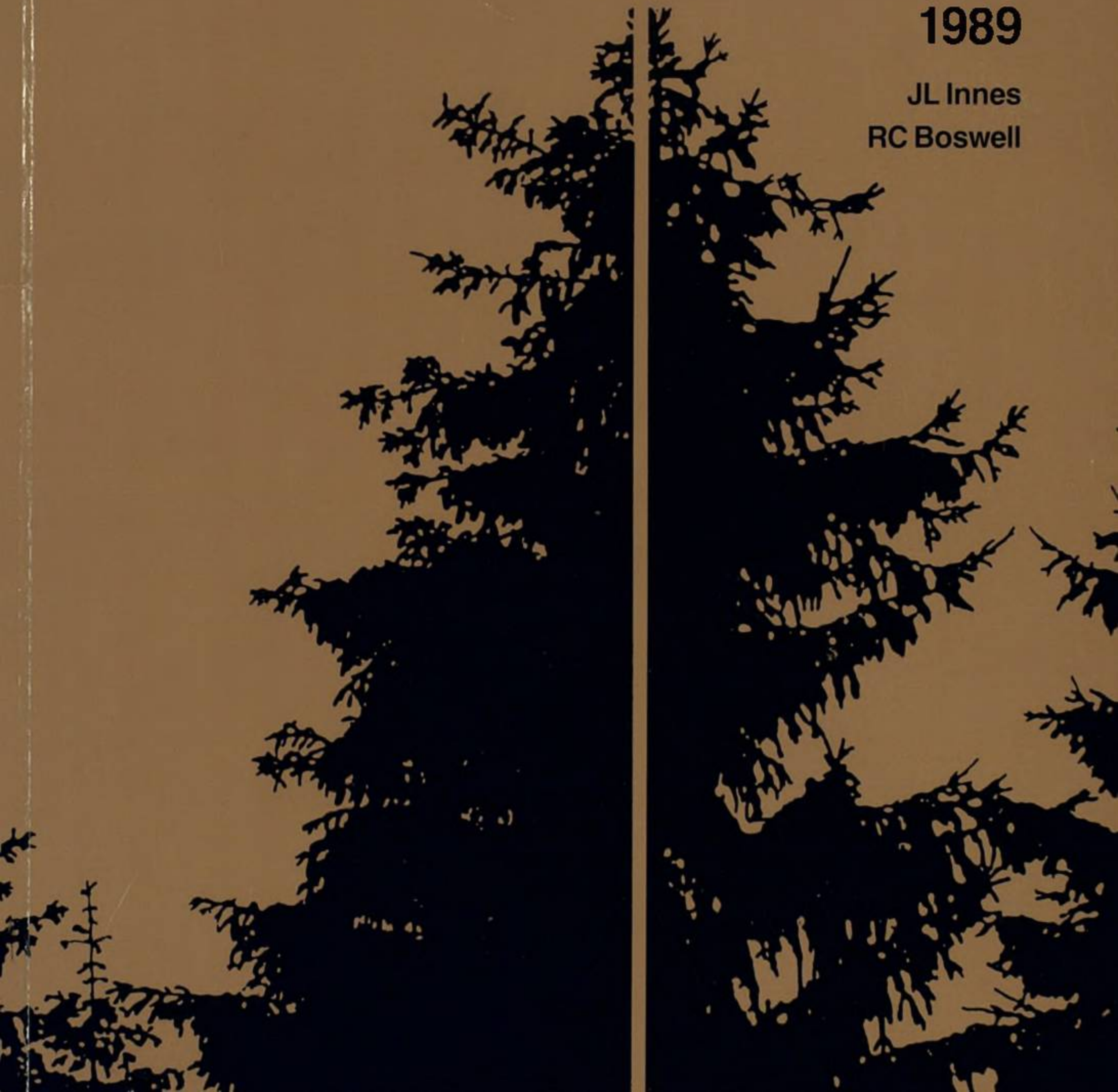
Forestry Commission
ARCHIVE

Forestry Commission

Bulletin 94

Monitoring of Forest Condition in Great Britain 1989

JL Innes
RC Boswell



FORESTRY COMMISSION BULLETIN 94

Monitoring of Forest Condition in Great Britain – 1989

J. L. Innes and R. C. Boswell
Forestry Commission

The projects described in this report were partially funded by grants from the European Community.

LONDON: HMSO

© *Crown copyright 1990*
First published 1990

ISBN 0 11 710293 8
ODC 425.1 : 423.1 : 181.45 : 524.6 : (410)

KEYWORDS: Tree health, Pollution, Forestry

Enquiries relating to this publication should be addressed to:
The Technical Publications Officer,
Forestry Commission, Forest Research Station,
Alice Holt Lodge, Wrecclesham,
Farnham, Surrey GU10 4LH

Front cover: *Composite silhouette of two Norway spruce* (Picea abies) *of different crown habits, showing the difference in light transmission. Left half, brush type; right half, comb type.*

Contents

Monitoring of Forest Condition in Great Britain – 1989

Summary

The results of the 1989 forest condition monitoring programme are presented. A total of 7436 trees were assessed, with the species being restricted to Sitka spruce (*Picea sitchensis*), Norway spruce (*P. abies)*, Scots pine (*Pinus sylvestris*), oak (*Quercus* spp.) and beech (*Fagus sylvatica*).

Crown condition is now assessed on the basis of a variety of indices rather than crown density alone. This enables a full evaluation of the health of individual trees to be made. However, as many of the indices have not been assessed previously, it is not possible to determine whether the figures depict a departure from the normal pattern of tree health that might be expected in pristine environmental conditions.

The crown densities of all species showed an overall improvement, although some individual Sitka spruce deteriorated as a result of defoliation by the green spruce aphid (*Elatobium abietinum*). The improvement in the condition of trees within forests contrasted with many open-grown trees which suffered from drought stress during the summer of 1989. The improvement can be attributed to the recovery of many trees following damage by the October 1987 storm, an absence of winter damage in 1988-1989 and the benefits brought about by the mild, wet conditions of the summer of 1988.

The severe infestations by *E. abietinum* had a significant impact on some of the indices collected for Sitka spruce (e.g. needle retention). In many trees, the crown length has been reduced as a result of the complete defoliation of lower branches. The effects were less marked in Norway spruce. High levels of foliar damage by insects were noted in both oak and beech.

The type of defoliation found in the two spruce species differs markedly from the type of defoliation reported from areas in central Europe suffering from the typical form of 'forest decline'. In spruce in Britain, defoliation usually takes the form of a relatively uniform loss of needles throughout the crown. Where severe aphid infestations have occurred, thinning may occur from the base of the crown upwards. Thinning of the upper crown, which is the prevalent form of thinning in central Europe, was present in less than 5% of the trees.

Crown dieback was widely reported in oak (40% of trees) and beech (21% of trees), although in most cases it was restricted to the death of relatively thin branches and involved only a small proportion of the upper crown. Death of relatively large branches was rare, being reported more frequently in oak than in beech.

Needle retention in Sitka spruce was markedly affected by aphid infestations and 4% of the trees that were assessed had only 1 or 2 years' needles present. Conversely, needle retention in both Norway spruce and Scots pine increased.

Discoloration of foliage was rare. The two spruce species showed rather less discoloration than in 1988 whereas there was an increase in the amount of yellowing of older needles of Scots pine. There was a marked reduction in the amount of yellowing in beech.

Leaf-rolling was present in the crowns of half of the beech trees that were assessed. In half of the affected trees, rolling was restricted to leaves in the upper crown and in most cases, the degree of rolling was fairly light.

The patterns of crown condition seen in 1987 and 1988 were repeated in 1989, with many trees appearing worse towards the north of the country. This is consistent with the general belief that climate and site quality play an important part in determining crown condition. There are exceptions to these general trends which can usually be related to site-specific factors.

Further analyses will be undertaken on the data as soon as information on the pollution levels in 1989 become available.

Contrôle de la Condition des Forêts dans La Grande-Bretagne – 1989

Résumé

On présente les résultats du programme 1989 sur le contrôle de la condition des forêts. On a évalué 7436 des arbres, à savoir l'épicéa Sitka (*Picea sitchensis*), l'épicéa commun (*Picea abies*), le pin sylvestre (*Pinus sylvestris*), le chêne (*Quercus* spp.), et le hêtre (*Fagus sylvatica*).

À l'heure actuelle on évalue la condition des couronnes grâce à une série d'indices plutôt que grâce à la densité des couronnes seulement. Ces indices permettent une évaluation complète de la santé des arbres individuels. Cependant, parce qu'on n'a pas évalué auparavant un grand nombre d'indices, il n'est pas possible de déterminer si ces chiffres décrivent vraiment une déviation de la santé habituelle des arbres qu'on peut attendre dans des conditions primaires d'environnement.

Les densités des couronnes chez toutes les essences ont prouvé une amélioration générale, bien que quelques épicéa Sitka individuels se sont détériorés à cause de la défoliation par les aphides (*Elatobium abietinum*). L'amélioration de la condition des arbres dans les forêts a contrasté avec beaucoup d'arbres en rase campagne qui souffrirent de la sécheresse pendant l'été 1989. On peut attribuer l'amélioration à la guérison de beaucoup d'arbres après les dégâts de l'orage en Octobre 1987, à l'absence des dégâts pendant l'hiver 1988-1989, et aux avantages de conditions douces et humides pendant l'été 1988.

Les infestations importantes de l'*Elatobium abietinum* ont exercé une grande influence sur quelques-uns des indices concernant l'épicéa Sitka (par exemple le rétention des aiguilles). Dans beaucoup des arbres, la longueur de la couronne se trouve réduite par suite de la défoliation complète des branches inférieures. Les effets étaient moins marqués chez l'épicéa commun. On a remarqué des dégâts importants sur le feuillage chez le chêne et le hêtre à cause des insectes.

Le type de defoliation que l'on retrouve chez les deux essences d'épicéa diffère d'une façon marquée du type de défoliation que l'on trouve en Europe centrale où les forêts souffrent de la forme typique du déclin des forêts. Chez l'épicéa dans La Bretagne la défoliation se manifeste d'habitude par la perte relativement uniforme des aiguilles sur toute la couronne. Là où des infestations importantes d'aphides se sont produites, l'effeuillage peut se développer à partir la base de la couronne. L'effeuillage de la couronne supérieure (principale sorte d'effeuillage en Europe centrale) se retrouvait dans moins de 5% des arbres.

On a signalé très souvent le dépérissement des couronnes chez le chêne (40% des arbres) et chez le hêtre (21%), bien qu'il se soit limité le plus souvent à la

mort des branches relativement minces et ait affecté seulement une faible proportion de la couronne supérieure. La mort des branches relativement grandes était rare, et ayant été observé plus souvent chez le chêne que le hêtre.

La rétention des aiguilles chez l'épicéa Sitka était grandement affecté par des infestations d'aphides, et 4% des arbres observés avaient seulement des aiguilles d'1 an ou 2. Au contraire, la rétention des aiguilles chez l'épicéa commun et le pin sylvestre s'améliorait.

La décoloration du feuillage était rare. Les deux essences d'épicéa ont montré plutôt moins de décoloration qu'en 1988, tandis qu'il y avait une augmentation dans le jaunissement des aiguilles plus âgées du pin sylvestre. Il y avait une réduction importante dans le jaunissement chez le hêtre.

Le roulement des feuilles était observable dans les couronnes de 50% des hêtres. Dans la moitié du nombres des arbres affectés, le roulement des feuilles se limitait aux feuilles dans la couronne supérieure, et dans la plupart le dégré du roulement était assez faible.

Les distributions de la condition des couronnes observées en 1987 et 1988 se repétérènt en 1989, avec beaucoup d'arbres dans un état pire vers le nord du pays. Ce fait se conforme à l'avis général que le climat et la qualité de la station sont d'une grande importance dans la détermination de la condition des couronnes. Il y a des exceptions à ces tendances générales qui d'habitude sont en rapport avec les facteurs spécifiques des stations.

On fera d'autres analyses sur les données aussitôt que les informations sur les niveaux de pollution de 1989 seront disponibles.

Überprüfung des Waldzustandes in Grossbritannien – 1989

Zusammenfassung

Die Ergebnisse des Programms für die Erfassung des Waldzustandes 1989 werden vorgestellt. Insgesamt wurden 7436 Bäume erfasst nämlich Sitkafichte (*Picea sitchensis*), Fichte (*Picea abies*), Kiefer (*Pinus sylvestris*), Eiche (*Quercus* spp.), und Rotbuche (*Fagus sylvatica*).

Der Kronenzustand wird jetzt nicht alleine auf der Kronendichte sondern auf einer Reihe verschiedener Kennziffern eingeschätzt. Dadurch wird eine ausführliche Beurteilung der Gesundheit einzelner Bäume ermöglicht. Da viele dieser Kennziffern nie vorher eingeschätzt worden sind, ist es jedoch nicht möglich zu bestimmen, ob diese Daten eigentlich eine Abweichung von dem normalen, in ehemaligen Umweltbedingungen erwarteten, Gesundheitszustand darstellen.

Die Kronendichte aller Baumarten erwies eine allgemeine Verbesserung, obgleich einige einzelne Sitkafichten als Folge der Frasstätigkeit des Fichtennadellauses (*Elatobium abietinum*) schlechter geworden sind. Die Verbesserung des Zustandes der Bäume im Wald steht im Gegensatz zu vielen alleinstehend gewachsenen Bäumen, die durch Dürrebelastung während des Sommers 1989 gelitten haben. Diese Verbesserung ist zur Erholung von vielen Bäumen nach den Sturmschäden im Oktober 1987, zur Abwesenheit von Winterschäden in 1988-1989, und zu den vorteilhaften milden nassen Wetterbedingungen im Sommer 1988 zurückzuführen.

Die starke Vermehrung von *E. abietinum* hat einige Kennziffern für Sitkafichte (z.B. Nadelbehaltung) schwerwiegend beeinflusst. In vielen Bäumen ist die Kronenlänge durch den Kahlfrass der unteren Zweige reduziert worden. Bei der Fichte war dieser Einfluss weniger auffallend. Schwere Blattschäden durch Insekten wurden bei Eiche und Rotbuche bemerkt.

Die Entblätterung bei den beiden Fichtenarten ist deutlich anders als die typische Form von Waldschäden, die in Mitteleuropa beobachtet wird. Bei den Fichten in Grossbritannien lässt sich die Entblätterung gewöhnlich als durch die ganze Krone verhältnismässig einheitlichen Nadelverlust erkennen. Wo schwere Nadellausvermehrungen vorgekommen sind, kann die Verdünnung von der Kronenbasis aufwärts gehen. Die Verdünnung der Oberkrone, die die Hauptverdünnungsform in Mitteleuropa ist, war bei weniger als 5% der Bäume zu beobachten.

Kronenabsterben wurde sehr oft bei der Eiche (40% der Bäume) und bei der Buche (21%) berichtet, umfasst aber meistens nur relativ kleine Zweige und nur einen kleinen Anteil der Oberkrone. Das Absterben von verhältnismässig

grösseren Zweigen war selten, und wurde öfter bei der Eiche als bei der Buche beobachtet. Die Nadelbehaltung bei Sitkafichte wurde stark von Nadellausvermehrungen beeinflusst, und bei 4% der erfassten Bäume waren nur noch 1- oder 2-jährige Nadeln vorhanden. Im Gegensatz dazu hat die Nadelbehaltung bei der Fichte und bei der Kiefer zugenommen.

Blattverfärbung war nur selten zu beobachten. Die beiden Fichtenarten zeigten etwas weniger Verfärbung als in 1988, aber die Vergelbung der älteren Nadeln bei der Kiefer hat zugenommen. Die Blattvergelbung bei der Buche war deutlich geringer.

Blattrollen wurde in den Kronen bei 50% der Buchen bemerkt. Bei der Hälfte der befallenen Bäume war das Rollen auf Blätter in der Oberkrone beschränkt, und meistens war der Rollengrad ziemlich leicht.

Die Verbreitungsbilder des Kronenzustandes in den Jahren 1987 und 1988 wurden im Jahre 1989 wiederholt, wobei anscheinend viele Bäume nach Norden schlechter wurden. Dies steht im Einklang mit der allgemeinen Meinung, dass Klima und Standort eine wichtige Rolle in der Bestimmung des Kronenzustandes spielen. Es gibt zwar Ausnahmen zu diesen allgemeinen Tendenzen, die aber meistens in Beziehung zu standortsbedingten Faktoren stehen.

Weitere Analysen der Daten werden gemacht, sobald Erkenntnisse auf Emissionsbelastungen von 1989 zur Verfügung stehen.

Monitoring of Forest Condition in Great Britain – 1989

J. L. Innes and R. C. Boswell, *Forestry Commission*

Introduction

The Forestry Commission started monitoring the condition of forests in 1984. Since then, reports have been produced each year (Binns *et al.*, 1985, 1986; Innes *et al.*,1986; Innes and Boswell, 1987, 1988, 1989). Major improvements have been made to the programme over the last 6 years and the changes reflect our greatly increased understanding of the nature of forest decline. However, the changes in methodology mean that data collected since 1987 cannot be compared with data collected in the period 1984–1986. Data collected over the last 3 years are internally consistent.

The monitoring programme is sufficiently flexible to be able to incorporate new methodological developments and the literature related to the assessment of forest condition continues to be evaluated. Major advances have occurred over the past 2 years and it has been possible to introduce many new techniques into our annual monitoring of tree condition. These new techniques enable more precise assessments of forest condition to be made. There have also been alterations enforced by European Community legislation and these have been incorporated into the 1989 assessments. The changes are detailed below.

In this report, the results of the main monitoring programme are presented. A second programme is conducted in Britain on behalf of the European Community and the Economic Commission for Europe of the United Nations. This is much smaller than the main programme and involves less detailed assessments of the trees. As the results are published separately by both bodies (e.g. United Nations Economic Council for Europe, 1988; Commission of the European Communities, 1989), they have not been included in this report.

Distribution of plots

Very few changes were made to the distribution of plots in 1989. Six plots were lost as a result of windblow or felling operations. Seven new plots were established, mainly in areas where the coverage was poor in 1988 (e.g. Charnwood and Epping Forests). As a result, in 1989 there were 63 Sitka spruce plots, 77 Norway spruce plots, 81 Scots pine plots, 53 oak plots and 36 beech plots. The plot distributions for each species are presented in Figure 1.

Assessment procedures

The biggest change to the assessment procedures occurred as a result of recommendations by the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests which were subsequently enforced by legislation within the European Community (Council Regulation (EEC) No. 2995/89 of 4 October 1989). In 1987 and 1988, trees were assessed in 10% crown density classes, with class zero being 0–10% loss of density, class 1 being 11–20% loss of density and so on. In 1989, 5% classes were introduced for the assessment of the crown density of trees; these were adopted for both of the Forestry Commission monitoring programmes to ensure consistency between the two.

In addition to the above, a number of the other indices were modified and some new indices were introduced. A complete list of the indices assessed in 1989 is given in Table 1. The

Table 1. Assessments made of each tree in the main survey. (SS: Sitka spruce; NS: Norway spruce; SP: Scots pine; OK: oak; BE: beech.)

Height (all). Measured every 5 years.
Diameter at breast height (all). This, and all subsequent assessments, are made annually.
Dominance (all).
Crowding (all). A measure of the degree of canopy closure around the tree.
Crown form (all). The type of crown. A variety of different forms are recognised for each species.
Crown density (all). A measure of the amount of foliage in the crown.
Defoliation type (SS, NS, SP). The pattern of needle loss within the crown.
Branch density (SS, NS, SP). A measure of the extent to which the crown density is influenced by the growth rate of the tree.
Number of needle-years present (SS, NS, SP).
Extent of shoot death in the crown (SS, NS, SP).
Location of shoot death in the crown (SS, NS, SP).
Dieback type (OK, BE). A measure of the severity of dieback within the crown.
Dieback location (OK, BE). The location of dieback within the crown.
Percentage of crown affected by dieback (OK, BE). The contribution of dieback to the crown density score.
Recent shoot growth (OK, BE). A measure of the state of degeneration of the crown.
Leader condition (SS, NS, SP).
Abundance of secondary shoots within the crown (SS, NS).
Location of secondary shoots on individual branches (SS, NS).
Number of stem epicormics (OK).
Number of branch epicormics (OK).
Extent of male flowering (SP).
Fruiting extent (all).
Number of green leaves on ground under tree (BE).
Leaf size (BE).
Degree of leaf-rolling in crown (BE).
Frequency of rolled leaves in crown (BE).
Overall discoloration of foliage (all).
Extent of browning of current year needles (SS, NS, SP).
Extent of yellowing of current year needles (SS, NS, SP).
Type of yellowing of current year needles (SS, NS, SP). Various forms are recognised.
Extent of browning of older needles (SS, NS, SP).
Extent of yellowing of older needles (SS, NS, SP).
Type of yellowing of older needles (SS, NS, SP).
Extent of browning of leaves (OK, BE).
Extent of yellowing of leaves (OK, BE).
Type of yellowing of leaves (OK, BE).
Extent of mechanical damage to crown (all).
Type of mechanical damage to crown (all).
Extent of butt damage (all).
Type of butt damage (all).
Extent of stem damage (all).
Type of stem damage (all).
Extent of fungal damage to foliage (all).
Extent of insect damage to foliage (all).

assessments are based on work by Alexander and Carlson (1988), Lesinski and Landmann (1988), Lesinski and Westman (1987), Gruber (1989), Niehaus (1989), Roloff (1989), Westman (1989) and Westman and Lesinski (1986).

All plots were assessed between 17 July and 1 September 1989.

Quality assurance

Quality assurance is a crucial aspect of any long-term monitoring programme (Cline *et al.*, 1989) and considerable emphasis has been placed on it in the British programme. Two aspects are now described: the reliability of the observations and the data completeness.

a. *Sitka spruce*

b. *Norway spruce*

c. *Scots pine*

d. *Oak*

e. *Beech*

Figure 1. *Location of plots used in the programme*

Reliability of observations

All observers attended a week-long training course. Three observers were new to the survey in 1989, but they were always accompanied by an observer with at least 2 years' previous experience. Each survey team was visited in its respective field area by a control team and its performance in relation to the other teams was determined. In addition, survey teams were encouraged to overlap with teams in adjacent areas, thereby improving observer standardisation.

Seven per cent of the stands were assessed by the control team. This is less than in 1988, when 13% of the stands were checked, and is close to the minimum (5%) indicated in the European Community legislation relating to inventories of forest condition. The lower figure was due to the increased time required to assess the extra indices in the main programme plots.

The accuracy of the assessments made by the individual teams varied. For Scots pine and beech, the majority (95%) of crown density assessments fell within ±12% of those made by the control team. The figures for Sitka spruce, Norway spruce and oak were ±13%, ±14% and ±17%, respectively. The values for oak indicate that the accuracy of the observations has deteriorated since 1988. There was also evidence of some systematic bias within the results: only Scots pine was free of it. Individual teams were generally overestimating crown density, with Norway spruce being the most affected. The greatest errors occurred in the middle of the range, a tendency also identified by Belanger and Anderson (1988).

Although the results of the observer tests compare favourably with those from other countries (Schlaepfer *et al.*, 1985; Schöpfer, 1985; Lick and Krapfenbauer, 1986; Neumann and Stowasser, 1986; Hägi, 1989; Mahrer, 1989), the deterioration in the quality of the results is worrying. Every attempt will be made to reverse this trend before it begins to seriously affect the results.

Data completeness

In all cases, there was a high level of completeness within the data set. The only major gap is the absence of information about the soils of the sites established in 1988 and 1989.

Results

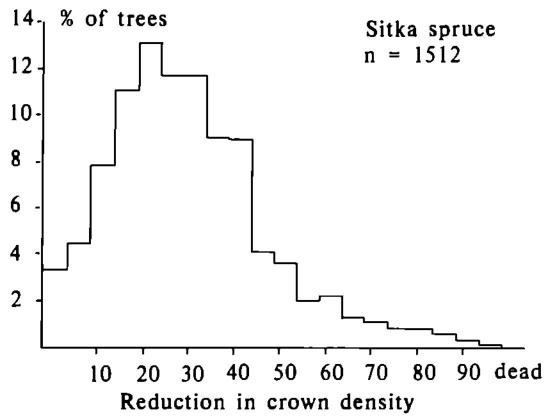
Crown density

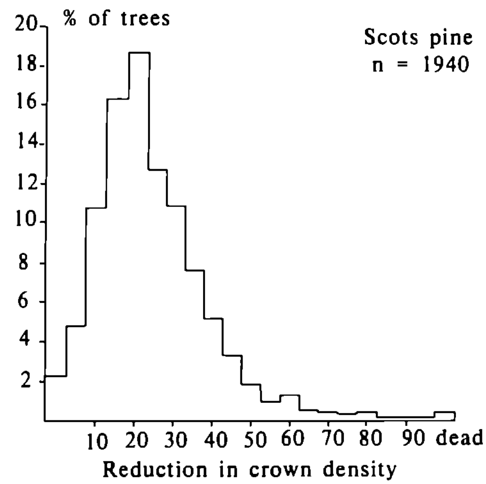
Data for crown density are presented in Table 2. Five per cent categories of crown foliage density have been used. In all cases, the distributions are highly skewed (Figure 2). No attempt has been made to derive area-related figures because of the inaccuracy of such estimates (Neumann, 1989a); the figures are representative only of the population that has been sampled.

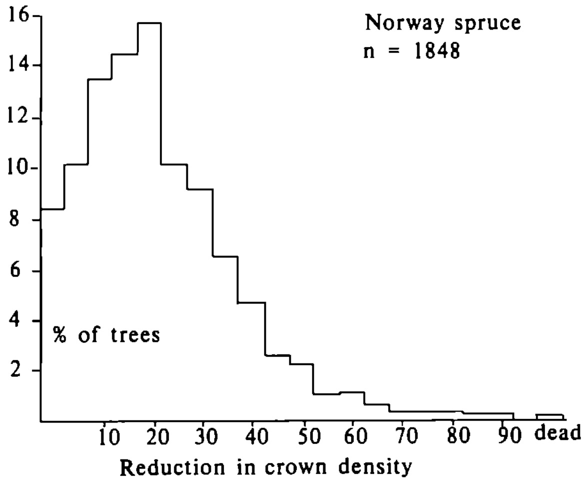
Table 2. The percentage of trees of each species in each crown foliage density category. A score of zero indicates no loss of density. A score of five represents 5% loss in crown density and so on. Sample sizes are given at the bottom of the table.

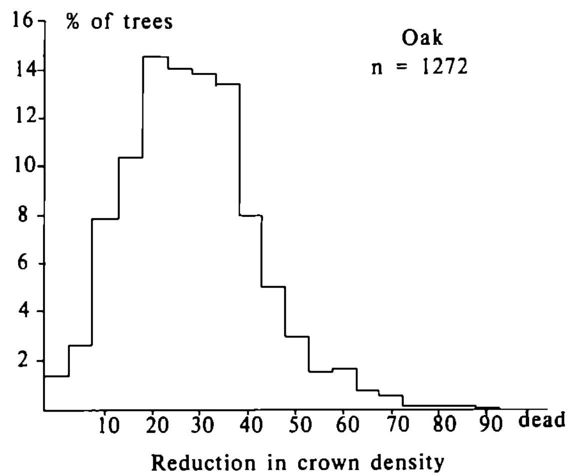
Class	*Sitka spruce*	*Norway spruce*	*Scots pine*	*Oak*	*Beech*
0	3.4	8.4	2.3	1.4	3.2
5	4.5	10.2	4.8	2.7	7.9
10	7.9	13.5	10.8	7.8	10.9
15	11.2	14.5	16.3	10.5	15.6
20	13.2	15.7	18.7	14.6	16.0
25	11.8	10.1	12.7	14.1	14.8
30	11.8	9.1	10.9	13.9	12.5
35	9.2	6.4	7.6	13.4	8.9
40	9.1	4.5	5.2	8.0	5.4
45	4.2	2.4	3.4	5.1	2.2
50	3.7	2.1	1.8	3.1	1.3
55	2.1	0.8	1.0	1.6	0.5
60	2.3	0.9	1.4	1.7	0.6
65	1.3	0.5	0.6	0.8	0.1
70	1.2	0.2	0.5	0.6	0
75	0.9	0.2	0.4	0.2	0
80	0.9	0.2	0.5	0.2	0
85	0.7	0.1	0.2	0.2	0
90	0.4	0.1	0.2	0.1	0
95	0.2	0	0.2	0	0
Dead	0	0.1	0.5	0	0.1
Sample size	1512	1848	1940	1272	864

Norway spruce had the most trees in the lowest (densest) three categories. All species had a modal class of 20% loss of foliage. Oak had a greater proportion of trees in the 30% and 35% classes than any of the other species. In the absence of any information about the crown density distributions in unpolluted environments, it is impossible to make any statement as to the significance of the data given in Table 2. However, trees with less than 20-25% needle loss are not normally considered to be damaged (Bengtsson, 1985; Kauppi, 1988; Jukola-Sulonen *et al.*, 1987) and there is evidence that, in certain situations, foliage loss of up to 40% may occur without any impact on annual increment (Becker, 1987a). The presence of a propor-









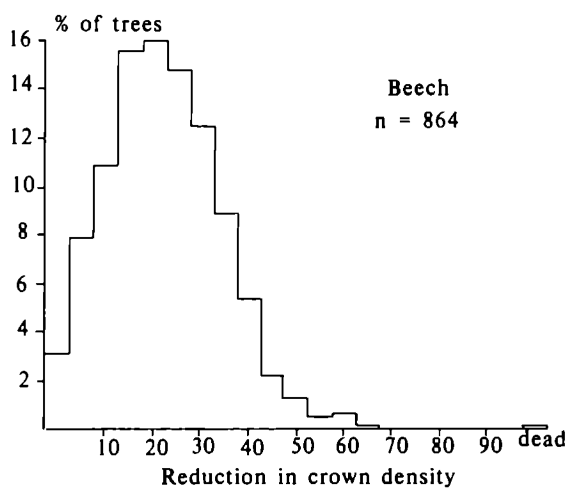
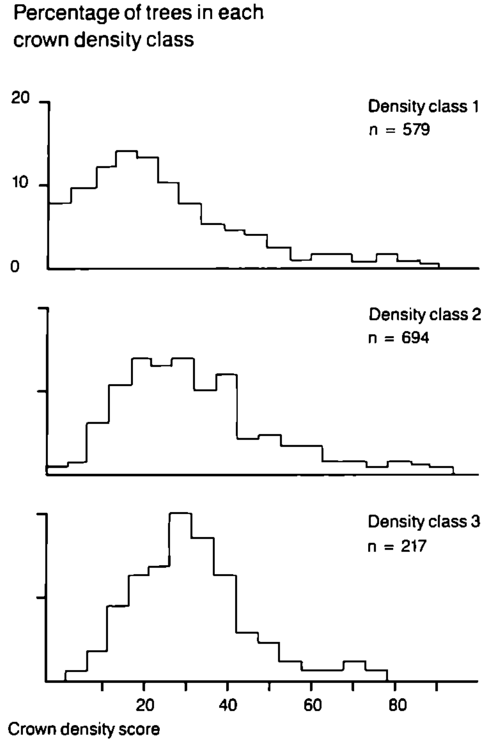


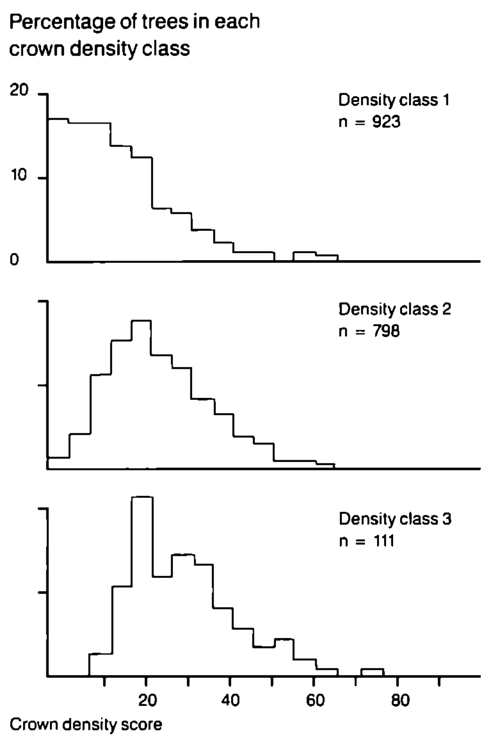
Figure 2. *Distributions of crown density scores for each species.*

tion of trees with thin crowns does not necessarily indicate a problem as crown density is not a good indication of tree vigour (Bauch *et al.*, 1985; Westman and Lesinski, 1985; Innes and Cook, 1989; Mahrer, 1989; Schmid-Haas, 1989; Rehfuess, 1989) but, if used in conjunction with other indices of crown condition, it may be useful (Anderson and Belanger, 1987).

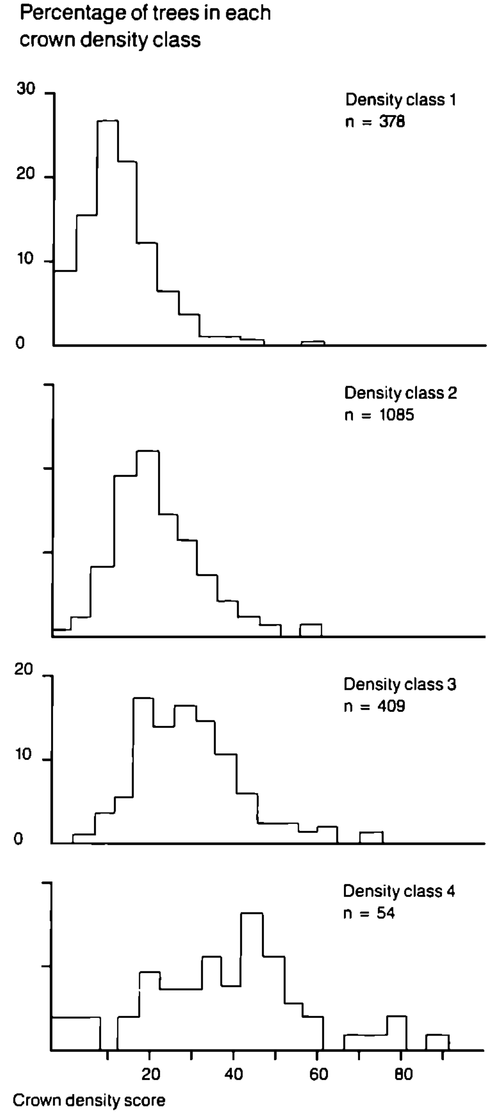
In the past, it has been suggested that one of the reasons that conifers in Britain have thin crowns is that they are growing rapidly, which results in the branches being widely separated. In 1989, branch density was noted and, for all three species, there is a clear trend for decreasing crown density with decreasing branch density



a. Sitka spruce



b. Norway spruce



c. Scots pine

Figure 3. *Relationship between crown density and crown branching score. High scores for branch density indicate widely spaced branches.*

(Figure 3). However, while it appears that branch density has an important impact on the assessment of the crown density at the lower end of the scale (i.e. the densest trees), branching density cannot be used to explain the condition of all trees, as thin-crowned trees occurred regardless of branching density.

Table 3. Comparison of tree crown density results for the period 1987–1989. The data for 1989 have been adjusted to take into account the change in measurement classes and are therefore not comparable with data in Table 2. As in 1987 and 1988, 10% categories have been used. Class 0 represents 0–10% reduction in density, class 1 represents 11–20% reduction, class 2 represents 21–30% reduction and so on. The numbers of trees compared within each species are given.

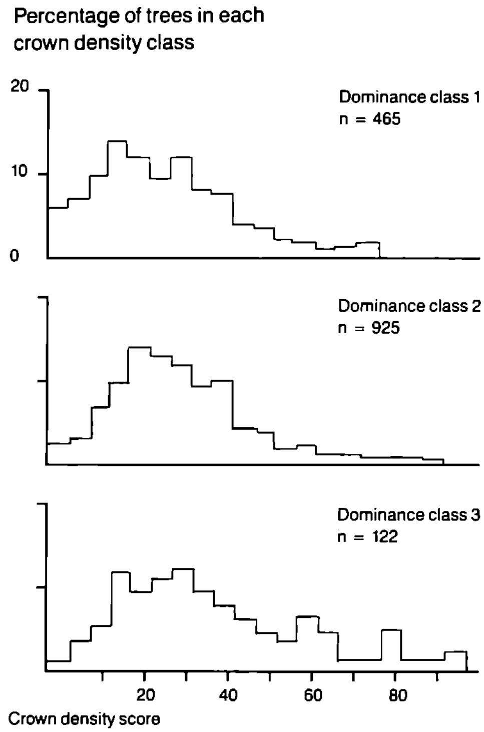
		Crown density class									
		0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Sitka spruce	1989	13	22	24	19	10	5	3	2	2	0
n = 1223	1988	8	22	26	23	14	6	1	0	0	0
	1987	14	23	25	19	12	5	2	0	0	0
Norway spruce	1989	27	28	22	14	6	2	1	0	0	0
n = 1512	1988	21	27	24	16	7	4	1	0	0	0
	1987	21	24	24	15	9	4	2	1	0	0
Scots pine	1989	13	31	27	15	6	3	2	1	1	1
n = 1459	1988	8	23	32	20	9	4	1	1	1	1
	1987	19	23	25	18	8	3	1	1	1	1
Oak	1989	7	22	31	26	10	3	1	0	0	0
n = 695	1988	4	16	29	27	14	6	2	1	1	0
	1987	9	15	21	29	15	6	4	1	0	0
Beech	1989	19	31	29	16	4	1	0	0	0	0
n = 672	1988	9	24	33	22	9	2	1	0	0	0
	1987	8	22	26	28	12	3	1	0	0	0

The dominance of individual trees and the degree of canopy closure in their immediate vicinity were also recorded. No evidence of a link between crown density and tree dominance was identified (Figure 4), contrasting with the situation in West Germany (Krause *et al.*, 1983; Prinz and Krause, 1989). This may be because the trees sampled in the British programme are all from even-aged plantations, with the result that the differences in height between dominant and co-dominant trees are relatively small. Young stands of Norway spruce in West Germany do not always show a relationship between social class and damage (Weber and Huber, 1988), suggesting that the relationship between social class and damage may be dependent on factors such as stand age and silvicultural practices.

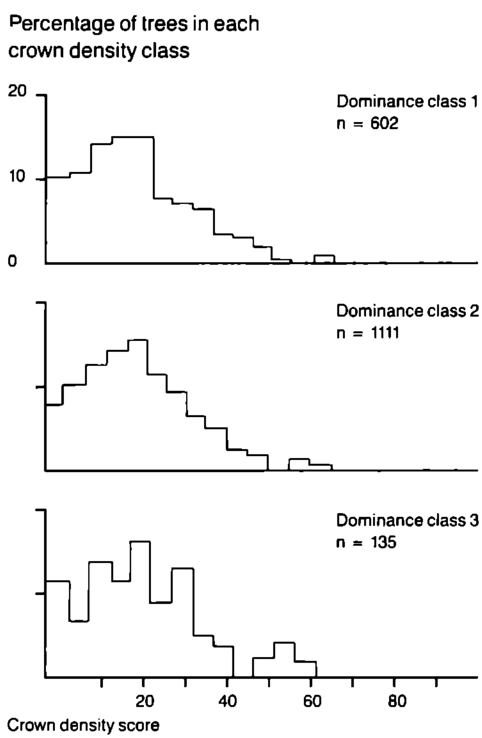
The degree of canopy closure appeared to have a relationship with crown density in several of the species (Figure 5). In Sitka spruce, a higher proportion of thin-crowned trees were present in the more open stands, and this trend was also apparent for Norway spruce. Similar results have been obtained for Norway spruce in West Germany (Denstorf *et al.*, 1984; Levin, 1985), Switzerland (Keller and Imhof, 1987) and Austria (Neumann, 1989b). Neither Scots pine nor oak showed any relationship between crown density and canopy closure. The most obvious trend occurred in beech; trees within relatively open canopies had significantly thinner crowns than trees within closed canopies, as has also been found in some stands in Switzerland (Keller and Imhof, 1987).

The changes in crown density from year to year are of particular interest. As some of the trees sampled over the 3 years have changed, the overall totals for each year are not directly comparable. However, valid comparisons are possible if those trees assessed in all 3 years are included, although this reduces the total number of trees assessed by about 25% on average. The change to 5% classes adds a further complication to the comparisons. However, it is possible to aggregate the 5% classes and to adjust the figures to take into account the slightly different class intervals (Table 3).

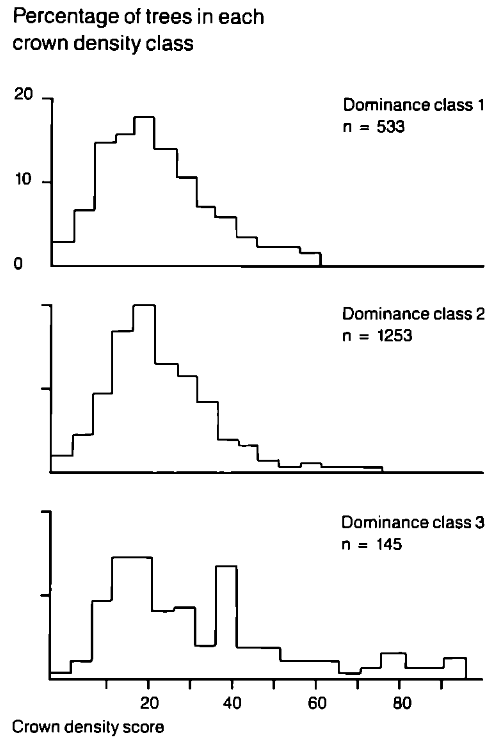
The crown densities of Norway spruce, oak and beech have increased since 1987 whereas



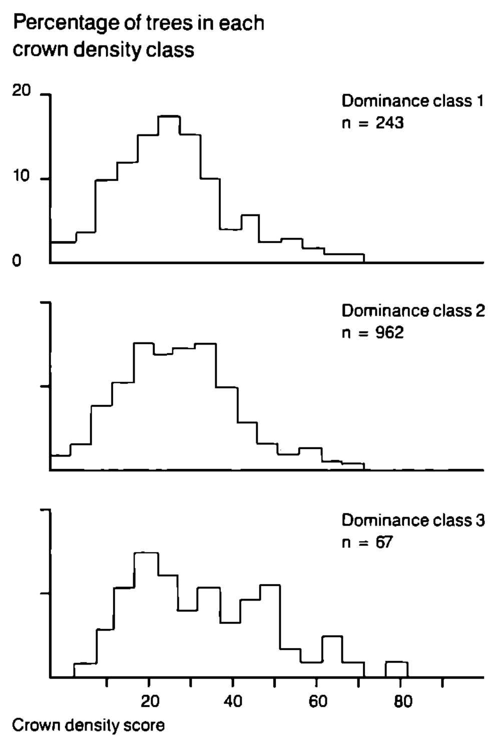
a. Sitka spruce



b. Norway spruce

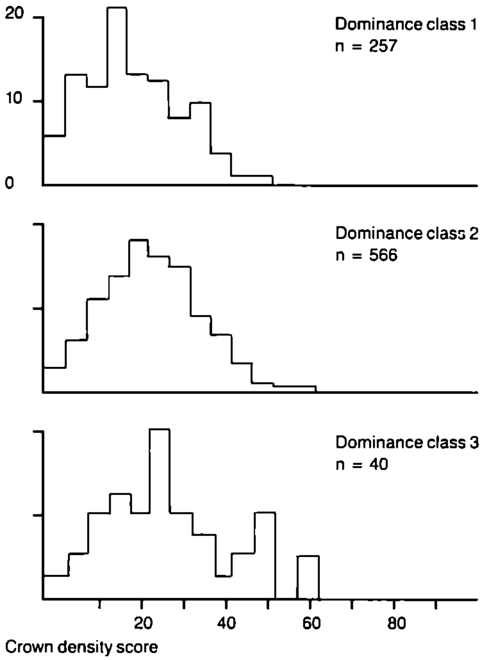


c. Scots pine



d. Oak

Percentage of trees in each crown density class



e. Beech

Figure 4. *Relationship between crown density and tree social class. A social class of 1 indicates a dominant tree, 2 a sub-dominant and 3 a canopy-level tree.*

Scots pine and Sitka spruce have shown little change over the period. Between 1988 and 1989, there was a clear increase in the crown densities of Norway spruce, Scots pine, oak and beech (Figure 6). Many Sitka spruce also improved, but there has been a concurrent increase in the proportion of trees with more than 50% defoliation. The proportion of severely defoliated Norway spruce, Scots pine and oak did not change between 1988 and 1989.

Crown form and defoliation type

There has been considerable criticism of the use of crown density as an index of tree condition and a variety of other indices exist. Crown form (Westman and Lesinski, 1986; Westman, 1989) is one such measure and, together with defoliation type, was assessed for conifers in 1989.

In both Sitka and Norway spruce, the most common crown form was a mixture of the brush/plate type (Table 4). This type is characterised by side shoots from main branches being orientated horizontally or slightly upwards. True comb-type trees, with pendulent side shoots, were relatively rare (1% for both species), but about 10% of trees of both species were classified as 'hanging brush', an intermediate stage between brush-type and comb-type. It is not clear whether trees in this category represent a genetically intermediate stage or whether they predominantly consist of brush-type trees with branches that have drooped as a result of some external factor. In both species, a number of trees showed more than one type of branching habit within the crown.

Table 4. Branch pattern in spruce and crown form in Scots pine. In spruce, 1: comb; 2: brush or plate; 3: hanging brush; 4: mixture. In pine, 1 to 6: progressive flattening of the crown from vigorous apical growth (1) to flat platform (6); 7: other.

	Branch pattern			
	1	*2*	*3*	*4*
Sitka spruce (%)	1	82	10	7
Norway spruce (%)	1	73	12	14

	Scots pine crown form					
	1	*2*	*3*	*4*	*5*	*6*
% trees	79	14	5	1	1	0

Crown form in Scots pine was classified according to the degree of apical dominance (Niehaus, 1989). The majority of trees had vigorous apical growth (Table 4), with complete loss of apical dominance being present in a very small number (8, i.e. 0.4%) of trees. This may be a reflection of the relatively young age range of the sample (the oldest stand was planted in 1900).

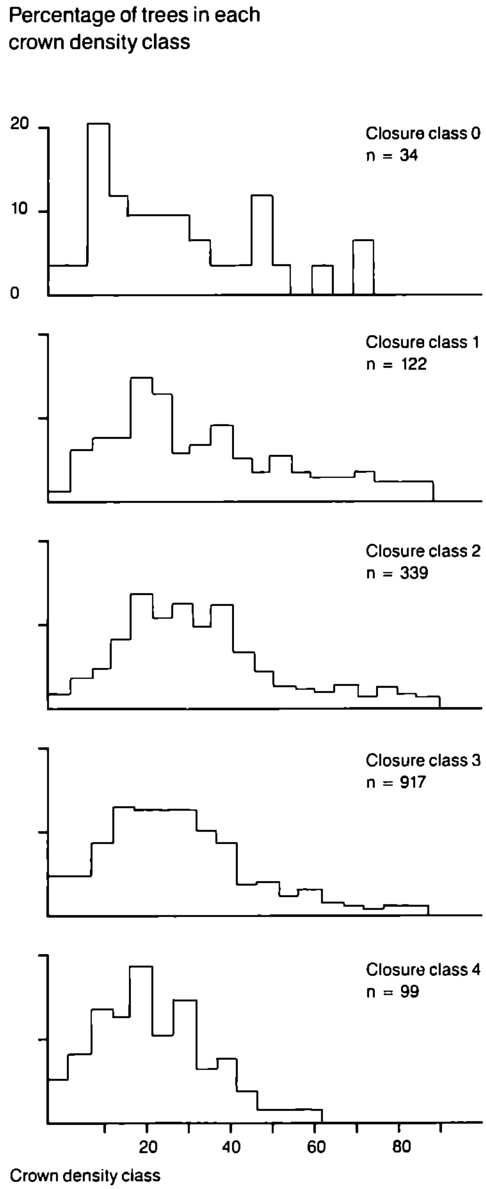
Defoliation types were assessed for both the spruce species and for Scots pine (Table 5). The most common type of spruce defoliation was uniform loss of needles, with thinning being apparent all over the crown. Thinning from the base upwards was also important. In Sitka spruce, needle loss at the base of the crown was particularly associated with defoliation by the

Table 5. (a) Defoliation types of spruce, 1989. 0: no obvious defoliation; 1: small window in upper crown; 2: large window in crown; 3: top-dying; 4: uniform loss of needles/branches; 5: peripheral loss; 6: bottom upwards; 7: other. (Figures given are percentages.)

	Defoliation type							
	0	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Sitka spruce	28	4	3	0	47	0	15	3
Norway spruce	45	3	4	1	33	1	12	1

(b) Percentages of Scots pine with different defoliation types. 0: no obvious defoliation; 1: lower part thinner than upper; 2: greatest defoliation at the ends of branches; 3: gap-like; 4: whole crown thin; 5: whole crown thin, but some branches with full needle complements; 6: upper part dead or much thinner than lower part; 7: other.

	Defoliation type							
	0	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Percentage	36	10	0	6	39	3	4	2



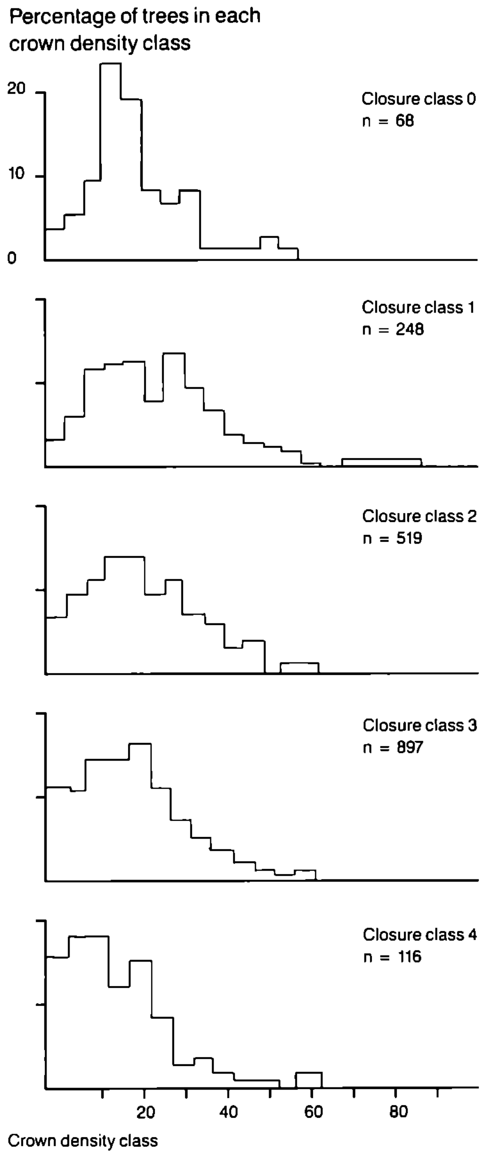
a. Sitka spruce

Figure 5. *Relationship between crown density and the degree of crowding of a tree. High crowding scores indicate a closed canopy.*

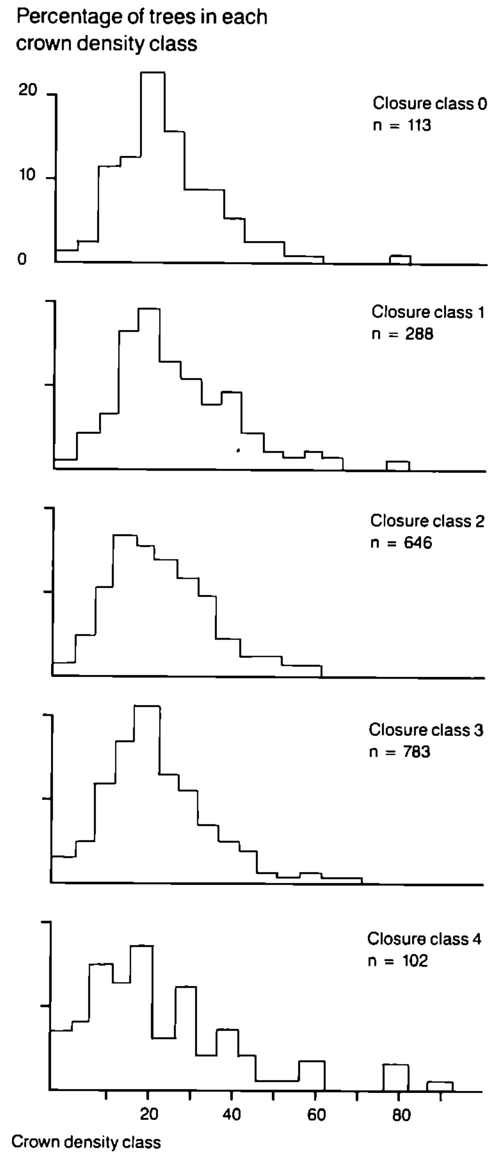
green spruce aphid *Elatobium abietinum* Walker (Hemiptera); the cause in Norway spruce was less apparent, but may also be related to infestation by *E. abietinum*. The most common type of defoliation in Scots pine also involved the uniform loss of needles over the whole crown, with other types of defoliation being relatively rare.

These results contrast markedly with those from continental Europe, where the decline of Norway spruce is normally associated with the development of windows in the upper crown (sometimes referred to as sub-top dying, type 1 in Table 5) (Schröter and Aldinger, 1985; Westman and Lesinski, 1986; Gruber, 1988a). The differences in the results suggest that different factors may be causing crown thinning in Britain and central Europe.

Crown form was also assessed for broadleaves. In 1987, an attempt was made to use the assessment system of Roloff (1985a, 1985b) to categorise the crown form of beech. This failed, largely as a result of inconsistencies in the assessments made by different observers. Some developments in technique have occurred since then (see, for example, Dobler *et al.*, 1988; Roloff 1989) and in 1989 an attempt was made to reintroduce the assessments. However, lack of consistency between observers again means that the results for 1989 must be discounted. There is also some uncertainty surrounding the signif-



b. Norway spruce



c. Scotts pine

icance of the Roloff scoring system; it appears that a proportion of the variation is genetically controlled, rather than being a response to stress (Thiebaut, 1988). In addition, the scores sometimes bear little relationship to crown density (Athari and Kramer, 1989; Ling *et al.*, 1989) and are consequently difficult to interpret.

One of the problems encountered with beech in both 1987 and 1989 was that many trees do not readily fall into one of Roloff's categories. The more detailed crown classification system of Westman (1989) largely resolves this problem. Westman's system was included in 1989 following detailed discussions with its designer. Seven main categories were recognised (Table 6) and these fall roughly into a linear system with the healthiest trees in class 0 and the least healthy ones in class 6. The majority (60% of oak and 52% of beech) were in classes 2 and 3, representing either small gaps in the foliage or gaps

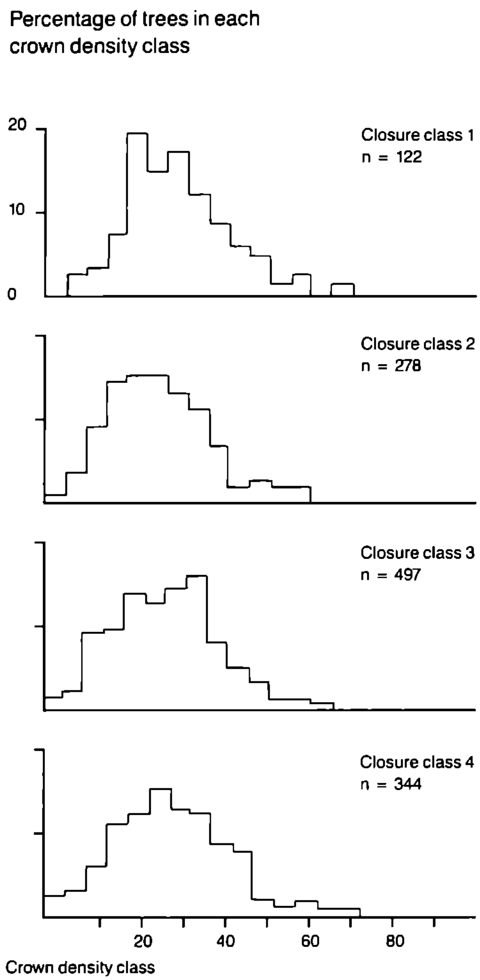
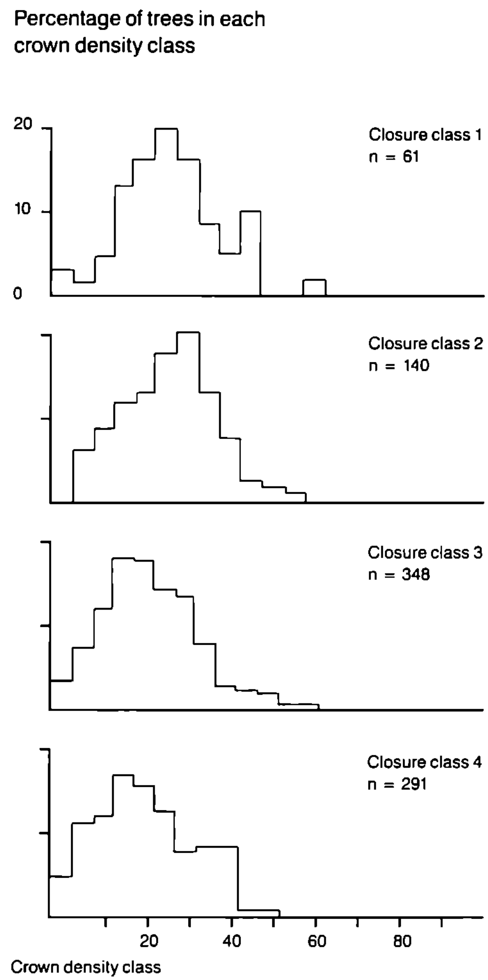


Figure 5. d. Oak



e. Beech

Table 6. Percentages of broadleaves in specific crown pattern categories.
0: 0-15% loss of density;
1: no clear pattern;
2: whole or part of crown transparent due to small gaps in the foliage;
3: gaps in the lateral branch system;
4: main branches bare almost to or including tips;
5: dominantly large gaps with leaves grouped at branch tips and possibly small groups on the branches;
6: whole or part of crown without leaves;
7: other.

	Type 0	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Oak	21	5	36	24	8	4	0	2
Beech	38	5	33	19	3	1	1	0

in the lateral branch system. Using this classification, beech was in better condition than oak, a conclusion confirmed by a number of other indices recorded in 1989.

The interpretation of these figures is difficult as there is nothing against which they can be compared. Wind may be involved in some of the higher scores, but the beech lacking leaves over all or part of the crown were all classed as being without mechanical damage; wind damage was mainly associated with trees with small- or medium-sized gaps in the crown. Similarly, wind damage was only noted on 18% of the oak in crown form classes 4 – 6 and the proportion of wind-damaged trees was even less in classes 2 and 3. There are a considerable number of trees in classes 4 – 6 and the condition of these needs to be carefully monitored in the future.

Dead shoots in conifers

The frequency of shoot death in the crowns of conifers was recorded (Table 7). Dead shoots were recognised by the absence of needles or by all needles being necrotic. The assessments were restricted to the area of live crown; lower shoots killed by suppression were excluded. Shoot death was present in about half of the trees, but the degree was rather less in Scots pine than in the two spruces.

Some shoot death within the live crown is to be expected as a result of suppression. In Sitka spruce, shoot death in the majority (82%) of trees was located in the lower half of the crown (30% of cases) or was distributed evenly throughout the crown (42% of cases). The former pattern is typical of damage caused by *E. abietinum*, once the new season's foliage has fully extended. Shoot death was restricted to the top half of the tree in only 15% of cases. A rather different pattern was present in Norway spruce. Shoot death was located in the bottom half of the tree in 30% of cases and all over the crown in 48% of cases. The proportion of trees with shoot death restricted to the lower crown probably reflects the better ability of Norway spruce to retain its needles following infestation by *E. abietinum*. Shoot death was restricted to the top half of the tree in 17% of cases. In Scots pine, shoot death was distributed throughout the crown in 41% of cases. In a further 21% of trees, it was restricted to the bottom half.

In all three species, shoot death increased with decreasing levels of crown density (Table 8).

Table 7. Extent of shoot death in the live crowns of conifers, 1989.

	Percentage frequency				
	Absent	*Rare*	*Scattered*	*Common*	*Abundant*
Sitka spruce	55	8	14	21	2
Norway spruce	54	8	18	19	1
Scots pine	51	19	19	10	1

Table 8. Shoot death in relation to crown density for the three conifer species. The number of trees in each category is given. Shoot death categories (columns): 0: none; 1: rare; 2: scattered; 3: common; 4: abundant.

	Sitka spruce					*Norway spruce*					*Scots pine*				
	0	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*
0	42	7	1	2	0	147	14	5	0	0	36	8	0	0	0
5	59	5	1	3	0	168	11	7	1	0	77	15	2	0	0
10	99	8	12	1	0	189	27	30	2	0	153	41	13	2	0
15	117	17	22	14	0	178	21	56	12	0	217	63	33	4	0
20	135	14	32	18	0	125	30	91	41	1	213	80	61	10	0
25	100	13	34	31	0	79	20	52	34	0	117	59	48	20	1
30	92	13	33	41	0	49	8	48	61	1	82	36	66	28	0
35	56	20	24	36	1	19	13	21	63	1	43	31	48	24	0
40	47	10	27	53	1	19	1	15	47	2	27	13	36	25	0
45	20	3	10	29	2	6	0	0	38	0	9	13	24	19	0
50	21	2	8	22	3	2	2	5	26	3	7	1	13	13	0
55	5	1	6	17	3	1	0	4	7	2	1	0	6	12	1
60	6	1	2	21	5	0	0	1	11	5	2	4	6	15	0
65	6	0	2	8	3	0	0	0	9	0	1	1	2	8	0
70	6	0	1	8	3	0	0	0	4	0	0	1	0	6	2
75	6	0	0	6	2	0	0	0	1	3	0	1	0	6	1
80	6	2	0	4	2	0	0	0	0	4	2	0	0	4	3
85	9	0	0	1	0	0	0	0	0	2	0	0	0	0	3
90	6	0	0	0	0	0	0	0	0	2	0	0	1	0	2
95	3	0	0	0	0	0	0	0	0	0	0	0	0	0	4

Crown dieback in broadleaves

In 1987 and 1988, crown dieback was assessed on the basis of a number of uneven-sized categories. This was changed in 1989 and several different indices were assessed. The type of dieback was identified, together with its location within the crown. In addition, the percentage of the crown density affected by dieback was assessed to the nearest 5%. The first two categories of dieback type do not represent dieback in a strict sense, and for calculating the percentages of trees affected, only classes 2 to 5 have been included. In 1989, 60% of oak and 79% of beech were without dieback. This contrasts with the results for 1988 when it appears that bare twigs, caused by leaf loss attributable to, for example, insect defoliation, were included as dieback.

In both species, the majority of cases where dieback was reported referred to death of relatively thin branches (Table 9). Death of thicker branches was largely restricted to oak while severe dieback, involving the death of the upper part of the main stem, was reported only in oak (1% of cases). In oak, dieback was located throughout the crown in about half of the affected trees and in the top half of the crown in the remainder. Dieback in beech, although similarly restricted to the uppermost branches in about half of the trees, was found throughout the crown in only 22% of the cases.

The extent of dieback is also given in Table 9. In oak, the majority of trees had less than 20% dieback, although five trees had more than 50%. In beech, the two worst cases involved the dieback of 45% and 50% of the crown. However, as in oak, the majority of cases involved 5 – 20% of the crown.

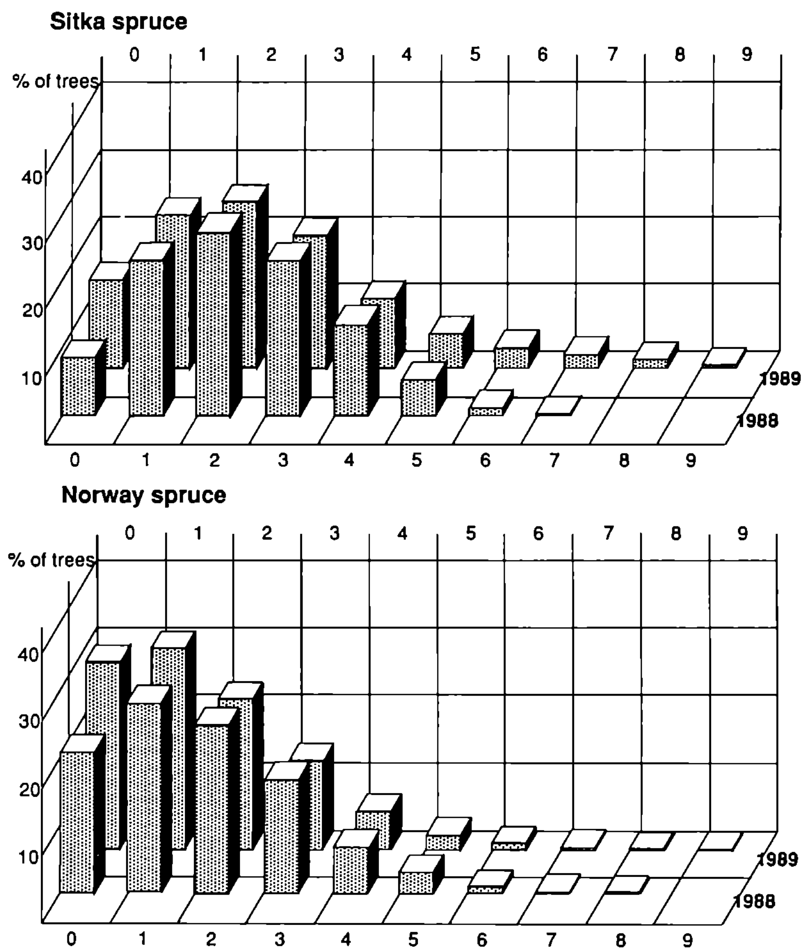
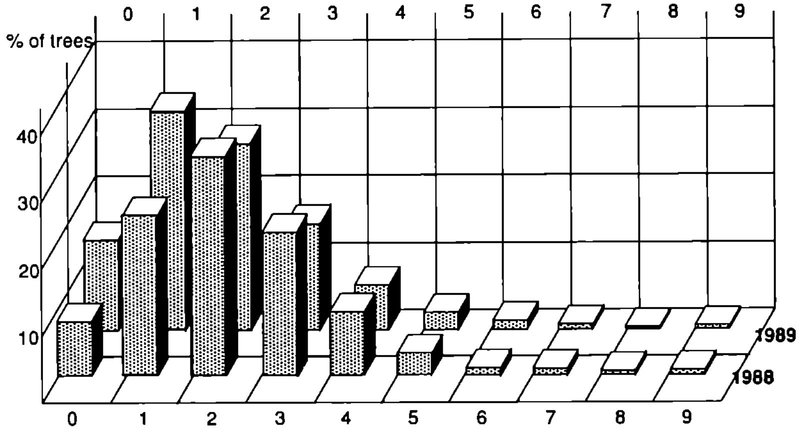
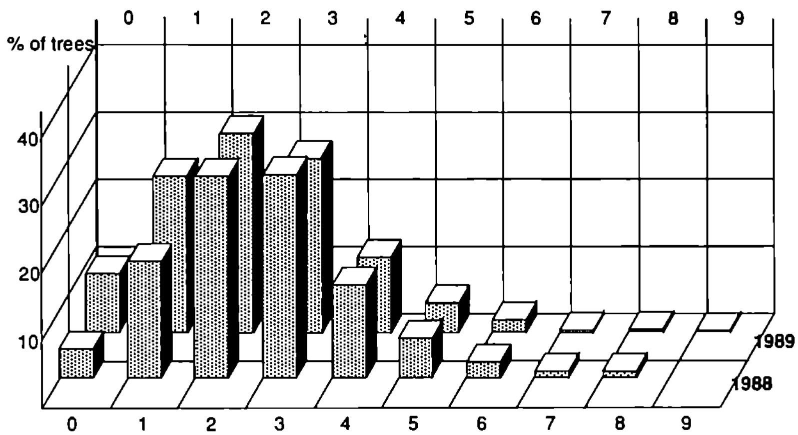


Figure 6. *Changes in crown density between 1988 and 1989.*

Scots pine



Oak



Beech

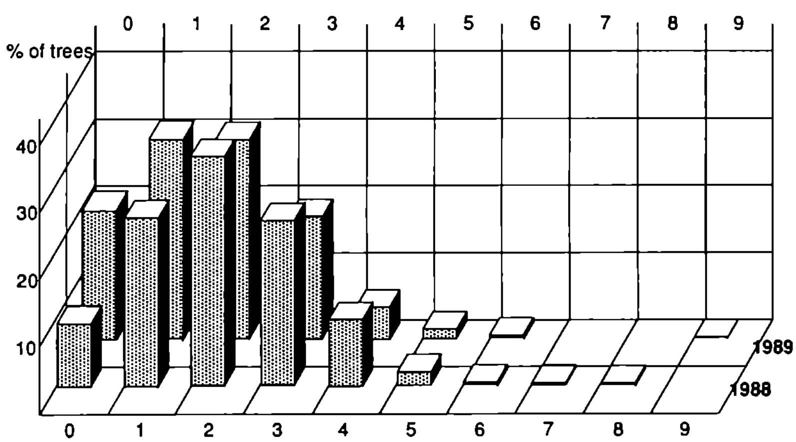


Table 9. (a) Percentages of oak and beech in each crown dieback class, 1989. 0: no dieback; 1: leaf loss only; 2: breaks to thin branches; 3: breaks to thick branches; 4: stem broken; 5: other.

	Class 0	1	2	3	4	5
Oak	45	15	28	11	1	0
Beech	47	32	18	3	0	0

(b) Extent of dieback (in 10% classes). The number of trees in each class is shown.

	0	*5-10*	*11-20*	*21-30*	*31-40*	*41-50*	*51-60*	*61-70*	*71-80*	*81-90*	*91-100*
Oak	620	379	182	58	20	8	2	0	3	0	0
Beech	464	253	121	17	6	2	0	0	0	0	0

Discoloration

As in previous years, discoloration in conifers has been separated by needle age and by colour. High levels of discoloration were very rare. Scots pine had the greatest proportion of discoloured needles but the reasons are uncertain. While fungal pathogens may have been responsible at particular sites, the widespread increase in the number of stands with one or more affected trees suggests that the most likely explanation is early autumnal senescence of older needles (Baum, 1981; Gloaguen and Touffet, 1976; Grozeva, 1986; Verzunov, 1987). Several factors could have caused this; they are discussed below.

Data from previous years are also presented in Table 10. These are the overall figures and the data have not been screened to include only those trees assessed in all 3 years. Apart from the increase in the yellowing of older Scots pine needles, there appears to have been little change in the overall levels of discoloration throughout the country over the 3 years. If anything, the two spruce species appear to have slightly fewer discoloured needles. However, as shown below, these figures conceal considerable changes to the distribution of sites with discoloration.

The extent of browning in the two broadleaved species remained fairly constant over the 3 year period (Table 11). In 1989, beech had a higher level of browning than oak; this can be related to damage by the beech leaf miner *Rhynchaenus fagi* L. (Coleoptera) and infection by the fungus *Apiognomonia errabunda* (Roberge) Höhnel. The amount of yellowing in oak also remained roughly constant whereas yellowing in beech showed marked variations. In beech, a major increase in the extent of yellowing in 1988 was not sustained into 1989, when a marked improvement occurred. Most yellowing was either localised within the crown (48% of the cases) or occurred in the upper crown (45% of the cases). Yellowing throughout the crown was very rare with only two trees being affected in this way. Yellowing was independent of the degree of canopy closure. In marked contrast, browning increased with degree of canopy closure, with 31% of trees in closed canopy situations showing browning and none in open situations.

Needle retention

As expected from the crown density data, the number of Sitka spruce with low needle retention figures increased markedly in 1989 (Table 12). Four per cent of trees had only 1- or 2-year needles present. This is likely to have serious implications for their future growth which will be monitored over the next few years. The number of Norway spruce with more than 7 years' needle retention increased. Needle retention in Scots pine also increased slightly, from 2.4 to 2.45 years. The majority of trees had either 2 or

Table 10. Percentages of trees in each discoloration class. Figures for 1989 are given in bold type; figures for 1987 and 1988 are given below.

(a) Percentages of trees in each needle-browning class, 1987–1989.

	Current					*Old*				
	0	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*
	0-10%	*11-25*	*26-60*	*>60*	*Dead*	*0-10%*	*11-25*	*26-60*	*>60*	*Dead*
Sitka spruce										
1989	**98**	**2**	**0**	**0**	**0**	**97**	**2**	**1**	**0**	**0**
1988	99	1	0	0	0	89	8	3	0	0
1987	94	6	0	0	0	91	8	1	0	0
Norway spruce										
1989	**99**	**1**	**0**	**0**	**0**	**95**	**4**	**1**	**0**	**0**
1988	99	1	0	0	0	88	8	4	0	0
1987	95	4	1	0	0	94	5	1	0	0
Scots pine										
1989	**93**	**7**	**0**	**0**	**0**	**92**	**7**	**1**	**0**	**0**
1988	96	4	0	0	0	93	6	1	0	0
1987	94	5	1	0	0	92	7	1	0	0

(b) Percentages of trees in each needle-yellowing class, 1987–1989.

Sitka spruce										
1989	**98**	**1**	**1**	**0**	**0**	**92**	**6**	**2**	**0**	**0**
1988	96	4	0	0	0	93	5	2	0	0
1987	97	2	1	0	0	89	9	2	0	0
Norway spruce										
1989	**98**	**2**	**0**	**0**	**0**	**97**	**2**	**1**	**0**	**0**
1988	97	3	0	0	0	95	4	1	0	0
1987	98	2	0	0	0	98	2	0	0	0
Scots pine										
1989	**97**	**3**	**0**	**0**	**0**	**89**	**8**	**3**	**0**	**0**
1988	97	3	0	0	0	94	5	1	0	0
1987	98	2	0	0	0	96	4	0	0	0

(c) Percentages of coniferous trees in each overall discoloration class, 1987–1989.

		Overall discoloration				
		0	*1*	*2*	*3*	*4*
Sitka spruce	**1989**	**90**	**7**	**2**	**1**	**0**
	1988	86	10	4	0	0
	1987	88	10	2	0	0
Norway spruce	**1989**	**93**	**5**	**2**	**0**	**0**
	1988	86	9	5	0	0
	1987	95	4	1	0	0
Scots pine	**1989**	**84**	**13**	**2**	**0**	**1**
	1988	90	8	2	0	0
	1987	91	7	1	0	0

Table 11. (a) Percentages of oak and beech showing leaf discoloration, 1987–1989.

	Browning					*Yellowing*				
	0	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*
	0-10%	*11-25*	*26-60*	*>60*	*Dead*	*0-10%*	*11-25*	*26-60*	*>60*	*Dead*
Oak										
1989	**96**	**4**	**0**	**0**	**0**	**92**	**5**	**2**	**1**	**0**
1988	95	5	0	0	0	92	7	1	0	0
1987	98	2	0	0	0	97	3	0	0	0
Beech										
1989	**75**	**20**	**4**	**1**	**0**	**70**	**22**	**7**	**1**	**0**
1988	72	24	4	0	0	47	35	16	2	0
1987	74	22	4	0	0	86	13	1	0	0

(b) Percentages of beech and oak showing overall discoloration, 1989.

	Class				
	0	*1*	*2*	*3*	*4*
	0-10%	*11-25*	*26-60*	*>60*	*Dead*
Oak	91	6	2	1	0
Beech	64	23	11	2	0

Table 12. Percentages of trees with needle life (needle retention) for a given number of years, 1987–1989.

	Number of years								
	0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*>7*
Sitka spruce									
1989	**0**	**2**	**2**	**4**	**7**	**13**	**15**	**18**	**39**
1988	0	0	0	1	5	15	16	18	45
1987	0	0	0	1	4	15	18	18	44
Norway spruce									
1989	**0**	**0**	**0**	**2**	**4**	**11**	**15**	**21**	**47**
1988	0	0	0	1	3	11	20	24	41
1987	0	0	0	1	6	17	23	20	33
Scots pine									
1989	**0**	**2**	**52**	**44**	**2**	**0**	**0**	**0**	**0**
1988	0	2	59	37	2	0	0	0	0
1987	0	2	49	44	5	0	0	0	0

3 years' needle retention, with a small proportion (4%) having 1 or 4 years. No Scots pine had more than 4 years' needle retention.

Leader condition in conifers

Leader condition was recorded for the first time in 1989. A large number of trees had damaged leaders, with missing leaders being the most common type of damage in spruce and double leaders being the most frequent type in Scots pine (Table 13).

Flowering in Scots pine

In 1989, the scoring for flowering, which is based on the presence of needle-less sections of shoot created by male flowering in the spring

Table 13. Percentages of trees with leader in a given condition, 1989. 0: normal; 1: shorter than current year side shoots; 2: missing; 3: bent or twisted; 4: double; 5: broken; 6: bare; 7: side shoot taken over; 8: tree with no apical dominance.

	Type 0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Sitka spruce	64	2	12	10	4	2	0	6	0
Norway spruce	68	6	11	3	6	1	1	4	0
Scots pine	60	3	5	2	12	0	1	8	9

and early summer, was split to reflect the major differences that can occur in the extent of flowering in the upper and lower crown. Flowering was significantly greater in the lower crown (Table 14). While it is difficult to compare the results with previous years, the extent of heavy flowering appears to have increased in 1989 and independent observations made in Forestry Commission seed orchards confirm that a relatively high level of flowering occurred.

Table 14. Percentage of pine in each flowering class, 1989. 0: none; 1: rare; 2: infrequent; 3: common; 4: abundant.

	Flowering class 0	*1*	*2*	*3*	*4*
Upper crown	52	26	13	8	1
Lower crown	14	19	23	23	21

Flowering is important as it is related to crown density. However, it is not clear whether flowering occurs in response to low crown densities or whether it is one of the reasons for the low crown density score. Increased levels of flowering are not associated with lower crown densities (Table 15); if anything, the reverse is

Table 15. Relationship between crown density and degree of flowering in Scots pine. All figures are given as the percentage of the total number of trees in each flowering category occurring in a particular crown density category.

Crown density	*Bottom half* 0	*1*	*2*	*3*	*4*	*Top half* 0	*1*	*2*	*3*	*4*
0	3.4	3.5	1.5	1.8	1.7	3.2	0.8	3.1	0	0
5	8.0	5.9	5.1	3.8	2.7	6.3	4.1	2.7	1.9	4.2
10	11.9	18.6	10.8	7.7	6.5	13.3	10.3	7.4	3.2	4.2
15	14.9	15.5	21.1	14.0	15.8	17.0	16.0	12.8	20.7	12.5
20	14.2	14.7	19.9	18.6	24.9	17.5	17.3	20.5	30.4	20.8
25	10.0	10.7	12.6	15.3	13.8	10.6	15.0	15.5	13.6	20.8
30	8.0	7.8	9.3	15.1	13.2	8.7	13.4	16.6	9.1	8.2
35	5.4	5.6	5.8	9.7	11.0	6.2	9.5	7.8	11.6	4.2
40	3.1	7.2	5.5	5.2	4.5	5.4	5.3	3.9	5.2	12.5
45	5.4	3.5	3.3	2.9	2.5	3.6	3.9	2.7	1.9	0
50	1.9	1.3	1.1	3.2	1.2	1.6	2.2	2.3	0.6	0
55	3.1	1.1	0.9	0.7	0.2	1.6	0.2	0.8	0.6	0
60	3.1	0.8	1.1	1.1	1.5	1.6	0.8	1.9	0.6	4.2
65	1.1	1.1	0.7	0.2	0.2	0.8	0.2	0.8	0	4.2
70	1.1	0.8	0.7	0	0	0.6	0.4	0	0	4.2
75	0.8	0.5	0.4	0.5	0	0.6	0.4	0	0	0
80	1.9	1.1	0	0.2	0	0.7	0	0.4	0.6	0
85	0.4	0	0.2	0	0.2	0	0.2	0.8	0	0
90	0.8	0.3	0	0	0	0.3	0	0	0	0
95	1.5	0	0	0	0	0.4	0	0	0	0

the case. Few severely defoliated trees were flowering, this trend being more marked in the upper crown than in the lower parts.

Coning, acorns and mast

The degree of fruiting in trees is of interest to wildlife managers and seed producers. There is strong evidence that fruiting can occur as a response to stress (Bernier *et al.*, 1989). Heavy fruiting is important since it can precede changes to crown form (Lüscher, 1990) or even significant shoot death in the following year (Gross, 1975; Gross and Harden, 1968; Skelly *et al.*, 1987). Coning was more frequent in Sitka spruce than in Norway spruce and was particularly common in Scots pine (Table 16). However, as the frequency of coning has not been assessed before, it is not known whether coning was more common than usual.

The amounts of acorns and mast in oak and beech were probably underestimated. Trees were assessed in late summer and, in some stands, the fruits would have been too small to have been seen from the ground. Approximately 40% of the trees were fruiting. Anecdotal accounts indicate that the quality of acorns was very high in 1989 but that much of the beech mast was of poor quality, with seed supplies having to be imported from the Netherlands. There was no evidence that fruiting trees had thinner crowns, as has been reported for beech in West Germany (Gärtner, 1988).

Table 16. Percentages of trees with a given level of fruiting. For spruce, only fresh cones were included. In Scots pine, only unopened second year cones were included.

	Frequency			
	None	*Scarce*	*Common*	*Abundant*
Sitka spruce	69	20	8	3
Norway spruce	90	8	2	0
Scots pine	17	38	30	15
Oak	58	24	13	5
Beech	59	29	9	3

Secondary shoots in spruce

Considerable problems were experienced with the assessment of this new index. However, it is an important parameter as it indicates the extent to which trees have recovered following defoliation and also how successful a tree is in replacing foliage lost through normal needle-shedding (Gruber, 1987; Lesinski and Westman, 1987; Lesinski and Landmann, 1988; Rehfuess and Rehfuess, 1988; Lesinski, 1989; Rehfuess, 1989). Both the presence of secondary shoots and their location on individual branches was noted, but the observer checks indicated that the level of consistency amongst the surveyors was poor. Consequently, the results have not been tabulated, although some broad trends can be determined from the data. Forty per cent of Norway spruce and 45% of Sitka spruce had secondary shoots present. Generally, the frequency of secondary shoots increased with decreasing levels of crown density.

The presence and distribution of secondary shoots is a particularly useful index for describing the condition of the crown (Lesinski, 1989) and will be pursued in more detail now that the problems of assessment have been identified.

Epicormic branches on oak

Epicormic branches form on both the main stem and the branches of oak. They tend to be more common on branches, frequently as a result of the pruning of stem epicormics. Their function is not entirely certain, but their abundance is at least partly controlled by the amount of light penetrating through the canopy. They may therefore be helpful in the assessment of tree condition.

Only 1% of the trees had no branch epicormics and on 66% epicormics were common or abundant. Fifteen per cent of the trees had no stem epicormics and they were common or abundant on only 22%.

There was some evidence of a link between the presence of epicormics on the stem and crown density. The highest proportions of trees without stem epicormics present had 10 – 20% reduction in crown density. Branch epicormics occurred more frequently in the trees with the densest crowns than in trees with thinner crowns.

Table 17. Percentages of beech with leaf rolling in the crown, 1987-1989. Extent classes: 0: none; 1: leaves on a few shoots in the upper crown; 2: leaves on a few shoots elsewhere; 3: half of upper crown affected; 4: half of shoots throughout crown affected; 5: most shoots in upper crown affected; 6: most shoots throughout crown affected; 7: virtually all leaves affected.

Degree of leaf rolling	*Extent* 0	1	2	3	4	5	6	7
None	50	0	0	0	0	0	0	0
Slight	0	14	1	12	3	6	5	0
Medium	0	2	0	3	0	3	1	0
Severe	0	0	0	0	0	0	0	0

Leaf-rolling in beech

In 1988, a marked spatial pattern was identified in the extent of leaf-rolling in beech. The cause remains unknown, but it is possible that it is related to water stress (Skelly *et al.*, 1987). Both the degree of rolling and its extent within the crown were recorded. The assessments of the extent of rolling were changed in 1989 as a result of difficulties reported by surveyors and are now more detailed. The results (Table 17) indicate that at least some degree of rolling was present on half of the trees. In about half of the affected trees, rolling was restricted to the upper crown and in 29% of cases only involved a few of the uppermost shoots. This is similar to the distribution of leaf-rolling in sugar maple (*Acer saccharum* Marsh.) (Bernier *et al.*, 1989) and it seems that rolling starts in the tops of crowns and then proceeds downwards. This would be consistent with a water-related stress. In 13% of the cases, leaves throughout the crown were affected. The degree of rolling was mostly fairly light, with 78% of trees being scored in the lightest rolling category. There was no indication that the frequency of rolling was greater on trees showing yellowing and the two indices are not correlated (Table 17). Rolling was more extensive on trees with thinner crowns, as has been reported in some West German beech stands (Gärtner, 1988), but the significance of this is not known.

Premature leaf loss in beech

As in 1988, the extent of green leaf fall below beech was recorded. Green leaves on the ground were infrequent under 15% of trees and common under 8%. These levels are similar to 1988.

Presence of insects and fungal pathogens

The presence of insect and fungal damage was recorded in all species, but there was some confusion for spruce over the inclusion of *E. abietinum* damage. Damage by this insect occurs early in the year. The needles of Sitka spruce turn brown and eventually drop. By July/August, when the assessments are undertaken, the brown needles have usually fallen (although they were recorded at some sites in the 1988 assessment). Consequently, there is little evidence that any needle loss was caused by *E. abietinum*, although the characteristic pattern of defoliation usually enables an accurate diagnosis to be made. The foliage of Norway spruce is more resilient although severe infestations result in the same characteristic pattern of defoliation as in Sitka spruce. Data for insect damage on the two spruce species in 1989 have been discounted and the position will be clarified with surveyors for the 1990 assessment.

In Scots pine, some degree of insect attack was noted in 26% of the trees (Table 18). In the majority (71%) of these cases, insect damage was rare, involving a small number of needles on a few shoots in the upper crown or small numbers of shoots. A variety of insects were recorded as having caused the damage, the most common being *Tomicus piniperda* L. (Coleoptera), which damages shoots in the crown. Other species recorded included *Bupalus*

Table 18. **(a)** Percentage of Scots pine with insect damage to foliage, 1989. The frequency scores refer to the number of needles affected.

	Frequency *None*	*Rare*	*Infrequent*	*Common*	*Abundant*
Percentage	74	19	5	2	0

(b) Insect damage in oak and beech. The percentage of trees with a given percentage of the leaves affected by insects is given.

	Percentage of leaves affected *0*	*5-10*	*11-20*	*21-30*	*31-40*	*41-50*	*51-60*	*61-70*	*71-80*	*81-90*	*91-100*
Oak	30	35	12	7	5	3	2	2	2	2	0
Beech	32	26	10	9	5	5	5	4	3	1	0

Table 19. **(a)** Percentages of conifers with mechanical damage to crown, 1989. 0: no damage; 1: abrasion of peripheral shoots; 2: broken shoots or branches; 3: prevailing wind effect (lop-sided crown); 4: felling damage (broken shoots or branches); 5: other.

	Type *0*	*1*	*2*	*3*	*4*	*5*
Sitka spruce	86	9	3	0	0	2
Norway spruce	88	10	2	0	0	0
Scots pine	78	12	6	1	2	1

(b) Percentages of broadleaves with specific types of mechanical and other damage in the crown. 0: none; 1: wind or snow damage; 2: prevailing wind effect; 3: felling damage; 4: non-mechanical damage; 5: other.

	Type *0*	*1*	*2*	*3*	*4*	*5*
Oak	62	28	4	4	0	2
Beech	83	8	1	1	1	5

piniaria L. (Lepidoptera), *Neodiprion sertifer* (Geoffrey in Fourcroy) (Hymenoptera) and *Rhyacionia buoliana* Denis and Schiffermueller (Lepidoptera). Fungal infections were noted very rarely in Scots pine, although *Brunchorstia pinea* (P. Karsten) Höhnel (the pycnidial state of *Ascocalyx abietina* (Lagerberg) Schlaepfer-Bernard) and *Peridermium pini* (Pers.) Lev. were both identified, the former more commonly.

In oak and beech, estimates were made of the proportion of leaves with bits eaten out of them. Spangling, galling and other types of damage were not included and the figures are therefore likely to underestimate the proportion of leaves with insect damage. In oak, 70% of crowns were recorded with damage, a substantially higher figure than 1987 or 1988 (Table 18). Forty-nine per cent of the affected trees had very light damage, involving 10% or less of the foliage. In beech, damage was noted on 68% of trees, a slightly higher figure than in either 1987 or 1988. In 39% of cases, damage involved 10% or less of the foliage.

Although the incidence of insect damage to oak and beech appears to be high, there is little evidence that normal levels of insect attack affect growth (Crawley and Akhteruzzaman, 1988) and experiments have shown no effects of defoliation of up to a third of the crown of oaks (Hilton *et al.*, 1987). Most studies of insect defoliation place the absolute amount of leaf area lost at between 3% and 17%, with a mean of about 9% (Landsberg and Ohmart, 1989). The figures collected in Britain refer to the proportion of foliage showing insect damage and are therefore not directly comparable, but reference to the crown density figures in relation to insect damage suggests that the figures for Britain are mostly within the range given by Landsberg and Ohmart (1989).

Mechanical damage to crowns

The extent of mechanical damage within the crowns was noted (Table 19). This was a new index, introduced to take into account the severe wind damage that was recorded on many broadleaves in 1988. Relatively few (less than 25%) conifers showed signs of mechanical damage, with the most common form being abrasion of peripheral shoots. The greatest amount of mechanical damage was noted in Scots pine.

Mechanical damage was far more common in oak than in beech and in 28% of oak, damage by wind or snow was noted. Given the distribution of the plots, wind damage is the more likely. Damage caused by felling operations was more common in beech and oak than in Sitka or Norway spruce.

Stem and butt damage

Another new index added in 1989 was the assessment of stem and butt damage. Damage to either area may have an effect on the overall condition of the trees (Shigo, 1985) and although a direct link has not been demonstrated, there is some evidence for an association between butt condition and the discoloration of foliage of Norway spruce (Innes, 1989). While the same classification was used for the three conifer species, separate classifications were developed for the two broadleaved species.

Stem damage was very rare in Sitka spruce, being recorded on only 3% of trees (Table 20). It was more common on Norway spruce, although no agent was identified as being particularly important. In the case of Scots pine, damage was recorded in 11% of trees. The most important cause of stem damage was classified as 'other' which, in the majority of cases, was caused by grey squirrels (*Sciurus carolinensis* L.).

Butt damage was particularly frequent in Norway spruce, with extraction damage being the most common cause (9% of trees, 47% of cases of damage). The greater frequency of extraction damage on Norway spruce than on Sitka spruce can be related to its greater susceptibility to damage and a number of current and past silvicultural practices, including the nature of the thinning regimes and stocking densities. In Scots pine, extraction damage was the only type of butt damage reported.

The stems of the majority (95%) of oak were free of damage, as were the majority (89%) of butts. The most common form of butt damage, usually involving skinning, was caused by timber extraction operations. Damage was much more frequent in beech, with 39% of stems and 63% of butts showing one or more forms of damage. Sixteen per cent of the stems and butts had the felted beech coccus (*Cryptococcus fagisuga* Lind.; Hemiptera) present and a further 5% had evidence of past attack, as indicated by the presence of dimples on the bark. Exposed xylem tissue was present on 12% of the beech butts.

Relationships among the indices

The relationships between the variables are presented as correlation matrices in Table 21. The correlations are based on site means for each variable; no attempt has been made to examine the correlations among individual trees. The matrices provide a clear indication of the variables that are related to each other. Although significance levels have been set at $p = 0.01$ and $p = 0.001$, care should be taken when interpreting the correlations as extreme values appear to exert an undue influence on the correlations (Innes and Boswell, 1989). When interpreting the correlations, it is important to remember that the crown density indices have low values for dense crowns and high values for thin crowns.

In Sitka spruce, two groups of correlations can be recognised. The first is among variables related to crown density, needle retention and shoot death, the second between the discoloration indices. Although significant at $p < 0.001$, none of the r values in the crown density group exceed 0.49, indicating that the correlations are relatively weak. A very high correlation was obtained between the browning of older needles and overall crown discoloration. Coning and browning of current needles appear to be independent of all the other variables.

Norway spruce shows a rather different pattern of correlations. Most of the variables are correlated with crown density. The correlations are all positive, indicating increases in the other

Table 20. (a) Percentages of trees with different types of stem (>1.3 m above the ground) or butt (<1.3 m above the ground) damage. For conifers, 0: none; 1: dead area with bark still present; 2: area of exposed xylem (excluding type 7); 3: resin flow from cracks or holes; 4: swelling; 5: crack at least 5 times longer than wide; 6: fungal fruiting body; 7: extraction damage; 8: insect activity (e.g. resin tubes); 9: other. Old, healed damage was not included.

Conifers	*Type* *0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Stem										
Sitka spruce	97	0	0	2	0	0	0	1	0	0
Norway spruce	94	0	1	1	0	1	0	2	0	1
Scots pine	89	0	0	1	0	0	0	1	0	9
Butt										
Sitka spruce	91	0	0	3	0	1	0	3	0	2
Norway spruce	81	0	2	3	1	2	0	9	0	2
Scots pine	96	0	0	0	0	0	0	4	0	0

(b) Percentage of oak with specific types of stem and butt damage, 1989. 0: none; 1: dead area with bark still present; 2: area of exposed xylem; 3: swelling; 4: crack; 5: fungal fruiting body; 6: extraction damage; 7: vandalism (excluding forestry operations); 8: pruning wounds; 9: other.

Oak	*Type* *0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Stem	95	1	1	0	1	0	1	0	0	1
Butt	89	1	2	1	2	0	4	0	0	1

(c) Percentage of beech with specific types of stem and butt damage, 1989. 0: none; 1: dead area with bark still present; 2: area of exposed xylem; 3: active beech coccus; 4: past beech coccus; 5: 3 and 4 combined; 6: tarry spots on bark; 7: swelling; 8: crack; 9: fungal fruiting body; 10: extraction damage; 11: vandalism; 12: pruning wounds; 13: other.

Beech	*Type* *0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Stem	61	1	4	14	5	2	0	1	6	0	2	1	1	2
Butt	37	2	12	12	5	4	0	1	6	1	5	3	0	12

indices with decreasing density. The extent of shoot death and crown density has a high r value (0.72), suggesting a link between the two (the relationship is much weaker for Sitka spruce). This is further indication of the importance of *E. abietinum* infestation which, while not killing shoots, had a major impact on the crown densities of many Sitka spruce in 1989. In Norway spruce, it appears that reductions in crown density were brought about mainly by shoot deaths, the results presented earlier indicating that these were spread throughout the crown. As with Sitka spruce, the browning of older needles appears to be the main determinant of overall crown discoloration. Coning is again independent of all the other variables.

Fewer significant correlations existed among the Scots pine variables. Crown density was strongly correlated with the extent of shoot death in the crown ($r = 0.77$) and with the mean needle retention ($r = -0.52$). It was not correlated with any of the discoloration variables. Yellowing of older needles had the greatest effect on overall crown discoloration, but the three other discoloration indices also contributed to the overall scores. Coning was correlated with

Table 21. Correlation between the response variables for each species, 1989.

Sitka spruce

cd	1.00												
sde	0.38	1.00											
cone	0.22	0.33	1.00										
ptlt7	0.49	0.45	−0.16	1.00									
bcur	0.24	0.08	0.22	−0.09	1.00								
bold	0.14	0.01	−0.05	0.11	0.05	1.00							
ycur	0.15	0.24	−0.09	0.22	−0.03	−0.05	1.00						
yold	0.12	0.33	0.05	0.17	0.10	−0.07	0.67	1.00					
tdisc	0.17	0.18	−0.06	0.22	0.10	0.80	0.48	0.44	1.00				
cd>20	0.80	0.39	0.27	0.36	0.12	0.14	0.11	0.08	0.16	1.00			
cd>50	0.91	0.34	0.18	0.47	0.30	0.12	0.19	0.17	0.17	0.52	1.00		
cd>75	0.74	−0.04	−0.04	0.29	0.22	0.15	0.05	0.01	0.12	0.31	0.82	1.00	
sdilc	0.34	0.95	0.28	0.41	0.10	0.12	0.20	0.32	0.26	0.38	0.26	−0.07	1.00
	cd	sde	cone	ptlt7	bcur	bold	ycur	yold	tdisc	cd>20	cd>50	cd>75	sdilc

Norway spruce

cd	1.00												
sde	0.72	1.00											
cone	0.10	0.18	1.00										
ptlt7	0.53	0.50	−0.09	1.00									
bcur	0.16	0.14	−0.03	0.25	1.00								
bold	0.31	0.10	−0.06	0.17	0.48	1.00							
ycur	0.32	0.24	−0.06	0.02	−0.05	0.09	1.00						
yold	0.30	0.17	−0.06	0.07	−0.09	0.23	0.41	1.00					
tdisc	0.36	0.16	−0.09	0.21	0.51	0.94	0.31	0.39	1.00				
cd>20	0.92	0.63	0.10	0.50	0.15	0.28	0.14	0.11	0.27	1.00			
cd>50	0.76	0.58	0.07	0.39	0.13	0.21	0.51	0.43	0.33	0.49	1.00		
cd>75	0.46	0.31	0.08	0.09	−0.01	0.14	0.68	0.61	0.33	0.21	0.65	1.00	
sdilc	0.64	0.96	0.10	0.49	0.15	0.14	0.17	0.11	0.18	0.57	0.49	0.22	1.00
	cd	sde	cone	ptlt7	bcur	bold	ycur	yold	tdisc	cd>20	cd>50	cd>75	sdilc

Scots pine

cd	1.00														
sde	0.77	1.00													
cone	−0.20	−0.09	1.00												
ndlage	−0.52	−0.56	0.35	1.00											
bcur	0.23	0.07	−0.27	−0.20	1.00										
bold	0.10	0.13	0.13	−0.16	0.28	1.00									
ycur	0.13	0.00	−0.05	0.07	0.26	0.13	1.00								
yold	−0.13	−0.18	0.04	0.13	−0.17	−0.01	0.19	1.00							
tdisc	0.17	0.05	−0.08	−0.10	0.36	0.47	0.44	0.63	1.00						
flowrt	0.05	0.04	0.03	0.08	0.02	−0.21	−0.04	0.06	−0.07	1.00					
flowrb	−0.03	0.02	0.12	0.13	0.07	−0.13	0.04	−0.01	−0.04	0.85	1.00				
cd>20	0.80	0.68	−0.08	−0.37	0.12	0.14	0.15	−0.20	0.12	0.25	0.29	1.00			
cd>50	0.91	0.68	−0.28	−0.48	0.25	0.12	0.15	−0.05	0.20	−0.10	−0.23	0.53	1.00		
cd>75	0.70	0.44	−0.34	−0.38	0.39	−0.05	0.03	−0.05	0.15	0.01	−0.18	0.28	0.79	1.00	
sdilc	0.59	0.90	−0.11	−0.44	0.04	0.06	−0.03	−0.24	−0.05	0.08	0.13	0.60	0.47	0.27	1.00
	cd	sde	cone	ndlage	bcur	bold	ycur	yold	tdisc	flowrt	flowrb	cd>20	cd>50	cd>75	sdilc

Oak

	cd	dieback	brown	yellow	tdisc	acorns	insects	fungi	crf	crf>2	cpat>3	bepic	cd>20	cd>50	cd>75
cd	1.00														
dieback	0.63	1.00													
brown	0.15	0.20	1.00												
yellow	−0.29	−0.11	−0.02	1.00											
tdisc	−0.25	−0.01	0.15	0.91	1.00										
acorns	−0.42	−0.52	0.06	0.08	0.05	1.00									
insects	0.15	0.09	−0.03	0.09	0.12	−0.33	1.00								
fungi	0.15	0.24	0.27	0.09	0.34	−0.20	0.26	1.00							
crf	0.53	0.59	0.24	−0.04	0.04	−0.37	0.10	0.29	1.00						
crf>2	0.45	0.58	0.21	0.00	0.05	−0.34	0.04	0.23	0.94	1.00					
cpat>3	0.67	0.62	0.30	−0.28	−0.11	−0.18	0.16	0.41	0.54	0.43	1.00				
bepic	0.33	0.31	0.33	0.07	0.13	−0.31	−0.08	0.08	0.25	0.28	0.12	1.00			
cd>20	0.90	0.50	0.21	−0.41	−0.33	−0.32	0.03	0.18	0.47	0.39	0.60	0.34	1.00		
cd>50	0.70	0.52	−0.02	−0.02	−0.04	−0.30	0.16	0.05	0.39	0.32	0.42	0.18	0.39	1.00	
cd>75	0.33	0.35	−0.02	−0.05	−0.05	−0.11	−0.10	−0.05	0.07	0.00	0.19	0.15	0.15	0.50	1.00

Beech

	cd	leafsz	dieback	rolld	rollf	brown	yellow	tdisc	mast	insect	fungi	pll	cd>20	cd>50	cd>75	cpat>3
cd	1.00															
leafsz	0.40	1.00														
dieback	0.62	0.36	1.00													
rolld	0.23	0.17	0.21	1.00												
rollf	0.37	0.28	0.51	0.85	1.00											
brown	−0.12	0.07	0.14	−0.13	−0.14	1.00										
yellow	−0.20	−0.05	−0.30	0.00	−0.17	−0.02	1.00									
tdisc	−0.06	0.19	0.07	0.05	−0.03	0.74	0.55	1.00								
mast	0.21	0.32	0.42	0.08	0.31	−0.20	−0.26	−0.26	1.00							
insect	0.25	0.16	0.52	−0.11	0.07	0.57	−0.33	0.27	0.12	1.00						
fungi	−0.35	−0.12	−0.10	−0.19	−0.19	0.07	0.28	0.12	0.06	−0.08	1.00					
pll	0.17	0.19	0.63	0.30	0.45	0.49	−0.03	0.55	0.21	0.45	0.18	1.00				
cd>20	0.97	0.41	0.56	0.21	0.34	−0.17	−0.13	−0.06	0.15	0.15	−0.33	0.08	1.00			
cd>50	0.61	0.44	0.59	0.30	0.48	0.07	−0.19	0.13	0.47	0.18	−0.15	0.53	0.50	1.00		
cd>75	0.29	−0.08	0.48	0.22	0.40	0.06	0.01	0.19	0.26	0.27	−0.05	0.55	0.19	0.52	1.00	
cpat>3	0.79	0.35	0.85	0.39	0.57	0.01	−0.23	0.06	0.22	0.40	−0.23	0.53	0.73	0.55	0.43	1.00

mean needle age (suggesting a possible provenance effect), but was rare at sites with a relatively high proportion of very thin-crowned trees and sites with higher levels of insect damage. The latter correlation was relatively weak ($0.01 < p < 0.001$).

Most of the recorded correlations in oak are related to the crown density and crown dieback variables. Crown density and crown dieback were strongly correlated although the proportion of very thin-crowned trees at a site was not correlated with the amount of dieback. Few acorns were recorded at sites with high levels of dieback or with thin-crowned trees. Discoloration was unrelated to crown density. Overall discoloration was determined by the amount of yellowing. Insect damage was not correlated with any of the other variables.

In beech, a number of correlations were identified. Crown density was strongly correlated with crown dieback ($r = 0.62$) and, in contrast to oak, the sites with the worst trees were also characterised by dieback. Insect damage and premature leaf loss were also high in sites with

Table 22. Upper and lower confidence limits (standard deviations) about the mean for the site crown density indices.

	−2 S.D.	−1 S.D.	*1989* Mean	+1 S.D.	+2 S.D.	*1988* Mean	S.D.
Sitka spruce	4.33	16.74	29.16	41.57	53.98	27.96	8.51
Norway spruce	—	9.96	20.45	30.94	41.43	22.86	9.73
Scots pine	3.31	14.03	24.76	35.48	46.2	27.68	10.99
Oak	12.43	20.31	28.2	36.09	43.97	31.59	8.49
Beech	7.54	14.83	22.11	29.39	36.67	25.89	7.12

high levels of dieback. Browning was the main form of discoloration associated with overall discoloration, but yellowing was also important. Browning was associated with premature leaf loss, an association that has not been identified previously.

Recognition of anomalous or unusual records

As in 1988, the data have been examined for potential outliers. For this, it has been assumed that the mean indices are distributed normally. Outliers have been defined as sites with mean crown density scores more than two standard deviations above the mean. The criteria for the recognition of such sites are given for each species in Table 22.

Eleven sites were identified as anomalous: one oak, three Sitka spruce, three Norway spruce and four Scots pine. All these sites have been visited by members of the Forestry Commission's Pathology Branch, who have confirmed the observations made by the surveyors. The oak plot is located on an exposed and dry, rocky slope in north-east Scotland and, given this environment, the crown condition of the trees is not considered to be exceptional. All three Sitka spruce sites were severely defoliated by *E. abietinum*, which accounts for their condition. One of the Norway spruce sites was affected by the syndrome known as 'top-dying' and a second had trees in the immediate vicinity with this problem. The third site was severely waterlogged and was also identified in 1988 as being in exceptionally poor condition. The four Scots pine plots are all located in southern Scotland or northern England. The symptoms present on the trees were similar at all four sites. Some needle loss had been caused by infection by the fungal pathogen *Lophodermium seditiosum* Minter *et al.* Needle loss also occurred as a result of shoot death and crown deformation due to the pine shoot beetle *T. piniperda*, and shoot dieback consistent with infection by *Brunchorstia pinea* and/or *Crumenulopsis sororia* (P. Karsten) Groves was also reported. The latter pathogen appears to be more active on trees predisposed to damage by other stresses (Batko and Pawsey, 1964) and the complex of factors leading to the poor condition of many Scots pine stands in the area remains unknown.

The limits identified in 1989 can be compared with those of 1988 to get some indication of their stability. The improvement in the mean crown density score for all species except Sitka spruce is clear. However, the between-site variation for these species has remained approximately constant. As might be expected, there has been a big increase in the between-site variation of Sitka spruce crown density values. This is consistent with the explanation put forward earlier (Innes and Boswell, 1989) that some Sitka spruce stands improved whereas others, notably those affected by *E. abietinum*, deteriorated. The values can be better compared if the coefficients of variations are calculated (Table 23). In all cases, these increased between 1988 and 1989. Norway spruce has the greatest amount of variation relative to the mean, oak and beech the least. The reasons for these interspecific variations are unknown.

Spatial patterns in crown condition

Indices of crown condition were mapped using the geostatistical techniques developed for the analysis of the 1988 data (Innes and Boswell, 1989). However, before this was done, site bias attributable to age was removed. Crown densities of the two spruce species are related to stand age (Innes and Boswell, 1988, 1989); stand age was also correlated with a number of the other indices of crown condition in the two spruce species (Table 24), although scattergrams illustrating the relationships suggested that many were very poor. Consequently, adjustments for stand age have only been made for the crown density maps of Sitka and Norway spruce. Although significant relationships between age and the extent of shoot death and the amount of yellowing of older needles were identified in Norway spruce, the maps have not been adjusted to take this into account because of the potential loss of important information. Stand age was not significantly ($p < 0.01$) correlated with any of the indices of crown condition for Scots pine, oak or beech.

Maps of crown condition are presented in Figures 7 to 11. Interpolation/extrapolation has only been undertaken over those distances where the analyses have indicated that such a procedure is valid. In many cases, this means that no interpolation was made, in others, interpolations were made over relatively long distances. Where interpolations were unsatisfactory, the centres of the grid squares on the maps have been left blank. Interpolations were only undertaken when the semi-variogram model explained 15% or more of the variance and when model convergence was achieved. This means that the number of blocked-in maps has decreased since 1988, when less rigorous acceptance criteria were used.

Table 23. Coefficients of variation (%) for the crown density indices in 1988 and 1989.

	1988	*1989*
Sitka spruce	30.4	42.6
Norway spruce	42.6	51.5
Scots pine	39.7	43.3
Oak	26.9	28.0
Beech	27.5	32.9

Sitka spruce

There is no clear pattern in the crown density indices of Sitka spruce (Figure 7a). This is consistent with the results for 1987 and 1988. For 1989, a new method of presenting crown density has also been used. This involves calculating

Table 24. Correlations between spruce parameters and stand age.

	Sitka spruce	*Norway spruce*
Crown density	0.45**	0.70**
Shoot death extent	0.42**	0.76**
% trees with shoot death	0.33**	0.69**
Coning	0.31	0.14
% trees with <7 needle years	0.30	0.46**
Browning of current year needles	0.20	0.09
Browning of older needles	−0.11	0.28
Yellowing of current year needles	0.17	0.22
Yellowing of older needles	0.07	0.32*
Overall discoloration	0.01	0.32*
% trees with >20 crown density score	0.35*	0.62**
% trees with >50 crown density score	0.42**	0.56*
% trees with >75 crown density score	0.22	0.35

*: p <0.01; **: p <0.001.

and mapping the proportion of trees at each site at a given level of crown density (Figures 7b and 7c). These provide a more consistent pattern than the mean crown density scores and enable the identification of sites or regions with low or high proportions of thin-crowned trees.

The mean crown density scores indicate that the thinnest trees were mostly located in the west and south-west of the country. The mean values were influenced by the numbers of trees with more than 50% loss in density ($r = 0.906$, $p < 0.001$). Both the Lake District and the south-west showed high scores for this index. A large number of the sites had a high proportion of trees with between 20% and 50% loss in density. The map shows the distribution of sites that appear to be in relatively poor condition. They are primarily located in Scotland and south-west England.

Discoloration was present in some plots, but was mainly restricted to older needles. Browning of older needles was again recorded in central Scotland although it was less widespread than in 1988 (Figure 7d). Yellowing of older needles was present in south-west and north-east England, where it was also recorded in 1988. Younger needles showed very little discoloration and the maps have not been reproduced.

The pattern of needle retention has changed since 1988 (Figure 7e). While the south-west remains the area with the lowest retention, other sites in south-east England and central Scotland now also show low retention values. This is related to the *E. abietinum* infestations.

Shoot death was recorded in more detail than in previous years, enabling extra indices to be mapped. The distribution of trees with shoot death in the live crown changed between 1988 and 1989 (Figure 7f). In 1989, the greatest numbers occurred in south-west England and in an area extending from Lancashire to central Scotland. In most cases, the frequency of shoot death on individual trees was fairly low; the frequency within trees is similar to the proportion of trees affected at a site, with sites with a high proportion of trees with shoot death generally having trees with a higher frequency of shoot death.

Coning was largely restricted to sites in Scotland and has not been mapped.

Norway spruce

The crown density indices of Norway spruce are generally lower in northern Britain than in the southern half of the country, indicating that thinner crowns are more common towards the north (Figure 8a). Other than this trend, no clear pattern is apparent. Very few sites had any trees with more than 50% loss of density; this map is of little value in the interpretation of the results and has therefore not been presented. The map showing the proportion of sites with trees with more than 20% loss of density (Figure 8b) is more useful, indicating that the majority of sites with a high proportion of trees in this category are in the Scottish Highlands. The differences between this map and the map for mean crown density are interesting; they indicate that the within-site variation increases northwards.

The greatest amount of needle discoloration was recorded in Scotland. Current browning of needles was very rare and the map has not been reproduced. Yellowing of current needles was more frequent, being reported at a number of coastal sites. Browning of older needles occurred mainly in Scotland and was particularly apparent at the northernmost site (Figure 8c). Infestation by *E. abietinum* appears to have been responsible. No obvious pattern was present in the distribution of sites with yellowing of older needles and this map has not been presented.

In accordance with the increases in crown density, the number of sites with a high proportion of trees retaining less than seven years of needles has decreased (Figure 8d). The distribution is again similar to that for 1988, with the south-west and west having the highest proportion of trees with low needle retention values.

Shoot death in individual trees was present at most sites (Figure 8e), although the north-west appears to have a higher than average incidence. However, the extent of shoot death was not particularly great at any site.

As with Sitka spruce, coning was very rare and the map has not been reproduced.

Scots pine

The pattern of mean crown density scores was similar to that in 1988 (Figure 9a), although the areas indicating the presence of relatively dense trees have increased, in line with the general increase in crown density recorded by the overall statistics. Central and south Scotland was again identified as the area with the thinnest crowns and this clearly warrants further investigation. The pattern is influenced by a number of sites with trees with more than 50% loss of density (Figure 9b). The worst sites have a substantial proportion (more than 40%) of trees with more than 75% reduction in foliage. Most sites have trees with between 20% and 50% reduction in density (Figure 9c); the south Scottish sites stand out as having most trees with more than 20% reduction in density and a substantial proportion with more than 50% or 75% loss of density.

Sites with discoloration were scattered over the country and no pattern was readily apparent. Browning of current needles was mainly restricted to west Scotland and the south-east of England. No pattern was evident in the distribution of sites with yellowing of current needles. Browning of older needles occurred in southern Scotland and central and southern England (Figure 9d). The pattern may be significant and is discussed in detail below. Although yellowing of older needles was evident, no clear pattern can be distinguished.

Insect damage was rare over most of England and Wales, but was recorded in the south-east and in central and north Scotland. The greatest incidence occurred in west Scotland, where infestation by *Tomicus piniperda* was identified as the main insect problem. In the south-east of England, *T. piniperda* was also identified as the main insect causing the damage; increased damage by this insect was predicted for areas suffering damage from the 1987 storm (Winter, 1988).

Mean needle retention can be calculated for Scots pine as accurate counts can be made of the needle years. The pattern found in 1989 was similar to that of 1988 although there were fewer sites in 1989 with a mean retention of less than 2 years (Figure 9e). The lowest retention was recorded in central and south Scotland, at sites where insect and fungal damage has been reported for several years.

Flowering increased towards the north of the country and there was further indication of the rather complex pattern identified in 1988.

Most of the sites in central and south Scotland have a high proportion of trees with shoot death in the live crown. Elsewhere, it is much less frequent, with the smallest proportion of affected trees being reported from central England. As expected, the extent of shoot death shows a similar pattern to the proportion of trees affected and the two indices are highly correlated (Table 21).

Coning was abundant in 1989 and occurred in most parts of the country. It was particularly frequent in east Scotland and throughout much of central and western England.

Oak

The pattern of mean crown density scores for oak in 1989 was remarkably similar to that for 1988 (Figure 10a). Generally, sites in England and Wales had denser crowns than sites in Scotland. This is shown in both the map of mean density scores and the map of the proportion of trees with more than 20% reduction in density (Figure 10b). As in previous years, the densest trees were located in eastern England, East Anglia excepted.

Crown dieback was present over much of the country, being more common in Wales and Scotland than over the remainder of the country (Figure 10c).

Foliage discoloration was most apparent in central Scotland and northern England. An area of severe discoloration in Yorkshire has not been recorded in previous years. The discoloration mainly took the form of yellowing and a number of trees were scored as showing a yellowish-green colour. In other cases, only the leaf margins were yellow.

Crown form, which is a reflection of recent growth trends, has a similar pattern to the mean crown density scores. Crown form is assessed on a non-linear scale with trees in good condition being scored as 0 and the worst trees as 3. Consequently, maps showing the proportions of trees at each site with a given level of crown form are of interest. The distribution of the proportion of trees at each site with a score of 2 or more (Figure 10d) indicates that there are isolated pockets of poor trees in England and Wales with the majority of trees falling into this class being located in Scotland.

Crown pattern was also examined, with the proportion of trees with a score greater than or equal to 3 being used as a site index (Figure 10e). The pattern bears little resemblance to the crown density scores, but shows some similarity with the dieback scores. Using this form of assessment, the worst trees are located in central Scotland, with trees in the north and west of Scotland appearing to be in better condition. No clear pattern is evident in England and Wales.

Acorn production may have been underestimated due to the early date of the survey. The majority of production was in central and southern England, with production being relatively rare at the Scottish sites.

Some pattern is evident in the incidence of insect damage (Figure 10f). The incidence is higher in central Scotland, central England and north and central Wales, with the amount of damage being less in the south and south-east.

Beech

The pattern for mean crown density in beech is similar to that for 1988, although the general increase in crown density that was recorded during 1989 is reflected in the absence of sites with relatively thin crowns along the south coast of England and in west Wales (Figure 11a). There has also been some improvement in central Scotland. As in previous years, the areas with the densest crowns are northern and central England. The sites with the highest proportion of trees with more than 20% reduction in density are mostly in Scotland (Figure 11b), although there is an area extending from the Wash through to Cornwall where there is also a high incidence of relatively thin crowned trees.

Crown dieback was more frequent in Scotland than in the rest of the country, being particularly prevalent in the Central Valley of Scotland (Figure 11c).

Total discoloration reflected the incidence of both browning and yellowing. Yellowing was most frequent in north England and in an area extending from Hampshire to Lincolnshire. Browning was more frequent in northern England and eastern and northern Scotland. Both distributions are broadly similar to those found in 1988.

The area of marked rolling identified in the south-east of England in 1988 was not repeated in 1989. Rolling was, however, more frequent in the south-east than in the rest of England and Wales. A second area where rolling was frequent was identified in central Scotland in 1989. The distribution is surprising as leaf-rolling in broadleaves is normally associated with drought (Skelly *et al.*, 1987; Bernier and Brazeau, 1988), yet no relationship was identified between the pattern of soil moisture deficits in Britain at the end of July 1989 and the distribution of leaf-rolling. However, the general increase in incidence may be related to the dry conditions that prevailed during much of the 1989 growing season.

Although problems of reproducibility mean that crown pattern scores cannot be properly tabulated, the two most severe categories can normally be confidently separated from the two least severe ones. This has been done using the proportion of trees at a site with a score of 2 or 3 (Figure 11d). The distribution clearly indicates that sites in the north of the country are worse than those in the south. Within the south, there is little evidence of a trend in the proportion of trees in categories 2 and 3, although there appears to be more trees in this grouping in the west than in the east. This corresponds with the findings of a study of twig growth of beech in the south of England (Lonsdale *et al.*, 1989).

A broadly similar pattern was obtained by plotting the proportion of trees with a crown pattern score of 3 or more at each site. Trees in the north of the country again appear to be worse, although there are also a number of sites in the south of England where condition appears to be poorer than elsewhere.

Very little premature leaf loss was recorded in southern England and Wales. It was infrequent in northern England and in Scotland.

Insect damage was recorded more frequently in north Wales and Scotland than in England. Little damage was recorded over most of southern England. The distribution is markedly different to the pattern of insect damage in oak, but the reasons for this are unknown.

Environmental factors affecting crown condition

In the past, emphasis has been placed on the statistical relationships between a variety of environmental parameters and different measures of crown condition. This approach suffers from a number of drawbacks, mainly related to the accuracy of the explanatory variable values and the extremely complex nature of the inter-relationships between them. In particular, there is some doubt whether deposition levels of pollutants to forests can be inferred from the type of models that are currently available because of the steep deposition gradients that are apparent at forest edges (Bleuten *et al.*, 1987; Hasselrot and Grennfelt, 1987; Draaijers *et al.*, 1988; Beier and Gundersen, 1989) and the local variations that occur in deposition as a result of altitude and other factors (Hicks and Meyers, 1988; Lindberg *et al.*, 1988; Fowler *et al.*, 1989; Unsworth and Wilshaw, 1989). In addition, it is clear that even when measurements are available, they may not be representative of the dose received by the tree (Schulte and Spiteller, 1987; Bringmark, 1989; Nykvist and Skyllberg, 1989).

Ridge regression of data collected in 1987 indicated that the multiple regression coefficients derived from these analyses were highly unstable, throwing doubt on any attempt to use them in a predictive capacity (Innes and Boswell, 1988). In the report for 1988, only correlation coefficients were presented, but these can be very misleading because of the influence of one or two extreme values. Consequently, similar analyses have not been undertaken this year.

The correlation of specific symptoms with spatial patterns of pollution remains an important approach to the problem of forest decline (Loehle, 1988), although it should always be used in conjunction with experimental studies (Skelly, 1989). However, it is clear there are too many assumptions inherent in the existing methods and alternative analytical techniques are being developed.

Discussion

Short-term factors affecting tree condition in 1989

The climatic conditions in 1989 have been unusual and are believed to have affected the results. The mild winter, which was 2.3°C above normal (Morison and Spence, 1989a), resulted in severe outbreaks of *E. abietinum* which caused extensive defoliation of spruce in some areas (Carter, 1989). A number of other insects have benefited from the mild winter and a variety of problems have been reported (Morison and Spence, 1989b). The dry summer resulted in many tree species showing drought symptoms by August and such symptoms were occasionally identified during the assessments. However, forest trees appeared to show far fewer drought symptoms than open-grown trees (Innes *et al.*, 1989).

There are no formal surveys of damage resulting from specific abiotic or biotic agents. However, the Pathology and Entomology Branches of the Forestry Commission collate anecdotal information about the state of trees in Britain. This is supported by visits to a limited number of forests throughout the country. Their findings are included below.

Sitka spruce

Pathological problems in Sitka spruce were insignificant in comparison to the extensive defoliation by *E. abietinum*. The condition of Sitka spruce appears to have been determined by the presence or absence of this aphid. Where no infestation occurred, the condition of the trees improved. Defoliation by aphids resulted in lower crown densities; in some cases, reductions of 50% or more were recorded. In some areas, drought may have caused problems, but Sitka spruce is largely absent from the areas most affected by the 1989 drought and few cases were reported.

Norway spruce

Norway spruce was also affected by *E. abietinum* although to a lesser extent than Sitka spruce. In some areas, the 'top-dying' syndrome was apparent, it is normally more noticeable after mild winters (Diamandis, 1979). It appears to be a complex physiological disorder brought about by a combination of factors, including growth disturbances caused by mild winters, early summer drought and changes in the water availability to the stand.

Scots pine

A number of insect pests were more abundant than usual in Scots pine. Loss of shoots caused by *T. piniperda* was widespread in areas affected by the 1987 storm. The beetles breed in fallen and damaged trees; the adults burrow into the shoots of standing trees giving rise to the characteristic loss of shoots. There were reports of *Schizolachnus pineti* Fabricius (Hemiptera) in some areas, an aphid that causes yellowing of the current foliage.

Sites in central and south Scotland continue to be affected by a combination of the fungi *L. seditiosum* and *B. pinea* and by *T. piniperda*. In 1989, many of the affected trees showed some signs of recovery. The problem appears to be restricted to higher sites (> 100m) and may be related to provenance, but this remains uncertain.

The increase in discoloration of Scots pine is difficult to explain. In some cases, insects or fungal pathogens appear to be the cause. This is the most likely explanation for the discoloration recorded in central and southern Scotland, where similar problems have been reported in the past (Innes and Boswell, 1987, 1989). In central and southern England, these pathogens did not appear to be particularly important, although *T. piniperda* was common in areas affected by the 1987 storm. Drought may be involved, but the absence of browning at sites in eastern Scotland, where drought conditions occurred in 1989, suggests that this is not the main cause of the discoloration. More ozone episodes were recorded in 1989 than in 1988 (Warren Spring Laboratory, personal communication), and it is possible that the increased number of ozone episodes was related to the observed increase in the browning of older needles. However, this possibility cannot be investigated further until the results of the 1989 ozone monitoring programme conducted by Warren Spring for the Department of the Environment are published.

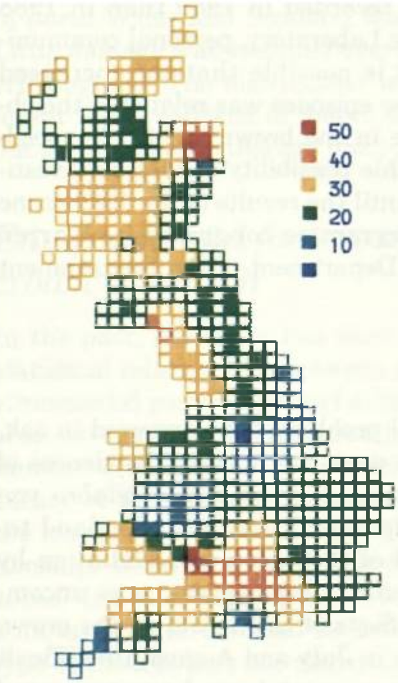
Oak

No pathological problems were reported in oak, although there were a number of incidences of leaf-browning caused by *Phylloxera glabra* von Heyden (Hemiptera) in southern England towards the end of the summer. Defoliation by *Tortrix viridana* L. (Lepidoptera) was uncommon, but the effects of this insect on the crown density of trees in July and August are difficult to distinguish, as most trees have recovered from early defoliation by this time. In the south of England, the improvement in both oak and beech may be partly attributable to the filling in of gaps in the crowns that had been created by the storm of October 1987.

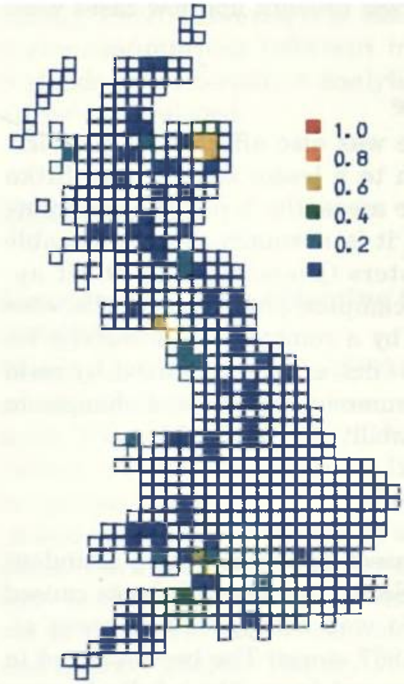
Beech

Minor drought effects were noted in some areas. Infestation by the leaf miner *Rhynchaenus fagi* appeared to be lower than usual in the south, but a reduction in the incidence of this insect was not noted in Scotland. The beech coccus, *C. fagisuga*, was recorded more frequently than in the period 1986–1988; 14% of trees in the monitoring programme were recorded with this problem in 1989.

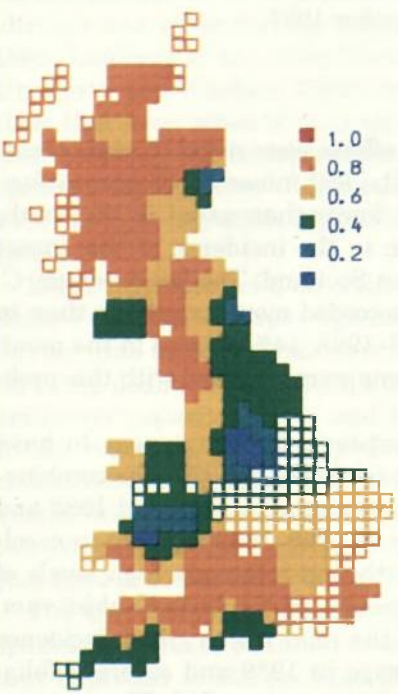
Overall, short-term factors appear to have favoured crown condition in 1989. The combination of two wet summers in 1987 and 1988 and the mild winter of 1988–1989 resulted in excellent shoot growth and relatively high levels of foliage. Many insects, particularly *E. abietinum*, benefited from the mild winter; their incidence was above-average in 1989 and severe defoliation of some trees was recorded. There was a higher number of ozone episodes in 1988 than



a. crown density score (a high score indicates a thin crown).

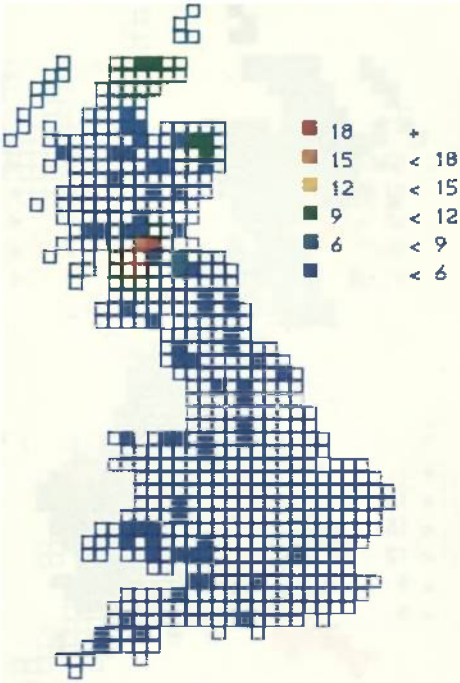


c. The proportion of trees at a site with 50% or more reduction of crown density.

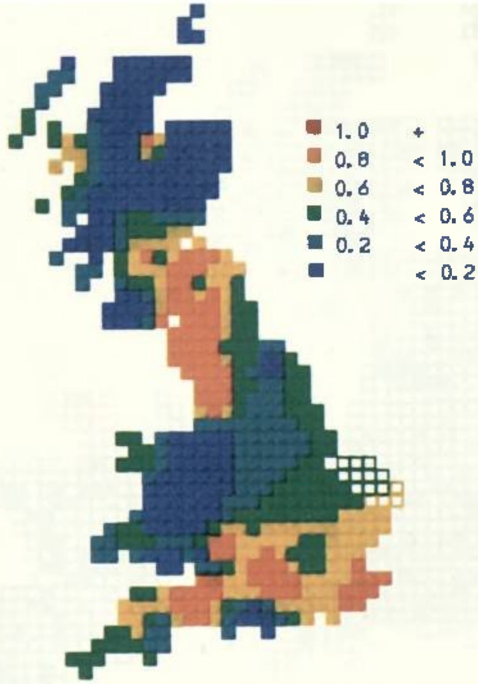


b. The proportion of trees with 20% or more reduction of crown density.

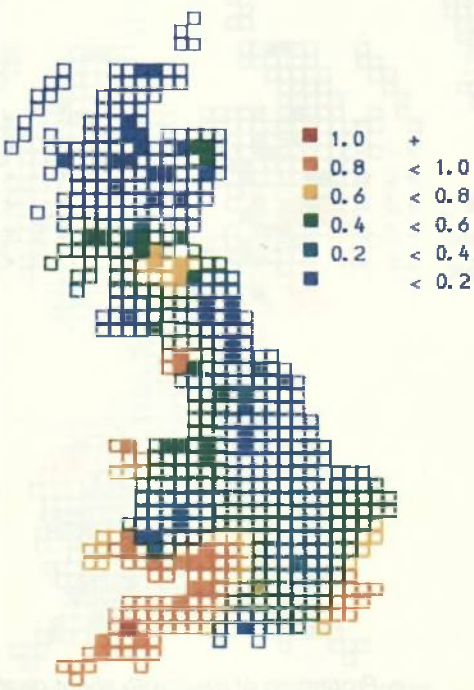
Figure 7. *Maps showing the distribution of various indices of Sitka spruce condition.*



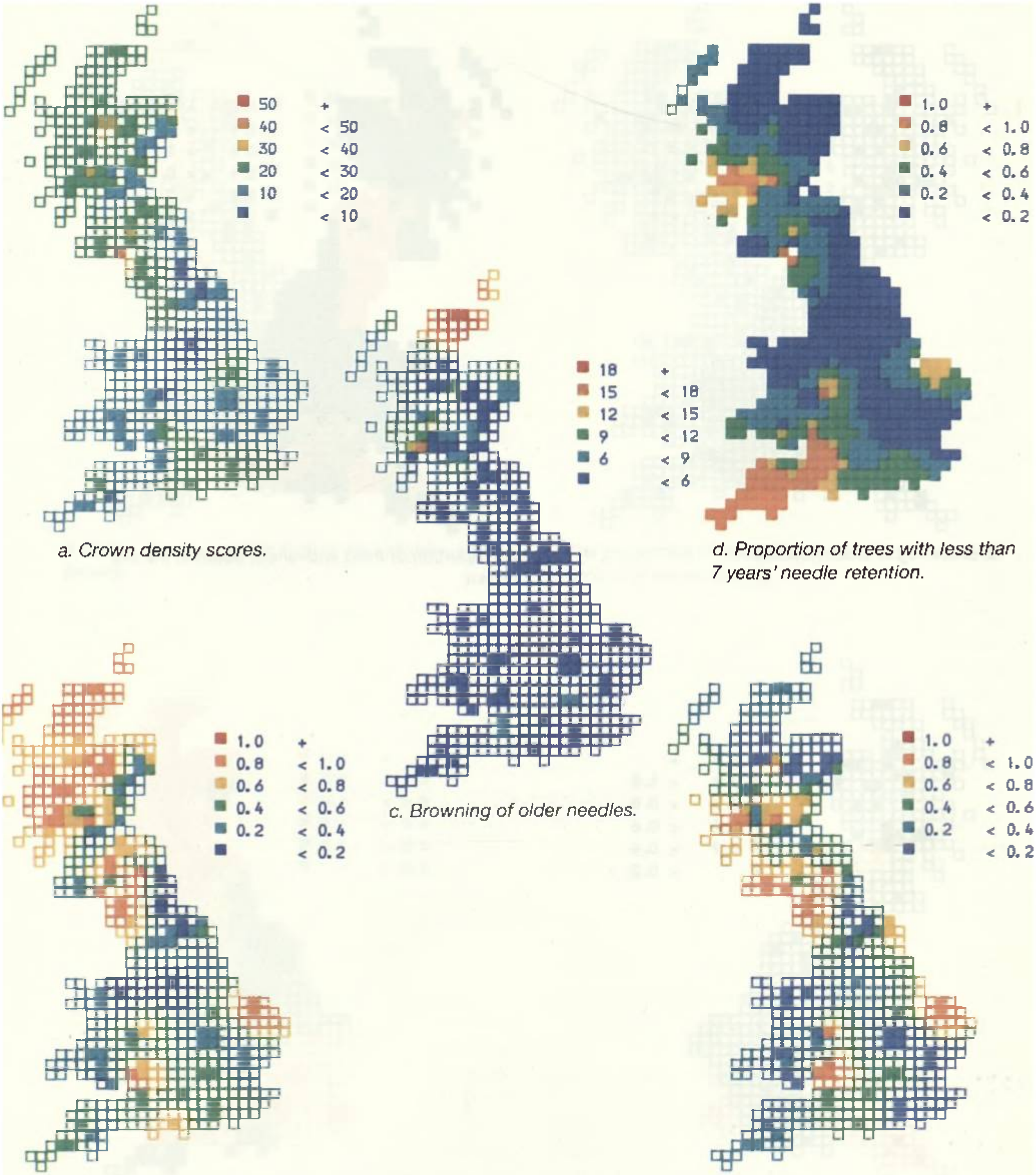
d. Browning of older needles.



f. Proportion of trees with shoot death in the live crown.



e. Proportion of trees with less than 7 years' needle retention.



a. Crown density scores.

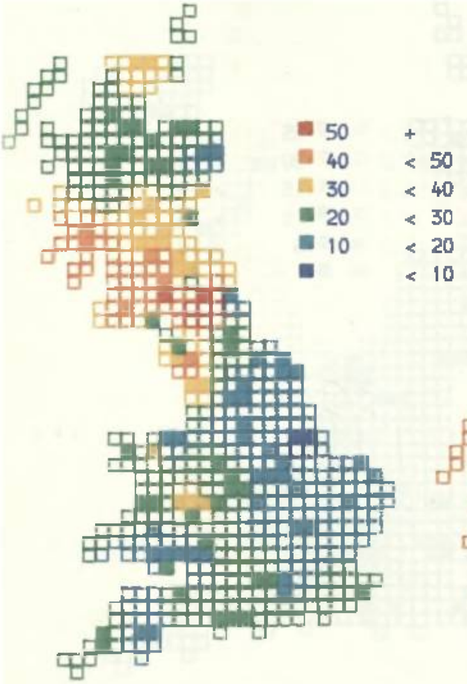
c. Browning of older needles.

d. Proportion of trees with less than 7 years' needle retention.

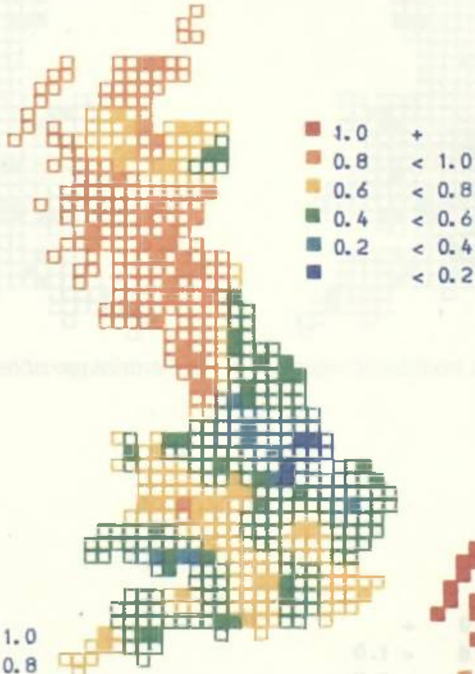
b. Proportion of trees at a site with 20% or more reduction in crown density.

e. Proportion of trees with shoot death in the live crown

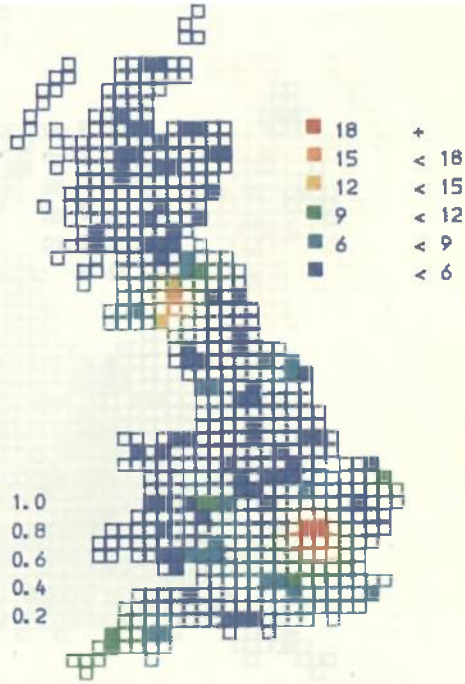
Figure 8. *Maps showing the distribution of various indices of Norway spruce condition.*



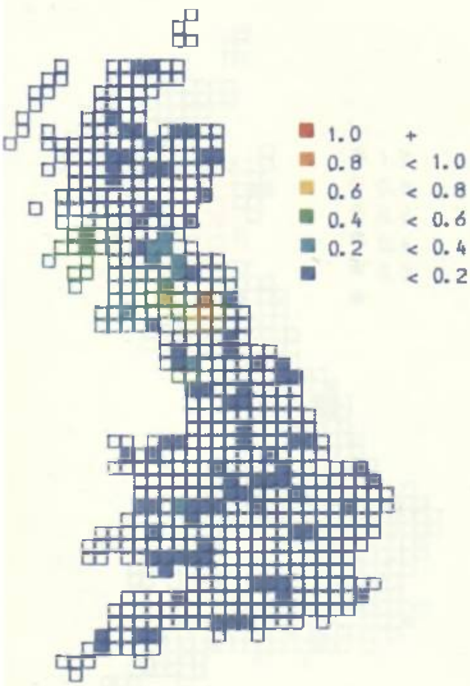
a. *Crown density scores.*



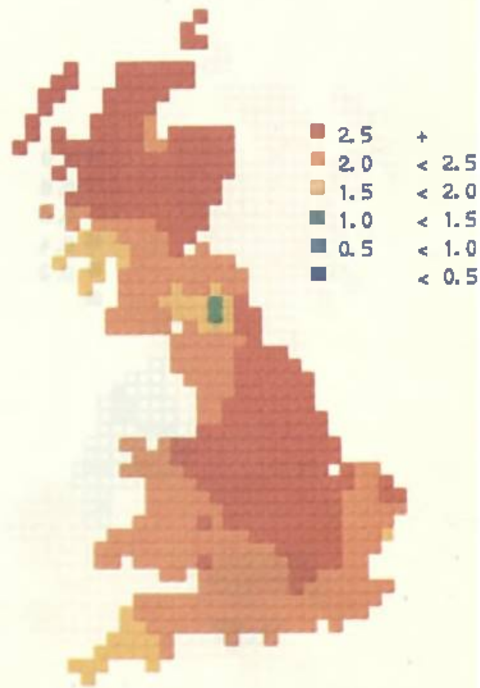
c. *Proportion of trees at a site with 20% or more reduction of crown density.*



d. *Browning of older needles.*

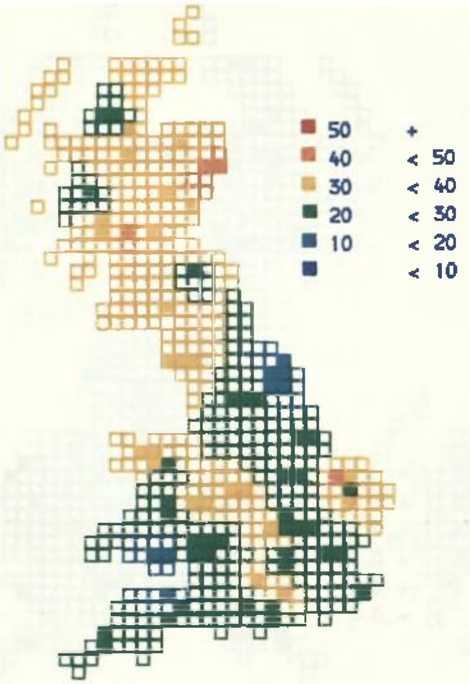


b. *Proportion of trees with 50% or more reduction in crown density.*

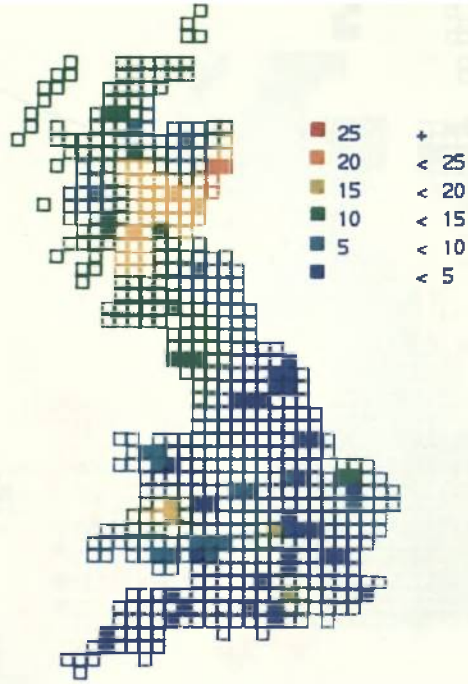


e. *Average needle retention (a high score indicates that needles are retained for a longer time).*

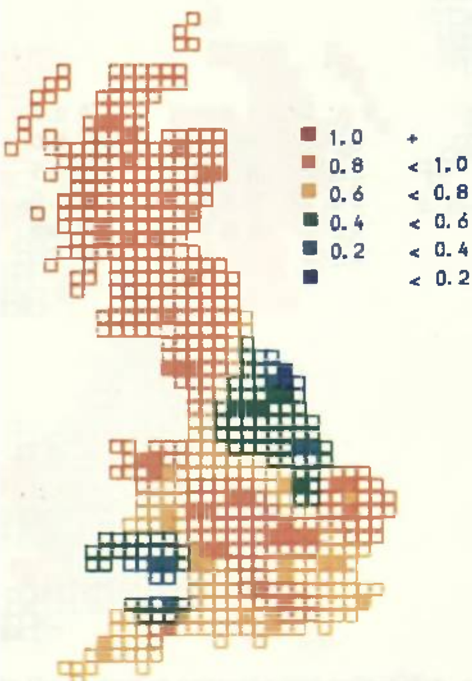
Figure 9. *Maps showing the distribution of various indices of Scots pine condition.*



a. Crown density scores

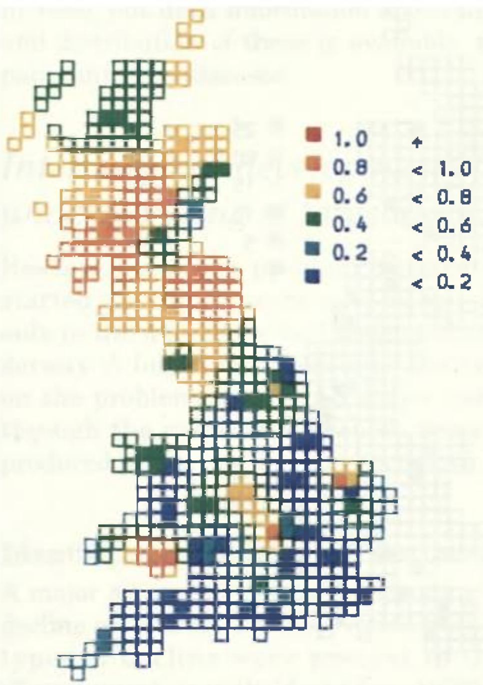


c. Percentage of trees with dieback.

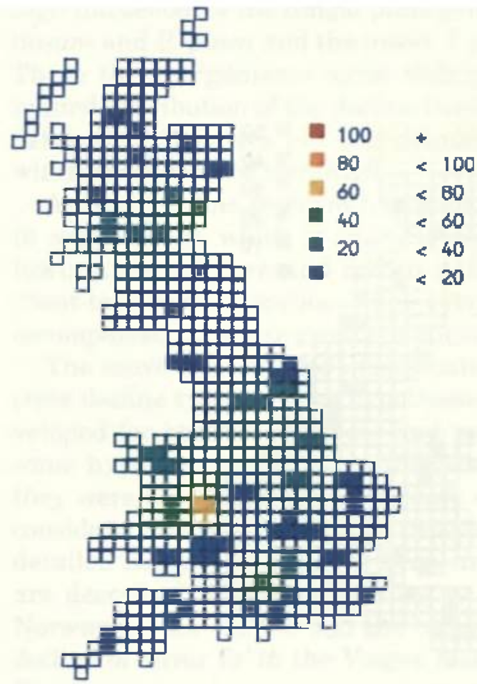


b. Proportion of trees at a site with 20% or more reduction in crown density.

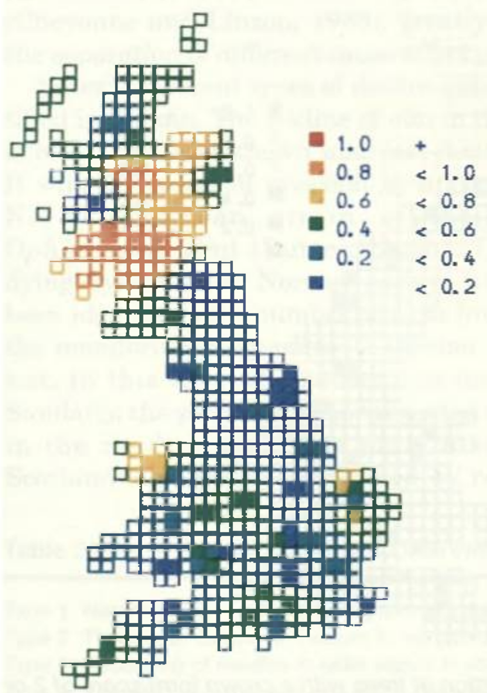
Figure 10. *Maps showing the distribution of various indices of oak condition.*



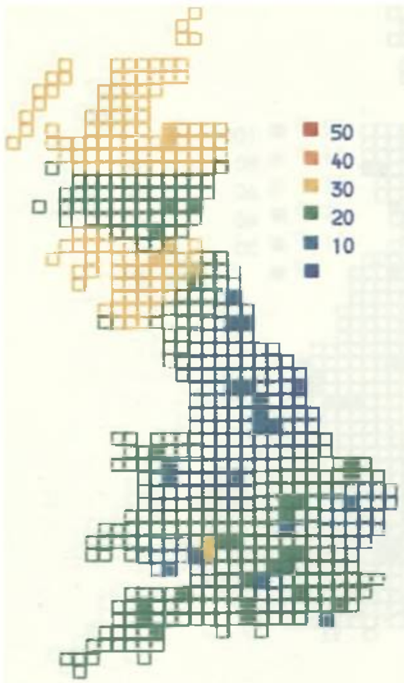
d. Proportion of trees at a site with a crown form score of 2 or more.



f. Average proportion of leaves damaged by insects.

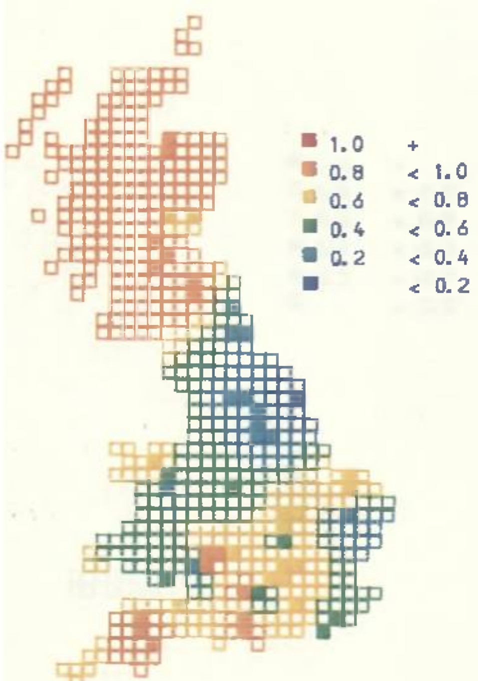


e. Proportion of trees at a site with a crown pattern score of 3 or more.

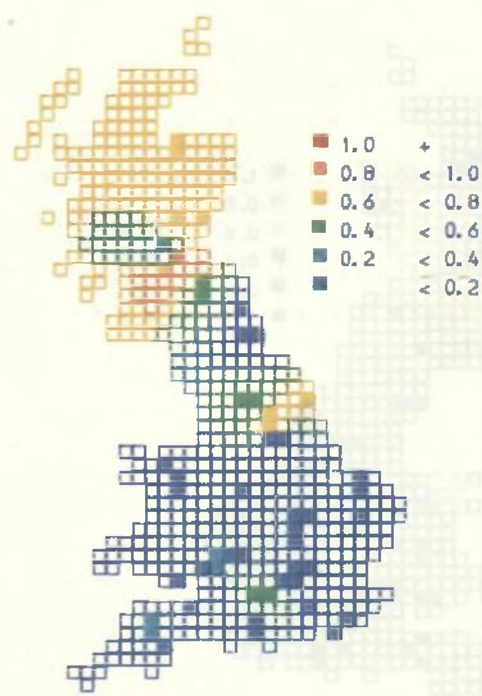


a. Crown density scores.

c. Average dieback score.



b. Proportion of trees with 20% or more reduction in crown density.



d. Proportion of trees with a crown form score of 2 or more.

Figure 11. *Maps showing the distribution of various indices of beech condition.*

in 1989, but until information about the nature and distribution of these is available, their impact cannot be assessed.

International developments in the understanding of forest decline

Research into the problem of forest decline started almost 10 years ago, although it was only in the mid-1980s that most studies got underway. A huge amount of work has been done on the problem, and it is a major task to sift through the numerous research reports being produced by the many groups involved.

Identification of different decline types

A major advance in the understanding of forest decline arose from the observation that different types of decline were present in Germany (Forschungsbeirat Waldschäden, 1986). In particular, five forms of decline were recognised in Norway spruce (Table 25). Similar damage classifications have been conducted in France (Landmann, 1988a) and North America (Chevonne and Linzon, 1988), greatly helping the separation of different cause-effect groups.

Several different types of decline can be identified in Britain. The decline of elm in the 1970s is one of the best-known and best-documented. It was the result of invasion by an aggressive North American strain of the fungus *Ophiostoma ulmi* (Buism.)Nannf. The 'topdying' syndrome in Norway spruce, which has been identified at a number of plots involved in the monitoring programme is another example but, in this case, the causes are uncertain. Similarly, the programme has reported a decline in the condition of Scots pine in southern Scotland which is characterised by relatively high incidences of the fungal pathogens *L. seditiosum* and *B. pinea* and the insect *T. piniperda*. These three organisms occur widely and the limited distribution of the decline therefore indicates that they are not the primary cause, which remains to be identified.

Another decline problem has been identified in south Wales, which is characterised by yellowing, needle loss and crown deformation ('bent-top') in Sitka spruce. These symptoms are accompanied by severe growth reductions.

The move towards the identification of discrete decline types enables hypotheses to be developed for specific problems and means that some hypotheses rejected in the past because they were not universally applicable can be reconsidered. By way of example, two areas where detailed investigations have been undertaken are described below, one dealing with Type I Norway spruce decline and the other with the decline of silver fir in the Vosges Mountains of France.

Type I damage in Norway spruce is characterised by yellowing of older foliage and needle loss. It is found at higher altitudes in a number of areas, including the Harz Mountains, the Bavarian National Park and the Black Forest. It is the only type of damage in Norway spruce in Germany that has resulted in a long-term reduction in volume growth; other types of decline have not shown any trend (Rehfuess, 1989) although individual symptomatic trees may have reduced increment (e.g. Kramer, 1986). The yellowing has been associated with magnesium deficiency (Zech and Popp, 1983; Bosch *et al.*, 1983; Zöttl and Mies, 1983; Kaupenjohann *et al.*, 1989). The magnesium content of needles is correlated with crown density (Gärtner, 1985), low magnesium contents being associated with high levels of defoliation. Detailed analyses have indicated that the yel-

Table 25. Decline types recognised for Norway spruce in Germany (FBW, 1986).

Type 1.	Needle yellowing at higher elevations of the German 'Mittelgebirge'.
Type 2.	Thinning of crowns at medium to high altitudes in the 'Mittelgebirge', with no yellowing.
Type 3.	Reddening of needles in older stands in southern Germany.
Type 4.	Yellowing at higher altitudes in the calcareous Alps of southern Bavaria.
Type 5.	Thinning of crowns in coastal areas in the north of Germany.

lowing is due to the transfer of magnesium from the older needles to the new needles (Lange *et al.*, 1987) rather than to processes such as ozone injury. This has been confirmed by histological and cytological studies (e.g. Fink, 1988; Schmitt *et al.*, 1986) and grafting experiments (Hüttl and Mehne, 1988).

The causes of the magnesium deficiency remain uncertain. Many soils have become more acidic in recent years and there is some evidence that cations such as Mg^{++} and Ca^{++} have been depleted (Zezschwitz, 1982, 1985; Hildebrand, 1986; Rost-Siebert and Jahn, 1988; Grimm and Rehfuess, 1986; Hauhs, 1985, 1989; Matzner *et al.*, 1982). Other processes, such as the removal of magnesium in biomass and reduced uptake caused by root restrictions resulting from unfavourable chemical environments (Matzner *et al.*, 1986; Oren *et al.*, 1988a, 1988b), are also likely to be important.

The decline of silver fir in the Vosges Mountains of north-eastern France has also been the subject of intensive investigations. The decline was noted in the early 1980s, with a sharp increase in the amount of yellowing being recorded in 1984 and 1985, since when there has been a recovery (Landmann, 1988b). Growth was depressed in the period 1973–1980 but returned to normal in the majority of stands by 1983 (Becker, 1987a, 1987b; Lévy and Becker, 1987). Similar growth depressions occurred in the periods 1917–1925 and 1943–1951 (Becker,1989; Becker *et al.*, 1989). There is a strong correlation with summer moisture conditions, with growth taking as much as 6 years to recover from particularly dry summers (Becker, 1989). There appears to be a strong influence of silvicultural practice: stands that were thinned more frequently in the 25 years prior to 1959–1964 (the period of dry summers) do not currently show the decline symptoms (Becker and Lévy, 1988; Becker *et al.*, 1989). Air pollution is not ruled out as a contributing factor and may be involved in some of the mineral deficiencies that have been observed (Bonneau, 1989), but this remains speculative.

Declines in forest health and/or vigour have also been reported from a number of other countries. Examination of these reports indicates that a variety of problems are present which are all being categorised as forest decline, despite a number of different causes being responsible. In some cases, even the presence of a decline is uncertain. For example, a reassessment of the surveys of pollution-damage in eastern white pine in the United States has suggested that many do not meet quality control criteria; out of 61 surveys examined, Bennett *et al.* (1989) rejected 56. In some cases, rejection was on the grounds that the diagnosis of the symptoms was inadequate (Linzon, 1989); in others, it was due to inadequate sampling. When the five surveys that met the acceptance criteria were examined, Bennett *et al.* (1989) concluded that there was little evidence of a major decline in the health of the species.

The role of air pollution

Several different mechanisms exist whereby air pollution can interact with trees. Johnson and Taylor (1989) identify three main processes: soil acidification, direct and indirect effects of gaseous pollutants and excess nitrogen deposition.

Soil acidification and related processes

Indirect, soil-mediated, effects are intensely debated. Soil acidification is known to alter the mineral supply within the soil, with nutrients such as magnesium and calcium being removed (Johnson *et al.*, 1985; Kreutzer and Bittersohl, 1986; Bergkvist, 1987) and this may be linked with the magnesium deficiency seen in Type I Norway spruce decline. The role of acidic deposition in the leaching of nutrients is uncertain as some studies have failed to show any effect (e.g. Nowak *et al.*, 1989). There is now evidence that as a cation becomes rarer, any losses through leaching will decrease and may stop altogether before the availability of the cation becomes so low that a deficiency in the trees occurs (Johnson and Taylor, 1989). It seems likely that the site conditions play an important part in determining exactly what processes occur.

As soils acidify, certain metals may become more available and concern has focused on aluminium. However, results of experimental studies with aluminium have been mixed, with some studies showing significant effects on growth or some other parameter (e.g. Jorns and Hecht-Buchholz, 1985; Godbold *et al.*, 1988; Bengtsson *et al.*, 1988; Joslin *et al.*, 1988; Thornton *et al.*, 1989; Balsberg Påhlsson, 1990) and others showing no effect at the level of concentration found in the soil (Berneike *et al.*, 1987; Goransson and Eldhuset, 1987).

The uncertainty arises from the difficulties in distinguishing between different forms of aluminium that occur in the soil. These exhibit different toxicities, which may be compounded by major inter- and intra-specific differences in the tolerance of trees to aluminium and variations in aluminium toxicity determined by other environmental factors (McCormick and Steiner, 1978; Eldhuset, 1988; Cronan *et al.*, 1989; Keltjens and van Loenen, 1989). The problems of determining sensitivity to aluminium are such that it is impossible to say categorically whether conditions for aluminium toxicity exist in forests (Cronan *et al.*, 1989). At some German sites (e.g. Solling), very high aluminium concentrations have been recorded and these may be sufficient to cause damage. Elsewhere, aluminium toxicity seems unlikely. Although reductions in fine root biomass have been recorded (e.g. Schulze *et al.*, 1987; Meyer, 1987; Matzner *et al.*, 1986), which is consistent with the theory of aluminium toxicity (Ulrich *et al.*, 1980), the available evidence suggests that the reduction is a secondary symptom related to magnesium deficiency (Schulze *et al.*, 1987), although this is disputed (Ulrich, 1989).

The direct effects of acidic deposition also remain a contentious issue. The rainfall acidity normally encountered in Europe and North America is insufficient to cause direct foliar injury (Morrison, 1984; Evans, 1984; Haines and Carlson, 1989). However, at higher elevations, cloudwater, which is much more acidic than rainfall, may be intercepted by trees. In some cases, the acidity of this water may be sufficient to cause injury, although this has yet to be demonstrated in forests.

The theory that acidic mist or rain interacts with ozone to cause increased leaching of nutrients from needles, thereby causing deficiency symptoms (Prinz *et al.*, 1982) has not been substantiated by field or experimental evidence. The results of some experiments must be discounted because of the effects of anhydrous nitric acid, which is produced as an impurity in ozonated air (Brown and Roberts, 1988). Other experiments (e.g. Bosch *et al.*, 1986; Mengel *et al.*, 1987) have not induced magnesium deficiency through leaching. Foliar leaching of cations has been clearly demonstrated in the field, but the amounts involved are small in comparison to storage within the foliage and other above-ground biomass (Bredemeier and Matzner, 1986; Hantschel *et al.*, 1988; Reisch, 1983).

Direct and indirect effects of gaseous pollutants

Direct damage by sulphur dioxide appears to be increasingly rare as a result of reductions in emissions of this pollutant. Damage is still present around certain point sources and this can be widespread in countries such as China (Ma Guangjing, 1989) and Czechoslovakia (Materna, 1988) with poor emission controls. Fears that relatively low concentrations of sulphur dioxide and other gaseous pollutants could be the cause of forest damage have not been substantiated by recent experimental work (e.g. Koch, 1989; Koch and Lautenschlager, 1989; Krause and Prinz, 1989; Lange *et al.*, 1989; Schulze, 1989; Schulze *et al.*, 1989a; Hotz *et al.*, 1990).

The role of ozone is much less certain and ozone injury to trees in Europe has not been clearly demonstrated (Mansfield, 1988; Prinz and Krause, 1989; Unsworth and Wilshaw, 1989). Ozone fumigation studies have not produced the type of symptoms seen in the field, but this does not rule out the presence of more subtle effects.

Excess nitrogen deposition

Concern still exists about the role of nitrogen in forest decline. Various tree species are affected and nitrogen has been implicated as a major cause of Type 5 Norway spruce decline. Nitrogen appears to be a particular problem in parts of the Netherlands (den Boer and van den

Tweel, 1985; Roelofs *et al.*, 1985), Belgium (de Temmerman and Coosemans, 1989) and northern Germany (Krzak *et al.*, 1988) and can be directly linked to ammonia emissions from intensive agricultural units (van Breemen and van Dijk, 1988; Draaijers *et al.*, 1989). Similar problems have been reported around intensive farming units elsewhere (e.g. Ferm *et al.*, 1988). A variety of mechanisms for interaction with trees exist, including soil acidification (van Breemen *et al.*, 1982; Breeuwsma and de Vries, 1984), mineral balance disruption (van Dijk and Roelofs, 1988; Mohren *et al.*, 1986) and increased infection by pathogens due to the changes in the nitrogen metabolism of the trees (Roelofs *et al.*, 1985). To date, no such effects have been noted in Britain (Miller and Miller, 1988).

Nitrogen availability may have a significant role in the development of magnesium deficiency seen in Type I Norway spruce decline in the Federal Republic of Germany. The dry summers of 1983 to 1985 caused an increase in mineralisation and nitrification (Rehfuess, 1989; Zöttl *et al.*, 1989) resulting in higher nitrogen availability. Schulze *et al.* (1989b) have demonstrated that yellowing in Norway spruce is the result of nitrogen-stimulated canopy growth when the supply of magnesium in the soil is limited, providing further evidence of a nitrogen–magnesium interaction.

The form of nitrogen is also important. For example, fertilisation by ammonium-nitrogen can induce magnesium deficiency in foliage, particularly on magnesium-deficient soils (Zöttl *et al.*, 1989). Norway spruce will preferentially take up ammonium in favour of nitrate, the latter being free to leach other nutrients from the soil (Schulze *et al.*, 1989a). This may aggravate any magnesium or calcium deficiency.

Where supplies of magnesium and other nutrients are sufficient, the deposition of nitrogen may stimulate growth. Increases in forest growth have been reported (Eichkorn, 1986; Lévy and Becker, 1987; Spiecker, 1987; Kenk and Fischer, 1988) and one of the most likely explanations is increased nitrogen availability. However, favourable climatic conditions may also be involved, and more work is required to identify the main mechanism involved in the growth increases.

Alternative explanations

Of the natural factors, climatic stress is viewed as being very important. It has a major effect on the increment of many European trees (e.g. Kramer, 1986; Visser and Molenaar, 1988; Abetz, 1988; Becker *et al.*, 1989) and is viewed as the trigger for the onset of the widespread yellowing in Norway spruce in the late 1970s and early 1980s (Prinz and Krause, 1989). This can take the form of either summer drought (Cramer and Cramer-Middendorf, 1984; Becker, 1987a; Donaubauer, 1987) or extreme frosts (Bosch and Rehfuess, 1988), or a combination of the two (Lenz *et al.*, 1988)

There is increasing interest in the possibility that management techniques may have played a part in the decline of some forest stands. Many declining stands are located on mineral-deficient soils and recover following fertilisation (Rehfuess, 1989; Zöttl *et al.*, 1989). In addition, over-stocking appears to have predisposed some stands to decline (Becker and Lévy, 1988; Becker *et al.*, 1989) as does over-thinning (Keller and Imhof, 1987).

In some cases, a combination of natural factors appears to be involved. For example, Bernier *et al.* (1989) attribute the decline of many sugar maple stands in eastern Canada to the triggering effect of two to three consecutive years of severe defoliation by the forest tent caterpillar (*Malacosoma disstria* Hbn.) and the Bruce spanworm (*Operophtera bruceata* Hulst.). Severe frost in early June 1980 resulted in the death of 75–100% of sugar maple foliage and a summer drought in 1983 is also thought to have been important. The problem appears to be linked to potassium and phosphorus deficiency although the cause of this remains unclear. Reduced availability appears to be important, as does disruption of nutrient balances due to the high availability of nitrogen (Bernier *et al.*, 1989).

Conclusions

The observations made in Britain are consistent with the idea that forest condition oscillates from year to year but, overall, maintains a steady state (Kandler, 1988). Since 1987, climatic conditions have been favourable for trees, although there may be some lag effects associated with the dry summer of 1989. This is reflected in the general improvement that has occurred in many trees. However, there is no indication that this is a long-term trend, and data will have to be collected for a number of years before the underlying patterns can be identified.

There are a number of important differences between the trees in Britain and those trees observed in areas of central Europe experiencing decline problems. The superficial similarities identified in assessments of crown density (United Nations Economic Commission for Europe, 1988; Commission of the European Communities, 1989) are not supported by more detailed assessments. In Britain, dominant and sub-dominant trees do not have thinner crowns, contrasting with trees in West Germany. The most common form of defoliation in spruces involved loss of density throughout the crown, whereas symptomatic German trees generally lose their density first just below the top of the crown.

Yellowing of older needles was present in Norway spruce in Britain in 1989, but only 3% of trees were affected, none seriously. The upper-surface yellowing, characteristic of Type I decline, has not been seen. Binns *et al.* (1986) showed that magnesium concentrations in Norway spruce needles were above the threshold for yellowing identified by Kaupenjohann *et al.* (1989) and a re-analysis of these data indicates that nitrogen:magnesium ratios of first- and second-year needles were in the range 8–28% and 11–39% respectively, much lower than the ratios with which problems have been associated in Germany (Zöttl *et al.*, 1989). This is entirely consistent with data on the deposition of magnesium in Britain; Roberts *et al.* (1989) have argued that Type I decline is unlikely in Britain because of the high levels of marine-derived magnesium deposition.

Although shoot death has been identified in both Sitka and Norway spruce, it is strongly correlated with age, suggesting that at least a proportion of the death is related to natural processes within the crown. The widespread occurrence of secondary shoots suggests that replacement of dead shoots is taking place, as would be expected from our knowledge of the normal development of spruce crowns through time (Gruber, 1986, 1987, 1988b; Lesinski and Landmann, 1988; Rehfuess, 1989).

The information for broadleaves is much more difficult to assess as different decline types, based on crown condition, have not been distinguished to date. Beech in well-thinned stands had thinner crowns than in dense woodland, and this is consistent with observations of crown thinning following the opening-up of the canopy. Both oak and beech showed some improvement in 1989, which has been attributed to the wet summer of 1988 and the mild 1988–1989 winter. The dry summer of 1989 had little immediate effect on the trees. Effects may be apparent in 1990 but, in England, these may be difficult to differentiate from twig damage caused by the storms in early 1990.

Correlation and regression analyses undertaken in the past have not revealed any patterns that might indicate an adverse effect of air pollution on tree condition. Instead, the analyses suggest that tree condition is better in those areas experiencing higher levels of most forms of gaseous pollution. Considerable developments have occurred in the characterisation of air pollution patterns in Britain and these are currently being reviewed. It is likely that more accurate estimates of the pollutant loading at individual sites will be available in the near future and these will be incorporated in future analyses. In addition, the increase in the amount of data related to tree condition opens up new opportunities for more sophisticated statistical analyses, and some techniques with considerable potential have now been identified. These will be used in future analyses of the data.

The patterns of crown condition identified in 1989 are broadly similar to the data for 1987 and 1988. One major difference is the increase in the amount of browning of older Scots pine needles that occurred in the southern part of the country in 1989. It is possible that this reflects the higher ozone concentrations recorded in 1989 as early senescence of older needles is one of the first symptoms of ozone damage that occurs in Scots pine. At the moment, it is impossible to substantiate this hypothesis as neither the 1988 nor the 1989 results of the Department of the Environment's ozone monitoring programme had been published at the time of writing.

Within a wider context, the role of air pollution is now seen as being extremely subtle in most areas. The widespread death of forests, as seen in parts of eastern Europe as a result of high concentrations of sulphur dioxide combined with extreme winter stress, has not occurred in western Europe. Instead, scientists increasingly believe that the direct effects of air pollution are relatively minor. However, there may be considerable indirect effects, either through soil-mediated processes or through changes in the susceptibility of trees to insects and fungal pathogens. The full impact of these remains to be evaluated.

A consensus appears to be emerging about the role of tree nutrition. Magnesium deficiency is clearly responsible for some forms of decline, although the reasons why the soils are low in magnesium remain uncertain. Acidic deposition has resulted in increased removal of base cations and is likely to be involved in the deficiencies, although depletion of base cation reserves in harvested timber is also likely to be an important factor where magnesium reserves in soils and atmospheric inputs are small. The simultaneous appearance of a variety of symptoms in different areas appears to be the result of extreme climatic conditions, with dry summers being particularly important. The effects of the dry summers are variable, depending on the physical and chemical soil characteristics which have determined the trees' responses.

The direct effects of gaseous pollutants appear to be very limited, although the potential for damage clearly exists. Experiments conducted in the field have shown no significant effects and symptoms of acute injury by, for example, ozone, have not been identified in Europe. Laboratory and other fumigation experiments have generally been short-term and have used unrealistic concentrations or gaseous mixtures. This makes the results very difficult to interpret. However, it seems that any regional-scale effects are small relative to other processes affecting tree condition, although the possibility that gaseous pollutants are exacerbating certain problems cannot be excluded.

The logic behind the Forestry Commission's approach to the problem of forest decline has been neatly summed up by Mason (1988, p.73):

> The problem becomes apparent when damage exceeds a certain level generally accepted as normal and then spreads or intensifies rapidly as the natural control mechanisms fail to cope. It is then necessary to determine, by careful observation and measurement, the nature, extent and intensity of the damage, the rate of change and whether these are gradual, episodic or step-changes, and to compare these with past records, if they exist. The next step is to correlate the damage symptoms with internal or external events judged to be the likely causes or contributors before involving more imaginative or fashionable hypotheses.

The results presented in this report indicate the progress that has been made in the understanding of the forest decline problem. Certain patterns are beginning to emerge and some of the early questions have now been answered. However, there are still many areas of uncertainty and the detailed observations that this programme entails will continue to provide important basic information on the condition of British forests.

ACKNOWLEDGEMENTS

This survey could not have been undertaken without the assistance of members of the Forestry Commission's Forest Surveys Branch. Their assistance is gratefully acknowledged. Miss Joan Lees helped with the administration of the project during 1989. Staff of the Warren Spring Laboratory of the Department of Trade and Industry provided unpublished information on the distribution of various pollutants in Britain.

REFERENCES

ABETZ, P. (1988). Untersuchungen zum Wachstum von Buchen auf der Schwäbischen Alb. *Allgemeine Forst- und Jagdzeitung* **159,** 215–223.

ALEXANDER, S.A. and CARLSON, J.A. (1988). *Visual damage survey pilot test project manual.* Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

ANDERSON, R.L. and BELANGER, R.P. (1987). A crown rating method for assessing tree vigor of loblolly and shortleaf pines. In *Proceedings of the 4th biennial southern silvicultural research conference,* 1986, Nov. 4–6, Atlanta, Georgia, ed. D.R. Phillips, 538–543. U.S. Department of Agriculture, Forest Service, General Technical Report SE-42, Asheville.

ATHARI, S. and KRAMER, H. (1989). Problematik der Zuwachsuntersuchungen in Buchenbeständen mit neuartigen Schadsymptomen. *Allgemeine Forst- und Jagdzeitung* **160,** 1–8.

BALSBERG PÅHLSSON, A.-M. (1990). Influence of aluminium on biomass, nutrients, soluble carbohydrates and phenols in beech (*Fagus sylvatica*). *Physiologia Plantarum* **78,** 79–84.

BATKO, S. and PAWSEY, R.G. (1964). Stem canker of pine caused by *Crumenula sororia. Transactions of the British Mycological Society* **47,** 257–261.

BAUCH, J., RADEMACHER, P., BERNEIKE, W., KNOTH, J. and MICHAELIS, W. (1985). Breite und elementgehalt der Jahrringe in Fichten aus Waldschadensgebieten. In *Waldschäden. Einflussfaktoren und ihre Bewertung.* Kolloquium Goslar, 18 bis 20 Juni 1985, ed. H. Stratmann, 943–959. VDI-Berichte **560.**

BAUM, U. (1981). Wirkungen von Meliorationsmassnahmen auf den Streufall und die Bioelemente in der Streu eines Oberpfalzer Kiefernbestandes (*Pinus sylvestris* L.). *Forstwissenschaftliches Centralblatt* **100,** 86–95.

BECKER, M. (1987a). Bilan de santé actuel et rétrospectif du sapin (*Abies alba* Mill.) dans les Vosges. Étude écologique et dendrochronologique. *Annales des Sciences Forestières* **44,** 379–401.

BECKER, M. (1987b). Santé de la forêt: le sapin témoignes. *Recherche* **18,** 1096–1098.

BECKER, M. (1989). The role of climate on present and past vitality of silver fir forests in the Vosges Mountains of northeastern France. *Canadian Journal of Forest Research* **19,** 1110–1117.

BECKER, M. and LÉVY, G. (1988). A propos du dépérissement des forêts: climat, sylviculture et vitalité de la sapinière Vosgienne. *Revue Forestière Française* **40,** 345–358.

BECKER, M., LANDMANN, G. and LÉVY, G. (1989). Silver fir decline in the Vosges Mountains (France): role of climate and silviculture. *Water, Air, and Soil Pollution* **48,** 77–86.

BEIER, C. and GUNDERSEN, P. (1989). Atmospheric deposition to the edge of a spruce forest in Denmark. *Environmental Pollution* **60,** 257–271.

BELANGER, R.P. and ANDERSON, R.L. (1988). *A guide for visually assessing crown densities of loblolly and shortleaf pines.* U.S. Department of Agriculture, Forest Service, South-East Forest Experiment Station Research Note SE-352, Asheville.

BENGTSSON, B., ASP, H., JENSEN, P. and BERGGREN, D. (1988). Influence of aluminium on phosphate and calcium uptake in beech (*Fagus sylvatica*) grown in nutrient solution and soil solution. *Physiologia Plantarum* **74,** 299–305.

BENGTSSON, G. (1985). Approach and methodology of the health of forests in Sweden. In *Inventorying and monitoring of endangered forests,* ed. P. Schmid-Haas, 205–208. Eidgenössische Anstalt für das forstliche Versuchswesen, Birmensdorf.

BENNETT, J. P., ANDERSON, R. L., MIELKE, M.L. and EBERSOLE, J. J. (1989). An historical perspective on forest decline of eastern white pine. In *Forest decline and air pollution,* eds J. B. Bucher and I. Bucher-Wallin, 69–75. Eidgenössische Anstalt für das forstliche Versuchswesen, Birmensdorf.

BERGKVIST, B. (1987). Soil solution chemistry and metal budgets of spruce forest ecosystems in S. Sweden. *Water, Air, and Soil Pollution* **33,** 131–154.

BERNEIKE, W., EHLERS, W., KNOTH, J. and RADEMACHER, P. (1987). Element patterns in healthy and diseased Norway spruce (*Picea abies*) measured by inductively-coupled plasma/atomic emission spectrometry and total-reflection X-ray fluorescence spectrometry. *Analytica Chimica Acta* **195,** 289–297.

BERNIER, B. and BRAZEAU, M. (1988). Nutrient deficiency symptoms associated with sugar maple dieback and decline in the Quebec Appalachians. *Canadian Journal of Forest Research* **18,** 762–767.

BERNIER, B., PARÉ, D. and BRAZEAU, M. (1989). Natural stresses, nutrient imbalances and forest decline in southeastern Quebec. *Water, Air and Soil Pollution* **48,** 239–250.

BINNS, W. O., REDFERN, D. B., BOSWELL, R. C. and BETTS, A. J. A. (1986). *Forest health and air pollution: 1985 survey.* Forestry Commission Research and Development Paper 147. Forestry Commission, Edinburgh.

BINNS, W. O., REDFERN, D. B., RENNOLLS, K. and BETTS, A. J. A. (1985). *Forest health and air pollution: 1984 survey.* Forestry Commission Research and Development Paper 142. Forestry Commission, Edinburgh.

BLEUTEN, W., IVENS, W. P. M. F. and DRAAIJERS, G. P. J. (1987). Throughfall sampling method for research on spatial variability of dry deposition in a forest-stand and the effects of forest-edges. In *Pollution climates in Europe and their perception by terrestrial ecosystems,* 107–115. Commission of the European Communities, Air Pollution Research Report 6. Commission of the European Communities, Brussels.

DEN BOER, W. M. J. and VAN DEN TWEEL, P. A. (1985). The health condition of the Dutch forests in 1984. *Netherlands Journal of Agricultural Science* **33,** 167–174.

BONNEAU, M. (1989). Que sait-on maintenant des causes du 'dépérissement' des forêts? *Revue Forestière Française* **41,** 367–385.

BOSCH, C., PFANNKUCH, E., BAUM, U. and REHFUESS, K. E. (1983). Über die Erkrankung der Fichte (*Picea abies* Karst.) in den Hochlagen des Bayerischen Waldes. *Forstwissenschaftliches Centralblatt* **102,** 167–181.

BOSCH, C., PFANNKUCH, E., REHFUESS, K. E., RUNKEL, K. H., SCHRAMEL, P. and SENSER, M. (1986). Einfluss einer Düngung mit Magnesium und Kalzium, von Ozon und saurem Nebel auf Frosthärte, Ernährungszustand und Biomasseproduktion junger Fichten (*Picea abies* (L.) Karst.). *Forstwissenschaftliches Centralblatt* **105,** 218–242.

BOSCH, C. and REHFUESS, K. E. (1988). Über die Rolle von Frostereignissen bei den 'neuartigen' Waldschaden. *Forstwissenschaftliches Centralblatt* **107,** 123–130.

BREDEMEIER, M. and MATZNER, E. (1986). Atmosphärischer Stoffeintrag in Waldbestände — Quantifizierungsansatz aus der Flussebilanz des Kronenraums. In *IMA-Querschnittsseminar Deposition,* eds K. D. Höfken and H. Bauer, 46–60. BPT-Berichte 8/86, GSF, Munich.

VAN BREEMEN, N., BURROUGH, P. A., VELTHORST, E. J., VAN DOBBEN, H. F., DE WIT, T., RIDDER, T. B. and REIJNDERS, H. F. R. (1982). Soil acidification from atmospheric ammonium sulphate in forest canopy throughfall. *Nature* **299,** 548–550.

VAN BREEMEN, N. and VAN DIJK, H. F. G. (1988). Ecosystem effects of atmospheric deposition of nitrogen in the Netherlands. *Environmental Pollution* **54,** 249–274.

BREEUWSMA, A. and DE VRIES, W. (1984). The relative importance of natural production of H^+ in soil acidification. *Netherlands Journal of Agricultural Science* **32,** 161–163.

BRINGMARK, E. (1989). Spatial variation in soil pH of beech forests in relation to buffering properties and soil depths. *Oikos* **54,** 165–177.

BROWN, K. A. and ROBERTS, T. M. (1988). Effects of ozone on foliar leaching in Norway spruce (*Picea abies* (L.) Karst.): confounding factors due to NOx production during ozone generation. *Environmental Pollution* **55,** 55–73.

CARTER, C. I. (1989). *The 1989 outbreak of the green spruce aphid,* Elatobium abietinum.

Forestry Commission Research Information Note 161. Forestry Commission, Edinburgh.
CHEVONNE, B. I. and LINZON, S. N. (1988). Tree decline in North America. *Environmental Pollution* **50,** 87–99.
CLINE, S. P., BURKMAN, W. G. and GERON, C. D. (1989). Use of quality control procedures to assess errors in measuring forest canopy condition. In *Transactions of the Air and Waste Management Association Annual Meeting*, June 1989, Arnhem, CA, *'Effects of air pollution on western forests'*, eds R. K. Olsen and A. S. Lefohn, 379–393. Air and Waste Management Association.
COMMISSION OF THE EUROPEAN COMMUNITIES (1989). *European Community forest health report 1987–1988.* Office for Official Publications of the European Communities, Luxembourg.
CRAMER, H. H. and CRAMER-MIDDENDORF, M. (1984). Studies on the relationships between periods of damage and factors of climate in the Middle European forests since 1851. *Pflanzenschütz-Nachrichten Bayer* **37,** 208–334.
CRAWLEY, M. J. and AKHTERUZZAMAN, M. (1988). Individual variation in the phenology of oak trees and its consequences for herbivorous insects. *Functional Ecology* **2,** 409–415.
CRONAN, C. S., APRIL, R., BARTLETT, R. J., BLOOM, P. R., DRISCOLL, C. T., GHERINI, S. A., HENDERSON, G. S., JOSLIN, J. D., KELLY, J. M., NEWTON, R. M., PARNELL, R. A., PATTERSON, H. H., RAYNAL, D. J., SCHAEDLE, M., SCHOFIELD, C. L., SUCOFF, E. I., TEPPER, H. B. and THORNTON, F. C. (1989). Aluminium toxicity in forests exposed to acidic deposition: the ALBIOS results. *Water, Air, and Soil Pollution* **48,** 181–192.
DENSTORF, O., HEESCHEN, G. and KENNEWEG, H. (1984). Ergebnisse der grossräumigen Inventur von Waldschäden 1983 mit Farb-Infrarot-Luftbildern im südlichen Schleswig-Holstein. *Allgemeine Forst- und Jagdzeitung* **155,** 126–131.
DIAMANDIS, S. (1979). 'Top-dying' of Norway spruce, *Picea abies* (L.) Karst., with special reference to *Rhizosphaera kalkhoffii* Bubåk. VI. Evidence related to the primary cause of 'top-dying'. *European Journal of Forest Pathology* **9,** 183–191.
VAN DIJK, H. F. G. and ROELOFS, J. G. M. (1988). Effects of excessive ammonium deposition on the nutritional status and condition of pine needles. *Physiologia Plantarum* **73,** 494–501.
DOBLER, D., HOHLOCH, K., LISBACH, B. and SALIARI, M. (1988). Trieblängen – Messungen und Buchen. *Allgemeine Forst Zeitschrift* **43,** 811–812.
DONAUBAUER, E. (1987). Auftreten von Krankheiten und Schädlingen der Eiche und ihr Bezug zum Eichensterben. *Österreichische Forstzeitung* **98,** 46–48.
DRAAIJERS, G. P. J., IVENS, W. P. M. F. and BLEUTEN, W. (1988). Atmospheric deposition on forest edges measured by monitoring canopy throughfall. *Water, Air, and Soil Pollution* **42,** 129–136.
DRAAIJERS, G. P. J., IVENS, W. P. M. F., BOS, M. M. and BLEUTEN, W. (1989). The contribution of ammonia emissions from agriculture to the deposition of acidifying and eutrophying compounds onto forests. *Environmental Pollution* **60,** 55–66.
EICHKORN, T. (1986). Wachstumsanalysen an Fichten in Südwestdeutschland. *Allgemeine Forst- und Jagdzeitung* **157,** 125–139.
ELDHUSET, T. D. (1988). Virkninger av aluminium på høyere planter ved lav pH: En litteraturoversikt. *Meddelser frå Norsk Institutt for Skogforskning* **40** (8). (19 pp.)
EVANS, L. S. (1984). Acidic precipitation effects on terrestrial vegetation. *Annual Reviews of Phytopathology* **22,** 397–420 .
FERM, A., HYTÖNEN, J., KOLARI, K. K., and VEIJALAINEN, H. (1988). Metsäpuiden kasvuhäiriöt turkistarhojen läheisyydessä. *Metsäntutkimuslaitoksen Tiedonantoja, Finland* **320.** (77pp.)
FINK, S. (1988). Histological and cytological changes caused by air pollutants and other abiotic factors. In *Air pollution and plant metabolism*, eds S. Schulte-Hostede, N. M. Darrall, L. W. Blank and A. R. Wellburn, 36–54. Elsevier Applied Sciences, Oxford.
FORSCHUNGSBEIRAT WALDSCHÄDEN

(1986). 2. Bericht, Karlsruhe.
FOWLER, D., CAPE, J. N. and UNSWORTH M. H . (1989). Deposition of atmospheric pollutants on forests. *Philosophical Transactions of the Royal Society, Series B* **324,** 247–265.
GÄRTNER, E. (1985). Mangangehalte in Altfichten, Boden und Kronendurchlass an jeweils gleichen Standorten. In *Waldschäden. Einflussfaktoren und ihre Bewertung. Kolloquium Goslar,* 18 bis 20 Juni 1985, ed. H. Stratmann, 559–573. VDI-Berichte **560.**
GÄRTNER, E. J. (1988). Operational forest decline symptomatology. In *Scientific basis of forest decline symptomatology,* eds J. N. Cape and P. Mathy, 295–306. Commission of the European Communities, Air Pollution Report 15, Brussels.
GLOAGUEN, J. C. and TOUFFET, J. (1976). Production de litière et apport au sol d'eléments minéreaux dans quelques peuplements resineux de Bretagne. *Annales des Sciences Forestières* **33,** 87–107
GODBOLD, D. L., FRITZ, E. and HUTTERMANN, A. (1988). Aluminium toxicity and forest decline. *Proceedings of the National Academy of Sciences, U.S.A.* **85,** 3888–3892.
GORANSSON, P. and ELDHUSET, T. D. (1987). Effects of aluminium on growth and nutrient uptake of *Betula pendula* seedlings. *Physiologia Plantarum* **69,** 193–199.
GRIMM, R. and REHFUESS, K. E. (1986). Kurzfristige Veränderungen von Bodenreaktion und Kationenaustauscheigenschaften in einem Meliorationsversuch zu Kiefer (*Pinus sylvestris* L.) auf Podsol-Pseudogley in der Oberpfalz. *Allgemeine Forst- und Jagdzeitung* **157,** 205–212.
GROSS, H. L. (1975). Crown deterioration and reduced growth associated with excessive seed production by birch. *Canadian Journal of Botany* **50,** 2431–2437.
GROSS, H. L. and HARDEN, A. A. (1968). *Dieback and abnormal growth of yellow birch induced by heavy fruiting.* Forest Research Laboratory, Sault Ste Marie, Ontario, Canada, Information Report O-X-79.
GROZEVA, M. (1986). The amount, composition and seasonal fluctuation in litter fall in representative Scots pine stands in the Rila mountains. *Gorskostopanska Nauka* **23,** 37–42.
GRUBER, F. (1986). *Beiträge zum morphogenetischen Zyklus der Knospe, zur Phyllotaxis und zum Triebwachstum der Fichte* (Picea abies *(L.) Karst.*) *auf unterschiedlichen Standorten.* Beiträge Forschungszentrum Waldökosystemen/Waldschäden A25. (215pp.)
GRUBER, F. (1987). *Das Verzweiggungssystem und der Nadelfall der Fichte (*Picea abies *(L.) Karst.) als Grundlage zur Beurteilung von Waldschäden.* Beiträge Forschungszentrum Waldökosystemen/Waldschäden A26. (214 pp.)
GRUBER, F. (1988a). Der Fenstereffekt bei der Fichte. *Forst und Holz* **43,** 58–60.
GRUBER, F. (1988b). Die Anpassung der Fichtenkrone (*Picea abies* (L.) Karst.) über die Triebbildungsarten. *Schweizerische Zeitschrift für Forstwesen* **139,** 173–201.
GRUBER, F. (1989). Phänotypen der Fichte (*Picea abies* (L.) Karst.). I. Verzweigungsphänotypen: Genotyp und Modifikation. *Allgemeine Forst- und Jagdzeitung* **160,** 157–166.
HÄGI, K. (1989). *Terrestrische Waldschadeninventur.* Eidgenössische Anstalt für das forstliche Versuchswesen, Berichte 314. Birmensdorf.
HAINES, B. L. and CARLSON, C. L. (1989). Effects of acidic precipitation on trees. In *Acidic precipitation. Volume 2: biological and ecological effects,* eds D. C. Adriano and A. H. Johnson, 1–27. Springer-Verlag, New York.
HANTSCHEL, R., HORN, R., KAUPENJOHANN, M. and ZECH, W. (1988). Connections between forest decline and element fluxes in forest ecosystems in NE Bavaria, FRG. In *Proceedings of the US/FRG Research Symposium: The effects of atmospheric pollutants on the spruce-fir forests of the eastern United States and the Federal Republic of Germany,* ed. G. D. Hertel, 461–494. United States Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, General Technical Report NE-120, Broomall, PA.
HASSELROT, B. and GRENNFELT, P. (1987).

Deposition of air pollutants in a wind-exposed forest edge. *Water, Air, and Soil Pollution* **34,** 135–143.

HAUHS, M. (1985). *Wasser- und Stoffhaushalt im Einzugsgebiet der Langen Bramke (Harz).* Berichte des Forschungszentrums Waldökosysteme/Waldsterben 17.

HAUHS, M. (1989). Lange Bramke: an ecosystem study of a forested catchment. In *Acidic precipitation.* Volume 1: *Case studies,* eds D. C. Adriano and A. H. Johnson, 275–304. Springer-Verlag, New York.

HICKS, B. B. and MEYERS, T. P. (1988). Measuring and modelling dry deposition in mountainous areas. In *Acid deposition at high elevation sites,* eds M. H. Unsworth and D. Fowler, 541–552. Kluwer Academic, Dordrecht.

HILDEBRAND, E. E. (1986). Zustand und Entwicklung der Austauschereigenschaften von Mineralbodöden aus Standorten mit erkrankten Waldbeständen. *Forstwissenschaftliches Centralblatt* **105,** 60–76.

HILTON, G. M., PACKHAM, J. R. and WILLIS, A. J. (1987). Effects of experimental defoliation on a population of penduncúlate oak (*Quercus robur* L.). *New Phytologist* **107,** 603–612.

HOTZ, A., BILGER, W., KAISER, W. M. and LANGE, O.-L. (1990). Chlorophyll-Fluoreszenz, Photosynthesekapazität, Chlorophyllund Nährstoffgehalte der Blätter 'ungeschädigter' und als 'geschädigt' eingestufter Buchen (*Fagus sylvatica* L.) im Gebiet um Würzburg. *Forstwissenschaftliches Centralblatt* **109,** 40–54.

HÜTTL, R. F. and MEHNE, B. M. (1988). New-type of forest decline, nutrient deficiencies and the Virus-hypothesis. In *Air pollution and ecosystems,* ed. P. Mathy, 870–875. D. Reidel, Dordrecht.

INNES, J. L. (1989). Rapid yellowing of needles of *Picea abies. European Journal of Forest Pathology* **19,** 21–28.

INNES, J. L. and BOSWELL, R. C. (1987). *Forest health surveys 1987. Part 1: results.* Forestry Commission Bulletin 74. HMSO, London.

INNES, J. L. and BOSWELL, R. C. (1988). *Forest health surveys 1987. Part 2: analysis and interpretation.* Forestry Commission Bulletin 79. HMSO, London.

INNES, J. L. and BOSWELL, R. C. (1989). *Monitoring of forest condition in the United Kingdom 1988.* Forestry Commission Bulletin 88. HMSO, London.

INNES, J. L., BOSWELL, R. C., BINNS, W. O. and REDFERN, D. B. (1986). *Forest health and air pollution: 1986 survey.* Forestry Commission Research and Development Paper 150. Forestry Commission, Edinburgh.

INNES, J. L. and COOK, E. D. (1989). Tree-ring analysis as an aid to evaluating the effects of pollution on tree growth. *Canadian Journal of Forest Research* **19,** 1174–1189.

INNES, J. L., MOFFAT, A. J. and LONSDALE, D. (1989). *Weather conditions during the summer of 1989 and their effect on trees.* Forestry Commission Research Information Note 162. Forestry Commission, Edinburgh.

JOHNSON, D. W., RICHTER, D. D., LOVETT, G. M. and LINDBERG, S. E. (1985). The effects of atmospheric deposition on potassium, calcium, and magnesium cycling in two deciduous forests. *Canadian Journal of Forest Research* **15,** 773–782.

JOHNSON, D. W. and TAYLOR, G. E. (1989). Role of air pollution in forest decline in eastern North America. *Water, Air, and Soil Pollution* **48,** 21–43.

JORNS, A. and HECHT-BUCHHOLZ, C. (1985). Aluminiuminduzierter Magnesium- und Kalziummangel im Laborversuch bei Fichtensämlingen. *Allgemeine Forst Zeitschrift* **46,** 1248–1252.

JOSLIN, J. D., KELLY, J. M., WOLFE, M. H. and RUSTAD, L. E. (1988). Elemental patterns in roots and foliage of mature spruce across a gradient of soil aluminium. *Water, Air, and Soil Pollution* **40,** 375–390.

JUKOLA-SULONEN, E.-L., MIKKOLA, K., NEVALAINEN, S. and YLI-KOJOLA, H. (1987). Havupuiden elinvoimaisuus Suomessa 1985–6. *Metsäntutkimuslaitoksen Tiedonantoja* **256,** 1–92.

KANDLER, O. (1988). Epidemiologische Bewertung der Waldschadenserhebungen 1983 bis 1987 in der Bundesrepublik

Deutschland. *Allgemeine Forst- und Jagdzeitung* **159,** 179–194.

KAUPENJOHANN, M., ZECH, W., HANTSCHEL, R., HORN, R. and SCHNEIDER, B. U. (1989). Mineral nutrition of forest trees: a regional survey. In *Air pollution and forest decline, a study of spruce (*Picea abies*) on acid soils,* eds E. D. Schulze, O. L. Lange and R. Oren, 282–296. Ecological Studies Volume 77. Springer-Verlag, Berlin.

KAUPPI, P. (1988). Advantages and disadvantages of expressing forest damage on a percentage basis. In *Workshop on Methodologies,* ed. K. Moisl and J. Zlinská, 37–39. Institute for Environment and Utilization of Natural Resources, Prague.

KELLER, W. and IMHOF, P. (1987). Zum Einfluss der Durchforstung auf die Waldschäden. 1. Teil: Erste Ergebnisse von Waldschadenuntersuchungen in Buchen-Durchforstungsflachen der EAFV. *Schweizerische Zeitschrift für Forstwesen* **138,** 39–54.

KELTJENS, W. G. and van LOENEN, E. (1989). Effects of aluminium and mineral nutrition on growth and chemical composition of hydroponically grown seedlings of five different forest tree species. *Plant and Soil* **119,** 39–50.

KENK, G. and FISCHER, H. (1988). Evidence from nitrogen fertilization in forests of Germany. *Environmental Pollution* **54,** 199–218.

KOCH, W. (1989). Der Reinluft/Standortsluft–Vergleich an Fichte. *Forstwissenschaftliches Centralblatt* **108,** 73–82.

KOCH, W. and LAUTENSCHLAGER, K. (1989). Vergleichende Gaswechselmessungen unter Reinluft und Standortsluft an Fichte zur Qualitativen Ermittlung von primarschaden durch gasformige Luftverunreinigungen. In *Forest decline and air pollution,* eds J. B. Bucher and I. Bucher-Wallin, 119–124. Eidgenössische Anstalt für das forstliche Versuchswesen, Birmensdorf.

KRAMER, H. (1986). Relation between crown parameters and volume increment of *Picea abies* stands damaged by environmental pollution. *Scandinavian Journal of Forest Research* **1,** 251–263.

KRAUSE, G. H. M. and PRINZ, B. (1989). Experimentelle Untersuchungen des LIS zur Aufklarung möglicher Ursachen der neuartigen Waldschäden. *LIS-Berichte* **80.** (221 pp.)

KRAUSE, G. H. M., PRINZ, B. and JUNG, K. D. (1983). Forest effects in West Germany. In *Air pollution and the productivity of the forest,* 297–331. Pennsylvania State University.

KREUTZER, K. and BITTERSOHL, J. (1986). Stoffauswaschung aus Fichtenkronen (*Picea abies* (L.) Karst.) durch saure Beregnung. *Forstwissenschaftliches Centralblatt* **105,** 357–363.

KRZAK, J., DONG, P. H., BUTTNER, G., HUTTERMAN, A., KRAMER, H. and ULRICH, B. (1988). Photosynthesis, nutrient, growth and soil investigations of a declining Norway spruce (*Picea abies*) stand in the coastal region of northern Germany. *Forest Ecology and Management* **24,** 263-281.

LANDMANN, G. (1988a). The main symptoms of forest decline in France and a tentative classification. In *Workshop on Methodologies,* eds K. Moisl and J. Zlinská, 51–58. Institute for Environment and Utilization of Natural Resources, Prague.

LANDMANN, G. (1988b). Observation au sol de l'état des forêts: évaluation critique des données 1983–1988. *Journées de Travail* DEFORPA, Nancy, France, 24–26 février 1988, 1.1.1–1.1.16.

LANDSBERG, J. and OHMART, C. (1989). Levels of insect defoliation in forests: patterns and concepts. *Trends in Ecology and Evolution* **4,** 96–100.

LANGE, O. L., WEIKERT, R. M., WEDLER, M., GEBEL, J. and HEBER, U. (1989). Photosynthese und Nährstoffversorgung von Fichten aus einem Waldschadensgebiet auf basenarmen Untergrund. *Allgemeine Forst Zeitschrift* **44,** 55–64.

LANGE, O. L., ZELLNER, H., GEBEL, J., SCHRAMEL, P., KOSTNER, B. and CZYGAN, F. C. (1987). Photosynthetic capacity, chloroplast pigments, and mineral content of the previous year's spruce needles with and without the new flush: analysis of the forest decline phenomenon of needle bleaching.

Oecologia **73,** 351–357.
LENZ, O, NOGLER P. and BRÄKER, O. U. (1988). L'évolution du temps et le dépérissement du Sapin blanc dans la région de Berne. *Berichte, Eidgenössische Anstalt für das forstliche Versuchswesen,* Birmensdorf, **303.** (44 pp.)
LESINSKI, J.A. (1989). Dynamics of injury symptoms in Norway spruce. In *International Congress on Forest Decline Research: State of Knowledge and Perspectives.* Poster Abstracts Vol. 1, 55–56. Forschungsbeirat Waldschäden/Luftverunreinigungen der Bundesregierung und der Länder, Bonn.
LESINSKI, J. A. and LANDMANN, G. (1988). Crown and branch malformation in conifers related to forest decline. In *Scientific basis of forest decline symptomatology,* eds J. N. Cape and P. Mathy, 92–106. Commission of the European Communities, Air Pollution Report 15, Brussels.
LESINSKI, J. A. and WESTMAN, L. (1987). Crown injury types in Norway spruce and their applicability for forest inventory. In *Acid rain: scientific and technical advances,* eds R. Perry, R. M. Harrison, J. N. B. Bell and J. N. Lester, 657–662. Selper, London.
LEVIN, M. J. (1985). Ergebnisse und waldbauliche Konsequenzen einer Immissionsschadenserhebung im Privatforstbetrieb Sachsenwald. *Waldhygiene* **16,** 19–22.
LÉVY, G. and BECKER, M. (1987). Le dépérissement du sapin dans les Vosges: rôle primordial de déficits d'alimentation en eau. *Annales des Sciences Forestières* **44,** 403–416.
LICK, E. and KRAPFENBAUER, A. (1986). Terrestrische Waldzustandsinventuren und Probleme einer Objektivierung. *Centralblatt für das gesamte Forstwesen* **103,** 227–241.
LINDBERG, S. E., SILSBEE, D., SCHAEFER, D. A., OWENS, J. G. and PETTY, W. (1988). A comparison of atmospheric exposure conditions at high- and low-elevation forests in the southern Appalachian mountain range. In *Acid deposition at high elevation sites,* eds M. H. Unsworth and D. Fowler, 321–344. Kluwer Academic, Dordrecht.
LING, K. A., POWER, S. A. and ASHMORE, M. R. (1989). A survey of the health of *Fagus sylvatica* in southern Britain. In *Forest decline and air pollution,* eds J. B. Bucher and I. Bucher-Wallin, 477–479. Eidgenössiche Anstalt für das forstliches Versuchswesen, Birmensdorf.
LINZON, S. N. (1989). Differential diagnosis of ozone injury and needle blight of eastern white pine. In *Forest decline and air pollution,* eds J. B. Bucher and I. Bucher-Wallin, 233–237. Eidgenössische Anstalt für das forstliche Versuchswesen, Birmensdorf.
LOEHLE, C. (1988). Forest decline: endogenous dynamics, tree defences, and the elimination of spurious correlation. *Vegetatio* **77,** 65–78.
LONSDALE, D., HICKMAN, I. T., MOBBS, I. D. and MATTHEWS, R. W. (1989). A quantitative analysis of beech health and pollution across southern Britain. *Naturwissenschaften* **76,** 571–573.
LÜSCHER, D. (1990). Die Blütenbildung bei Bäumen und ihre Auswirkung auf die Struktur der Krone: IV. Die Buche (*Fagus sylvatica* L.). *Schweizerische Zeitschrift für Forstwesen* **141,** 147–154.
McCORMICK, L. H. and STEINER, K. C. (1978). Variation in aluminium tolerance among six genera of trees. *Forest Science* **24,** 565–568.
MA GUANGJING (1989). La pollution atmosphérique et le dépérissement des forêts. In *Forest decline and air pollution,* eds J. B. Bucher and I. Bucher-Wallin, 51–54. Eidgenössische Anstalt für das forstliche Versuchswesen, Birmensdorf.
MAHRER, F. (1989). Problems in the determination and interpretation of needle and leaf loss. In *Air pollution and forest decline,* 229–231, eds J. B. Bucher and I. Bucher-Wallin. Eidgenössische Anstalt für das forstliche Versuchswesen, Birmensdorf.
MANSFIELD, T. A. (1988). Air pollution: how does it kill trees? *Plants Today,* Jan.–Feb.1988, 12–15.
MASON, J. (1988). Acid rain. Its causes and consequences. *Interdisciplinary Science Reviews* **13,** 73–81.
MATERNA, J. (1988). Air pollution and forestry in Czechoslovakia. *Environmental Assessment and Monitoring* **12,** 227–235.

MATZNER, E., KHANNA, P. R., MEIWES, K. S., LINDHEI, M., PRENZEL, J. and ULRICH, B. (1982). Elementflüsse in Waldökosystemen in Solling. Datendokumentation. *Göttinger Bodenkundliche Berichte* **71,** 1–267.

MATZNER, E., MURACH, D. and FORTMANN, H. (1986). Soil acidity and its relationship to root growth in declining forest stands in Germany. *Water, Air, and Soil Pollution* **31,** 273–282.

MENGEL, K., LUTZ, H. J. and BREININGER, M. T. (1987). Auswaschung von Nährstoffen durch sauren Nebel aus jungen intakten Fichten (*Picea abies*). *Zeitschrift für Pflanzenernährung und Bodenkunde* **150,** 61–68.

MEYER, F. H. (1987). Das Wurzelsystem geschädigter Waldbestände. *Allgemeine Forst Zeitschrift* **42,** 754–757.

MILLER, H. G. and MILLER, J. D. (1988). Response to heavy nitrogen applications in fertilizer experiments in British forests. *Environmental Pollution* **54,** 219–231.

MOHREN, G. M. J., van den BURG, J. and BURGER, F. W. (1986). Phosphorus deficiency induced by nitrogen input in Douglas fir in the Netherlands. *Plant and Soil* **95,** 191–200.

MORISON, J. I. L. and SPENCE, R. A. (1989a). Early season temperatures and plant development. *Weather* **44,** 176–179.

MORISON, J. I. L. and SPENCE, R. A. (1989b). Warm spring conditions and aphid infestations. *Weather* **44,** 374–380.

MORRISON, I. K. (1984). Acid rain: a review of literature on acid deposition effects in forest ecosystems. *Forestry Abstracts* **45,** 483–506.

NEUMANN, M. (1989a). Zu Fragen der Waldzustandserfassung durch grossräumige Inventuren. *Centralblatt für das gesamte Forstwesen* **106,** 161–178.

NEUMANN, M. (1989b). Einfluss von Standortsfaktoren auf den Kronenzustand. In *Forest decline and air pollution,* eds J. B. Bucher and I. Bucher-Wallin, 209–214. Eidgenössische Anstalt für das forstliche Versuchswesen, Birmensdorf.

NEUMANN, M. and STOWASSER, S. (1986). Waldzustandsinventur: Zur Objektivität von Kronenklassifizierungen. In *Annual Report for 1986 of the Forstlichen Bundesversuchsanstalt, Vienna,* 101–108.

NIEHAUS, G. (1989). Terrestrische Zustandserfassung von Kiefernkronen (*Pinus sylvestris*) – ein differenzierter Anspracheschlüssel. *Forst und Holz* **44,** 200–206.

NOWAK, C. A., SHEPARD, J. P., DOWNARD, R. B., WHITE, E. H., RAYNAL, D. J. and MITCHELL, M. J. (1989). Nutrient cycling in Adirondack conifer plantations: is acidic deposition an influencing factor? *Water, Air, and Soil Pollution* **48,** 209–224.

NYKVIST, N. and SKYLLBERG, U. (1989). The spatial variation of pH in the mor layer of some coniferous forest stands in northern Sweden. *Scandinavian Journal of Forest Research* **4,** 3–11.

OREN, R., SCHULZE, E. D., WERK, K. S. and MEYER, J. (1988a). Performance of two *Picea abies* (L.) Karst. stands at different stages of decline. VII. Nutrient relations and growth. *Oecologia* **77,** 163–173.

OREN, R., WERK, K. S., SCHULZE, E.-D., MEYER, J., SCHNEIDER, B. U. and SCHRAMEL, P. (1988b). Performance of two *Picea abies* (L.) Karst. stands at different stages of decline. VI. Nutrient concentration. *Oecologia* **77,** 151–162.

PRINZ, B. and KRAUSE, G. H. M. (1989). State of scientific discussion about the causes of the novel forest decline in the Federal Republic of Germany. In *Forest decline and air pollution,* eds J. B. Bucher and I. Bucher-Wallin, 27–34. Eidgenössische Anstalt für das forstliche Versuchswesen, Birmensdorf.

PRINZ, B., RRAUSE, G. H. M. and STRATMANN, H. (1982). Waldschäden in der Bundesrepublik Deutschland. *LIS-Berichte* **28.** LIS, Essen.

REHFUESS, C. and REHFUESS, K. E. (1988). Ersatztriebe an Fichten – Entwicklung, Nährstoffversorgung und Bedeutung für die Kronenmorphologie. *Allgemeine Forst- und Jagdzeitung* **159,** 20–26.

REHFUESS, K. E. (1989). Acidic deposition – extent and impact on forest soils, nutrition, growth and disease phenomena in central

Europe: a review. *Water, Air, and Soil Pollution* **48,** 1–20.

REISCH, W. (1983). Bioelementverteilung in Fichtenökosystemen der Bärhalde (Südschwarzwald). *Freiburger Bodenkundliche Abhandlungen* **11,** 1–239.

ROBERTS, T. M., SKEFFINGTON, R. A. and BLANK, L. W. (1989). Causes of Type 1 spruce decline in Europe. *Forestry* **62,** 179–222.

ROELOFS, J. G. M., KEMPERS, A. J., HOUDIJK, A. L. F. M. and JANSEN, J. (1985). The effect of air-borne ammonium sulphate on *Pinus nigra* var. *maritima* in the Netherlands. *Plant and Soil* **84,** 45–56.

ROLOFF, A. (1985a). Schadstufen bei der Buche. *Der Forst- und Holzwirt* **40,** 131–134.

ROLOFF, A. (1985b). Untersuchungen zum vorzeitigenn Laubfall und zur Diagnose von Trockenschäden in Buchenbeständen. *Allgemeine Forst Zeitschrift* **40,** 157–160.

ROLOFF, A. (1989). *Kronenentwicklung und Vitalitätsbeurteilung ausgewählter Baumarten der gemässigten Breiten.* Schriften aus der Forstlichen Fakultät der Universität Göttingen 93.

ROST-SIEBERT, K. and JAHN, G. (1988). Veränderungen der Waldbodenvegetation während der letzten Jahrzehnte – Eignung zur Bioindikation von Immissionswirkungen? *Forst und Holz* **43,** 75–81.

SCHLAEPFER, R., MANDALLAZ, D., COMMARMOT, B., GÜNTER, R. and SCHMID, B. (1985). Der Gesundheitszustand des Waldes im Revier Schaffhausen. Zur Methodik und Problematik der Erhebung auf Betriebsebene. *Schweizerische Zeitschrift für Forstwesen* **136,** 1–18.

SCHMID-HAAS, P. (1989). Do the observed needle losses reduce increments? In *Air pollution and forest decline,* eds J. B. Bucher and I. Bucher-Wallin, 271–275. Eidgenössische Anstalt für das forstliche Versuchswesen, Birmensdorf.

SCHMITT, U., LIESE, W. and RUETZE, M. (1986). Ultrastrukturelle Veräanderungen in grunen Nadeln geschädigter Fichten. *Angewandte Botanik* **60,** 441–450.

SCHÖPFER, W. (1985). Das Schulungs- und Kontrollsystem der terrestrischen Waldschadensinventuren. *Allgemeine Forst Zeitschrift* **40,** 1353–1357.

SCHRÖTER, H. and ALDINGER, E. (1985). Beurteilung des Gesundheitszustandes von Fichte und Tanne nach der Benadelungsdichte. *Allgemeine Forst Zeitschrift* **41,** 438–442.

SCHULTE, A. and SPITELLER, M. (1987). Veränderungen bodenchemischer Parameter im Stammablaufbereich von Buchen. *Der Forst- und Holzwirt* **42,** 150–154.

SCHULZE, E.-D. (1989). Air pollution and forest decline in a spruce (*Picea abies*) forest. *Science* **244,** 776–783.

SCHULZE, E.-D., OREN, R. and LANGE, O. L. (1989a). Processes leading to forest decline: a synthesis. In *Forest decline and air pollution. A study of spruce (*Picea abies*) on acid soils,* eds E.-D. Schulze, O. L. Lange and R. Oren, 459–468. Ecological Studies vol. 77. Springer-Verlag, Berlin.

SCHULZE, E.-D., OREN, R. and LANGE, O. L. (1989b). Nutrient relations of trees in healthy and declining Norway spruce stands. In *Forest decline and air pollution. A study of spruce (*Picea abies*) on acid soils,* eds E.-D. Schulze, O. L. Lange and R. Oren, 392–417. Springer-Verlag, Berlin.

SCHULZE, E.-D., OREN, R. and ZIMMERMANN, R. (1987). Die Wirkung von Immissionen auf 30jahrige Fichten in mittleren Hohenlagen des Fichtelgebirges auf Phyllit. *Allgemeine Forst Zeitschrift* **42,** 725–730.

SHIGO, A. L. (1985). Wounded forests, starving trees. *Journal of Forestry* **83,** 668–673.

SKELLY, J. M. (1989). Forest decline versus tree decline – the pathological considerations. *Environmental Monitoring and Assessment* **12,** 23–27.

SKELLY, J. M., DAVIS, D. D., MERRILL, W., CAMERON, E. A., BROWN, H. D., DRUMMOND, D. B. and DOCHINGER, L. S. (1987). *Diagnosing injury to eastern forest trees.* United States Department of Agriculture, Forest Service, Forest Pest Management, Atlanta, Georgia and the Pennsylvania State University, University

Park, Pennsylvania.
SPIECKER, H. (1987). Düngung, Niederschlag und der jährliche Volumenzuwachs einiger Fichtenbestände Südwestdeutschlands. Ergebnisse einer neuen Methode der Zuwachsermittlung. *Allgemeine Forst- und Jagdzeitung* **158,** 70–76.
DE TEMMERMAN, L. and COOSEMANS, P. (1989). Ammonia and ammonium deposition on pine stands in Belgium. In *Air pollution and forest decline,* eds J. B. Bucher and I. Bucher-Wallin, 91–96. Eidgenössische Anstalt für das forstliche Versuchswesen, Birmensdorf.
THIEBAUT, B. (1988). Tree growth, morphology and architecture, the case of beech: *Fagus sylvatica* L. In *Scientific basis of forest decline symptomatology,* eds J. N. Cape and P. Mathy, 49–72. Commission of the European Communities, Air Pollution Report 15, Brussels.
THORNTON, F. C., SCHAEDLE, M. and RAYNAL, D. J. (1989). Tolerance of red oak and American and European beech seedlings to aluminium. *Journal of Environmental Quality* **18,** 541–545.
ULRICH, B. (1989). Effects of acidic precipitation on forest ecosystems in Europe. In *Acidic precipitation.* Volume 2: *Biological and ecological effects,* eds D. C. Adriano and A. H. Johnson, 189–292. Springer-Verlag, New York.
ULRICH, B., MAYER, R. and KHANNA, P. K. (1980). Chemical changes due to acid precipitation in a loess derived soil in Central Europe. *Soil Science* **130,** 193–199.
UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE (1988). *Forest damage and air pollution. Report of the 1986 forest damage survey in Europe.* United Nations, Geneva.
UNSWORTH, M. H. and WILSHAW, J. C. (1989). Wet, occult and dry deposition of pollutants on forests. *Agricultural and Forest Meteorology* **47,** 221–238.
VERZUNOV, A. I. (1987). Fall dynamics and litter formation in young forest phytocoenoses of the Kokchetav hills. *Lesovedenie* 1987 (2), 59–66.
VISSER, H. and MOLENAAR, J. (1988). Kalman filter analysis in dendroclimatology. *Biometrics* **44,** 929–940.
WEBER, M. and HUBER, W. (1988). Waldbau und Waldschaden Ergebnisse mehrjährige Untersuchungen in geschädigten Fichten–Jungbeständen. *Fortwissenschaftliches Centralblatt* **107,** 26–38.
WESTMAN, L. (1989). A new method for assessment of visible damage to birch and other deciduous trees. In *Air pollution and forest decline,* eds J. B. Bucher and I. Bucher-Wallin, 223–228. Eidgenössische Anstalt für das forstliche Versuchswesen, Birmensdorf.
WESTMAN, L. and LESINSKI, J. A. (1985). Thinning out of the tree crown – what is hidden in that integrated measure of forest damage? In *Inventorying and monitoring of endangered forests,* ed. P. Schmid-Haas, Eidgenössische Anstalt für das forstliche Versuchswesen, Birmensdorf.
WESTMAN, L. and LESINSKI, J.A. (1986). *Kronutglesning och andra förändringar i grankronan.* Naturvårdsverket Rapport 3262.
WINTER, T. G. (1988). *Insects and storm-damaged conifers.* Forestry Commission Research Information Note 134. Forestry Commission, Edinburgh
ZECH, W. and POPP, E. (1983). Magnesiummangel, einer der Gründe für das Fichten- und Tannensterben in NO-Bayern. *Forstwissenschaftliches Centralblatt* **102,** 50–55.
VON ZEZSCHWITZ, E. (1982). Akute Bodenversauerung in den Kammlagen des Rothaargebirges. *Der Forst- und Holzwirt* **37,** 275–276.
VON ZEZSCHWITZ, E. (1985). Immissionsbedingte Änderungen analytischer Kennwerte nordwestdeutscher Mittelgebirgsböden. *Geologisches Jahrbuch F* **20,** 3–41.
ZÖTTL, H. W., HÜTTL, R. F., FINK, S., TOMLINSON, C. H. and WISNIEWSKI, J. (1989). Nutritional disturbances and histological changes in declining forests. *Water, Air, and Soil Pollution* **48,** 87–109 .
ZÖTTL, H. W. and MIES, E. (1983). Der Fichtenkrankung in den Hochlagen des Südschwarzwaldes. *Allgemeine Forst- und Jagdzeitung* **154,** 110–114.

Printed in the United Kingdom for HMSO
Dd.0291299 C18 9/90

HMSO

HMSO publications are available from:

HMSO Publications Centre
(Mail and telephone orders only)
PO Box 276, London, SW8 5DT
Telephone orders 071-873 9090
General enquiries 071-873 0011
(queuing system in operation for both numbers)

HMSO Bookshops
49 High Holborn, London, WC1V 6HB 071-873 0011 (counter service only)
258 Broad Street, Birmingham, B1 2HE 021-643 3740
Southey House, 33 Wine Street, Bristol, BS1 2BQ (0272) 264306
9-21 Princess Street, Manchester, M60 8AS 061-834 7201
80 Chichester Street, Belfast, BT1 4JY (0232) 238451
71 Lothian Road, Edinburgh, EH3 9AZ 031-228 4181

HMSO's Accredited Agents
(see Yellow Pages)

and through good booksellers

£8.50 net

ISBN 0-11-710293-8

9 780117 102934