using multivariate statistics; the initial approach making use of stepwise multiple regression. The results of this analysis confirmed the observations made at the descriptive stage, in that the only significant relationship existed between crown condition, elevation, topographic position and radiation index. Other relationships were identified for individual species but the only ones that were consistent for all three species were the three stated above.

The regression analysis also provided an opportunity to define equations which could be used to predict tree crowns which are susceptible to damage. The regression equations defined the probability that a crown will be in a particular condition class based upon the observed relationships. On the face of it, this 'risk rating' approach is limited in that it could only be applied to an area of similar physical characteristics and pollution climate where the same variables are likely to dominate. This is a problem faced by any model attempting to encapsulate natural phenomena, however, by relaxing the parameters it would still be possible to apply the model to a larger area without losing its significance. The next logical step would be to define areas of similar physical characteristics, tree species, and pollution climate depending on the damaging agent. In this way a model could be defined for each area based upon the application of the defined methodology to sampled areas within each physical region.

In order to confirm the relationships defined by regression analysis the data were submitted to discriminant analysis. For all three species the first discriminant function explained almost all of the crown condition variation and for all three species this function was dominated by elevation and topographic position. Therefore, it became clear that the relationship between crown condition and elevation / topographic position was a significant one.

Having established the presence of a relationship, the final stage of the analysis entailed devising a method of representing the distribution of crown condition as it related to the elevation / topographic position. Firstly a map of crown condition distribution was produced from the original spreadsheet data. The elevation and topographic position variables were represented by a DEM of the area derived from the 1 : 25, 000 topographic map. By combining these two surfaces and applying a perspective projection the resulting surface provided the graphical information on the influence that elevation / topographic position exerts on crown condition.

The same procedure was followed for data from 1986, and this provided the potential for observing the difference that two years made to the condition distribution. Subtracting the original surface from the new surface resulted in a difference surface representing any positive change (an increase in the crown condition class or decline in crown condition). This image therefore contained both a spatial and temporal element (mirroring the observations made by Baden - Wurrtemberg foresters) and showed that between 1984 and 1986 the greatest decline in crown condition was occurring at lower elevations.

12.2 Summary

The research has demonstrated the possibility of quantifying a relationship between crown condition and site / stand factors; using only photographic and map sources. On a small scale the technique offers a chance of defining a possible cause of damage based on the mapped distribution. Whilst on a regional or national scale the possibility of undertaking an inventory based on a number of these small scale studies has been suggested.

Returning to the UK, the official attitude towards forestry in this country mirrors the attitude shown throughout the world to our tropical forest resource. Lip service is paid to the conservation and sustained management of both yet in practice both are treated as a constant supply of timber or simply get in the way.

This project has attempted to consider the whole forest decline problem in order that the reader will understand the remote sensing approach as well as the political tumoil surrounding the effects of pollution on the environment.

Appendix 1

Stock map of Black Forest study area

The data in the table was compiled as part of the Baden - Wurttemberg forest cencus survey on 1 / 10 / 80.

Stand	Area	Age	Area substand	Species	Area species	Inc.100	Survey
15 : 1	24.1	7	9.5	Fir	4.8	8	1
				Beech	3.8	4	1
				Bah	0.5	4	1
				Oak	0.4	3	1
		7	8.6	Fir	5.2	9	3
				Spruce	0.4	8	3
				Beech	3.0	4	3
		6	2.1	Fir	1.6	10	1
				Beech	0.5	5	1
		6	3.9	Fir	2.7	10	3
				Beech	1.2	5	3
15 : 2	8.6	5	5.0	Spruce	2.8	10	3
				Fir	2.0	11	3
				Beech	0.2	4	3
		5	2.0	Fir	1.0	10	7
				Spruce	0.2	9	7
				Dgl	0.2	14	7
				Beech	0.6	4	7
		4	1.6	Fir	0.8	10	9
				Spruce	0.2	9	9
				Dgl	0.1	14	9
				Beech	0.5	4	9
15 : 3	0.5	2	0.4	Dgl	0.2	14	3
				Spruce	0.2	9	3
		1	0.1	Spruce	0.1	9	7
15 : 4	3.1	1	1.9	Dgl	1.9	14	3
			1.2	Fir	1.2	10	7
19 : 1	27.3	6	27.3	Beech	17.2	4	2
				Fir	8.5	9	2
				Spruce	1.1	5	2
				Dgl	0.5	10	2
19 : 2	1.3	2	1.3	Spruce	0.7	8	3
				Fir	0.1	9	3
				Dgl	0.3	12	3
				Beech	0.1	5	3
				Bah	0.1	5	3
21 : 1	20.8	7	3.4	Spruce	2.8	5	1
				Fir	0.3	8	1
				Beech	0.3	3	1

				Beech	7.0	4	2
				Spruce	0.8	7	2
21 : 2	0.9	2	0.9	Spruce	0.9	7	3
21 : 3	2.5	1	2.4	Spruce	1.7	7	3
				Fir	0.6	7	3
				Beech	0.1	3	3
		1	0.1	Spruce	0.1	7	7
21 : 4	3.2	1	3.2	Spruce	2.9	8	3
				Fir	0.3	9	3
22 : 1	17.5	7	17.5	Beech	11.4	4	1
				Fir	4.4	9	1
				Spruce	1.7	7	1
	3.8	2	3.8	Spruce	1.6	8	3
				Fir	1.1	9	3
				Beech	1.1	5	3
	2.0	1	2.0	Spruce	1.4	8	3
				Fir	0.2	9	3
				Beech	0.4	5	3
	7.4	1	2.3	Fir	2.3	9	3
		1	3.7	Spruce	2.2	8	7
				Fir	0.2	9	7
				Beech	1.1	5	7
				Bah	0.2	5	7
		1	1.0	Spruce	0.7	8	9
				Fir	0.3	9	9
			0.4	Bl	0.4		9

Stock (m3)	Stock (ha)	Tree (ha)	S.B.A. (m2 / ha)	Vol (%)
2745	289	170	23	65
1298	137	180	12	30
166	17	10	1	4
49	5	10	1	1
4128	480			
964	459	290	35	82
212	101	160	8	18
2184	560			
2700	540			
1000	500			
720	450			
32	80			
5019	184	220	15	47
4949	181	120	14	46
424	16	20	1	4
270	10		1	3
39	30			
1119	329	210	30	77
250	73	40	6	17
90	26	50	2	6
3627	208	160	17	65
1529	88	190	8	27
455	26	20	2	8
9	10			

2569	147	80	10	36
1016	58	40	4	14
228	60			

Stand : Stand number

Area : Area in hectares

Age : Class (1 = 1 - 20, 2 = 21 - 40, 3 = 41 - 60, 4 = 61 - 80, 5 = 81 - 100, 6 = 101 - 120
7 = > 121)

Inc.100 : mean annual increment in 100 years

Survey : method of determination (1 / 5 = survey of all trees, 2 / 6 = representative survey
3 / 7 / 9 = estimation)

Stock (m3) : growing stock (standing volume m3)

Stock (ha) : growing stock per hectare

Tree (ha) : number of trees per hectare

S.B.A. (m2 / ha) : stand basal area

Vol. (%) : stand volume

Appendix 2

Distribution of elevation and slope values

Table A 2.1 Elevation values

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	51	52	53	54	55
1	1010	990	980	965	955	940	915	900	900	900	905	910	910	905	900	890	890	890	890	890	895	895	890	880	870	855	820	800	780	770	750	790	715	720	730	750	765	780	790	785	770	780	770	760	760	770			790	770	760	750	740		755	755
2	1010	1000	965	970	960	940	920	900	890	890	890	895	895	890	880	880	875	870	870	875	880	880	880	880	870	855	810	800	780	765	750	735	720	710	720	740	750	760	770	770	755	760	750	740	740	750	765		760	760	740	740	730	735	740	740
3		1000	985	970	960	940	920	900	890	875	880	880	875	870	870	860	860	855	850	855	860	870	870	870	870	860	820	800	760	765	750	735	730	705	710	720	735	745				750	740	730	730	740	750		770		745	730	725	720	725	730
4		990	980	965	950	955	915	900	880	870	865	860	860	860	855	850	840	840	840	840	840	850	855	860	860	855	830	805	765	770	750	735	720	700	700	710	720	730	735	735	730	735	730	720	720	730	740	750		750	735	725	715	710	710	710
5			965	950	940	920	900	890	885	875			850	840	830	835	825	820	820	820	820	835	840	850	850	850	830	810	790	770	755	735	720	705	690	700	710	720	720	720	715	720	720	715	720	730	735	750	755	750	730	720	700	695	695	700
6				935	920	915	910	900	885	880	870			840	825	815	800	800	800	800	810	815	825	835	840	840	830	810	795	780	760	740	730	710	700	685	700	710	710		700	715	710	710	715	725	735	740	735	730	720	710				
7				940	935	925	910	900	900	890							800	785	780		790	800	810	820	830	830	830	815	800	780	765	745	735	720	705	680	680	690	700		695	705	705	705	715	725	730	725	725	720	710	700	690			
8		970	960	950	935	925	920	920	910	900	890									770	775	790	800	810	815	820	825		805	790	770	750	740	725	710	700	680	670	660	665	685	700	700	705	715	720	720	710	710	705	700	690				
9	995	980	965	950	955	935	935	930	925	920	905	890				840				770	770	780	790	800	805	810	815	815	810	795	780	760	745	730	710		665	670	665	670	670	690	695	705	710	710	705	700	690	685						
10	1000	990	970	950	950	950	950	950	940	925	910	900	885							780	760	760	780	785	790	800	800	810	810	800	785	765	750	740	725	710	690	675	660	650		685	695	700	700	695	685	675	670		655					
11	1000	990	980	970	970	965	965	960	945	930		910	890	875							770	755	760	765	775	780	795	800	805	800	790	770	755	740	730	710	700		670	650		680	685	690	690	680	665									
12	1015	1000	990	980	980	980	975	965	950	940	925	910	895	880	875				805	790		755	730	735	740		740	790	800	800			760	740	730	720	705	695	660	660		670	675	675	670	660										
13	1030	1010	1005	1000	995	990	980	970	955	940	930	915	900	880	870					795		760	750	745	750	755	770			790						720	710	700	690		640	665	660	660	655											
14	1040	1020	1015	1010	1005	1000	990	975	960	950	930	920	900	885	870	855							750	740	740		755									730	720	710	695	680	660	650		640		640	635			620						
15	1060	1040	1030	1025	1015	1005	990	980	960	950	935	920	905	890	870	860	840					760	750	740	730	735	740	750		780	760	780		755	745	730	720	710	700	680	670		620													
16	1070	1060	1050	1040	1025	1010	995	980	965	950	935	920	910	890	875		845	830						740	730	725	730	740	760	770	765	775	775	760	750	735	725	715	700	685	670	690														
17					1030	1010	995	980	965	950	935	920	910	890	875		845	830				770	760	750	750	725	725	735	750	760	770	770	770	760	750	740	725	715	700	680	670	630	620													
18					1025	1000	995	980	965	950	935	920	910	890	880	865	860	835	820				765		740	725	720	730	740	750	755	760	760	750	745		725	710	700	680	660							610	620	645	670	680	685	690	715	725
19	1040			1040	1025	1005	990	970	960	950	930	920	905	890	880	865	850	840	825	810			765		735	725	710	720	730	735	740	750	750	740	735	730	720	710	700	680	660	630					600	610	620	640		680	690	700		730
20	1080	1070	1055			1000	980	965	950	940	925	915			880	865	850	840	820	810		775		760		720	700	710	720	725	730	740		735	725	720	715	705	700	680	660			610			600	615	625	640	660	675				
21			1040	1020	1000	985	970	955	940	930	920	905			870	860	850	835	815	810	805	790					690	700	705	710		750	730	730	720	710	710	700	695	680	680						620	630	650	665	690				710	720
22	1060	1040	1025	1000	985	970	950	940	930											810	790						685	690	695		700	715	720	720	710	705	700	695	695		680				605		600	615	630	650	665			695	700	715
23	1050	1030	1015	1000	975	960	945	930	920	910	900									810	795	750	730		760		675	675			690		710	715	705	700	690	685	685	685	680					590	600	610	630	645	660	675				
24	1030	1020	1000	980	960	950	950	920	910	900	890	880							815	805	790												690	700	705	690	680				670						615	615	620	635	650	660				
25	1015	1005	990	970	955	940	925	910	895	890	875	870	860					810	795	780	775			730			670	665				680		700	700		690	675	660	650	630	600	590		615	625	630	630	635	640		660				
26	1000	990	980	960	950	930	915	900	890	880	860	855	850				820	805	790	780							675								690	690	685	680	665	640	625	590	600		625	635	640	645	650	655	660	660	660	670	685	
27	980	980	970	955	940	925	910	900	880	870	855	850	835	835	835		830		805	795		760				710		660							660	680	670	655	640			590		620	655	650	655	660	665	670	675	680	680	680	690	710
28	965		960	950	930	920	905	895	880	855		850	835	835	830		830		805		780		750	735								645	650			675	665	660	640	620		600		620	630	645	655	660	680	685	690	695	700	700		
29	950		945	940	930	925	905	895	880	860	845	830	820	815	810	810	805								720												665	655	640				610	625	640	650	660	665	670	680	690	700				
30				930	920	915	905	895	880	855	845	830	820	805			785								715																	590	605	615	625	640	645	650	660	670	680	700				
31				920	915	910	900	890	875		840	830	810	805	790	775	760	760																				640	630				610	620	630	640	650	655	660	675	690	700	715	725	740	755
32	905	905	910	910	905	905	895	890	875		840	840				775																										600	610	630	640	650	665	670	680	690	700	710	720	730	750	760
33	895	895	895	900	900	895	890	880	870			850	820			775				715																			620			600	610	630	650	660	670	680	690	700		720	735	745	750	765
34	885	885	885	890	890	885	885	880	870	850								740																					600			600	610	630	640	650	665	680	690	700	710	730	740	740	750	760
35	860	870	870	870	870	875	875	870	870	860								745							715							615					600		600	600	580	590	605	615	630	640	655	670	685	690	700	700	720	720	725	730
36	875	865	865	865	860	860	860	860															680										610						605	595	580	590	600	620	630	645	660	675	685	695	700	700	700	705	710	715
37	870	855	855		855	860	855	850											730																		590		570	590	600		605	620	630	650	660	665	670	680	680	680	680	685	695	700
38																			740		715		685										605				585	590	590	590	570		600	610	620	630	640	645	650	650	650	650	655	660	675	
39																		740															600	600						580	570			590	595	605	620	625	630	625	625	630	640	650	670	690

Table A 2.2 Slope values

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	51	52	53	54	55
1	50	50	50	50	50	50	56	36	31	31	31	31	31	31	31	31	31	60	60	60	60	60	60	60	60	60	50	50	50	50	50	50	50	36	36	36	67	67	67	67	67	67	67	40	40	40			42	42	45	50	50		50	50
2	50	50	50	50	50	50	56	56	31	31	31	31	31	31	31	31	31	60	60	60	60	60	60	60	60	60	50	50	50	50	50	50	36	36	36	36	36	67	67	67	67	40	40	40	40	40	42		42	42	45	45	50	50	50	50
3		50	50	50	50	50	50	36	31	31	31	31	31	31	31	31	31	60	60	60	60	60	60	60	60	60	50	50	50	50	50	50	36	36	36	36	36	36				40	40	40	40	40	42		42		45	45	50	50	50	50
4		50	50	50	50	50	50	50	60	31	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	50	50	50	50	50	50	42	36	36	36	36	36	36	36	36	40	40	40	40	40	42	42		45	45	45	45	50	50	50
5			50	50	50	50	50	33	33	60			60	60	60	60	60	60	60	60	60	60	60	60	60	60	50	50	50	50	50	50	42	36	36	36	36	36	36	36	36	40	40	40	45	45	45	45	45	45	45	45	45	50	50	33
6				50	50	50	50	33	33	33	33			60	60	60	60	60	60	60	60	60	60	60	60	60	50	50	50	50	50	50	42	36	36	36	36	36	36		36	45	45	45	45	45	45	45	45	45	45	45				
7				50	50	50	33	33	33	55							60	60	60		60	60	60	60	60	60	50	50	50	50	50	50	50	42	36	36	36	36	36		36	45	45	45	45	45	45	45	45	45	45	45	45			
8		45	45	45	45	45	45	50	50	50	50									60	60	60	60	60	60	60	50		50	50	50	50	50	42	42	36	36	36	36	31	36	45	45	45	45	45	45	45	45	45	45	45				
9	71	71	45	45	45	50	50	50	50	50	50	50				60				60	60	60	60	60	42	42	50	50	50	50	50	50	50	42	42		36	36	36	36	36	45	45	45	45	45	45	45	45	45						
10	71	71	45	45	50	50	50	50	50	50	50	50	50							60	60	60	42	42	42	42	42	50	50	50	50	50	50	50	42	42	42	42	36	36		45	45	45	45	45	45	45	33		33					
11	71	71	50	50	50	50	50	50	50	50		50	50	50							60	42	42	42	42	42	42	42	50	50	50	50	50	50	42	42	42		36	36		45	45	45	45	45	45									
12	71	71	71	50	50	50	50	50	50	50	50	50	50	50	50				55	55		42	42	42	42		42	42	42	50			50	50	50	42	42	42	42	36		45	45	45	45	45										
13	71	71	71	50	50	50	50	50	50	50	50	50	50	50	50					37		42	42	42	42	42	42			42						42	42	42	42		42	45	45	45	45											
14	71	71	71	71	50	50	50	50	50	50	50	50	50	50	50	50							42	42	42		42									42	42	42	42	42	42	56		45		56	20			37						
15	71	71	71	71	71	50	50	50	50	50	50	50	50	50	50	50	50					57	42	42	42	42	42	42		36	36			42	42	42	42	42	42	42	42		28													
16	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50		50	50						42	42	42	42	42	36	36		42	42	42	42	42	42	42	42	42	42	28														
17					50	50	50	50	50	50	50	50	50	50	50		50	50				37	37	42	42	42	42	36	36	36	36	36	42	42	42	42	42	42	42			28	28													
18					50	50	50	50	50	50	50	50	50	50	50	50	50	50	55				57		42	42	30	36	36	34	36	36	36	42	42		42	42	42	42								75	75					36		
19	50			50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	55				37		42	42	36	36	36	36	36	36	36	42	42	42	42	42	42	42	42	28					75	75	75	36						
20	50	50	50			50	50	50	50	50	50	50			50	50	50	50	55	55		37		37		42	36	36	36	56	36	36		36	42	42	42	42	42	42	42			28			75	75	75	36	36	36				
21			50	50	50	50	50	50	50	50	50	50			50	50	50	50	55			37					36	36	36	36		36	36	36	42	42	42	42	42	42							75	75	75	36	36					
22	66	66	66	66	66	66	66	66	66																		36	36	36		36	36	36	36	42	42	42	42							28		75	75	75	75	75					
23	66	66	66	66	66	66	66	66	50	50	50											37	37		37		50	50			36		36	36	36	42	42	42								75	75	75	75	75	75	75				
24	66	66	66	66	66	66	66	66	50	50	50	50																								42	42										75	75	75	75	75	75				
25	66	66	66	66	66	66	66	50	50	50	50	50	50											39			50	50				50		36	42					44	44	44	44		69	69	69	69	69	69		75				
26	62	66	66	66	66	66	66	50	50	50	50	50	50														57								42					44	44	44	44		69	69	69	69	69	69	69	69	69	69	69	
27	62	66	66	66	66	66	50	50	50	50	50	50	50	50	50											39		37							50	42	44	44	44			44		69	69	69	69	69	69	69	69	69	69	69	69	69
28	62		66	66	66	50	50	50	50	50		50	50	50	50									34								50	50			50	42	44	44	44		44		69	69	69	69	69	69	69	69	69	69	69		
29	62		62	66	50	50	50	50	50	50	50	50	50												39												42	44	44				69	69	69	69	69	69	69	69	69	69				
30				35	35	50	50	50	50	50	50	50													39																	69	69	69	69	69	69	69	69	69	69	69				
31				35	35	35	50	50	50		50	50	50																									44	44				69	50	50	50	50	50	50	50	50	50	36	36	36	36
32	62	35	55	55	35	35	35	50	50		50																															50	50	50	50	50	50	50	50	50	50	36	36	36	36	36
33	35	35	35	35	35	35	35	35	35											28																			44			50	50	50	50	50	50	50	50	50		36	36	36	36	36
34	35	35	35	35	35	35	35	35	35	35								28																					44			50	50	50	50	50	50	50	50	50	50	36	36	36	36	36
35	50	35	35	35	35	35	35	35	35	35								28							21							32					11		44	44	44	50	50	50	50	50	50	50	50	50	50	36	36	62	62	62
36	50	35	55	55	55	55	55	35															28										32						44	44	44	50	50	50	50	50	50	50	50	50	50	50	50	50	62	61
37	50	50	35		35	35	35	35											46																		11		30	44	44		50	50	50	50	50	50	50	50	50	50	50	57	57	62
38																			46		46		46										32				11	50	30	30	44		50	50	50	50	50	50	50	50	50	57	57	57	57	
39																		46															25	32						30	30			50	50	50	50	50	50	57	57	57	57	57	57	57

Appendix 3

Regression equations

Eqn. A 3.1 Spruce

Yo = 0.03106 + 1.964706 x 10-3 (X1) + 1.473296 x 10-3 +/- 0.62717

where : Yo = Crown condition class
X1 = Elevation
X2 = Radiation index (R1)

Eqn. A 3.2 Beech

Yo = - 0.22093 + 1.701331 x 10-3 (X1) - 3.62351 x 10-3 (X2) +/- 0.26510

where : Yo = Crown condition class
X1 = Elevation
X2 = Stand position

Appendix 4

Standardised canonical discriminant functions

Table A 4.1 Spruce

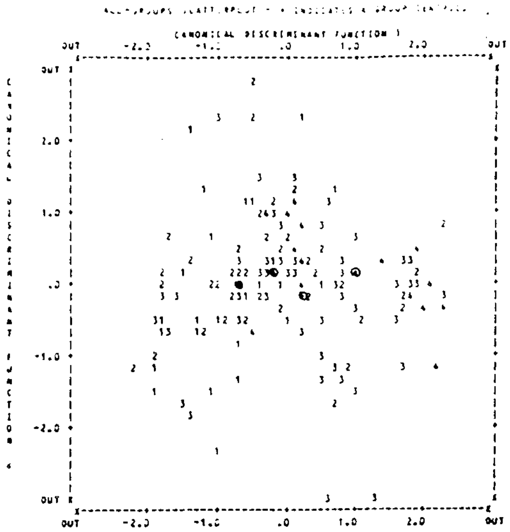
	Function 1	Function 2	Function 3
Elev	0.41038	-1.02138	-0.78335
Slope	0.03545	0.14382	0.99551
Posit	0.09089	0.07545	0.60895
Topo	0.33517	0.16214	0.22499
Rone	0.33910	0.42673	0.83999
Rtwo	0.10992	0.91886	-0.32685
Comp	-0.28432	-0.17447	0.06329

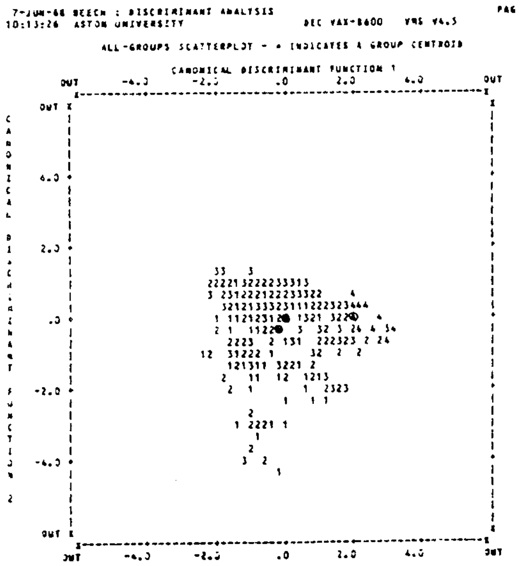
Table A 4.2 Beech

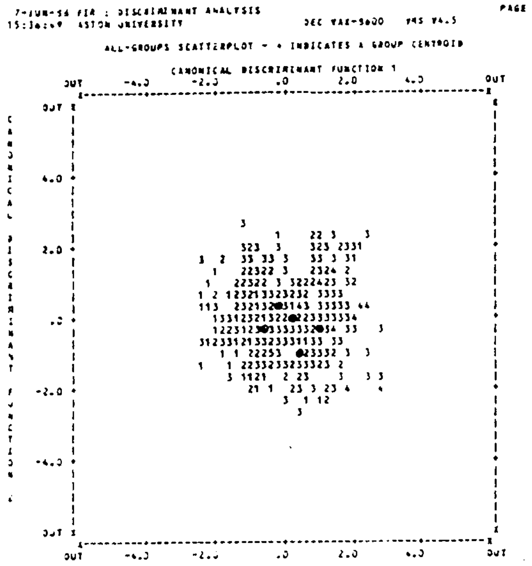
Elev	0.73010	-0.00971	-0.07353
Slope	0.18599	-0.44656	0.37717
Posit	-0.45085	0.06539	-0.10531
Topo	0.34150	-0.11898	-0.81619
Rone	-0.18163	0.76695	0.58360
Rtwo	0.29730	-0.15198	0.59454
Comp	-0.16353	0.20195	0.13300

Appendix 5

All groups scatterplots







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