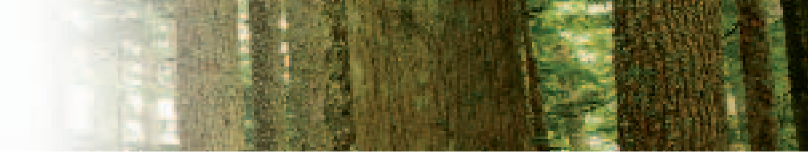
Monitoring of forest health in Britain: The Forest Condition Survey and Level I networks

Steven Hendry

Introduction

Every year, Forest Research undertakes an extensive survey of the condition of Britain's forest trees. The Forest Condition Survey has been carried out since 1984 and, in addition to providing comprehensive information on tree health in Britain, it contributes to an EU programme monitoring the health of a forest area of over 150 million hectares. As well as detecting, quantifying and determining the causes of short-term damage to trees, the presence of long-term trends in the condition of particular tree species can also be detected by the survey. The Forest Condition Survey therefore plays an important role not only in the immediate identification of particular tree health problems but provides information of relevance to studies of pollution effects, climate change and sustainable forest management. This article provides an overview of the history, structure and function of the survey and details its relationship to the ICP-Forests Level I network.



Background

In the mid-1970s, reports of declining forest health began to emanate from Central Europe. Initially, these reports did not cause undue concern since they mainly related to the condition of European silver fir *(Abies alba)*, a species which was known to have suffered periodic declines for at least the previous 100 years (Wachter, 1978). However, by the early 1980s accounts of new and widespread damage to Norway spruce and a number of broadleaved species were being received from Germany and other central European countries. The scale and development of the forest damage which was apparently occurring in Europe prompted many countries to establish national surveys in order to assess the condition of their own forests.

The Forestry Commission initiated the first survey of forest health in Britain in 1984, assessing the condition of Sitka spruce, Norway spruce and Scots pine (Binns *et al.*, 1985). By 1987, the programme had been expanded to include oak and beech and the age range of the trees assessed in the survey had been widened to incorporate older crops of the coniferous species. Plots were also established on private land to increase the survey's geographical coverage and to provide a more representative sample of British forests (Innes and Boswell, 1987).

Forest decline was linked with air pollution by certain scientists and foresters during the 1980s. Concern over atmospheric pollution had already given rise to the Convention on Long-Range Transboundary Air Pollution (CLRTAP) in 1979 and, under its auspices, an International Co-operative Programme on Assessment and Monitoring of Air-Pollution Effects on Forests (ICP-Forests) was set up in 1985. In co-operation with the European Commission (EC), which introduced legislation requiring member states to undertake forest health monitoring programmes in 1986 (Regulation EEC No. 3528/86), an extensive network of forest monitoring plots (the Level I network) was established. By 2002, 17 countries from outwith the EU and 15 EU member states including the United Kingdom were contributing to an ICP-Forests Level I network consisting of approximately 132 000 trees located in 5900 plots and representing a forest area of over 150 million hectares (Lorenz *et al.*, 2003).

The Level I survey was designed to provide accurate information on changes in the extent, distribution and symptoms of forest damage occurring at a European scale. However, to obtain sufficient data to allow the identification of trends in forest condition at a national level many countries, including Britain, established and retained networks of plots at a higher density than that required for the Level I survey. The survey protocols followed by individual countries, although sharing many of the assessments laid out in the ICP-Forests manual (Anon., 1998), also differed according to national requirements (Innes, 1990). This article provides a detailed account of the structure and function of the annual Forest Condition Survey (FCS) carried out in Britain and details its relationship to the ICP-Forests Level I network.

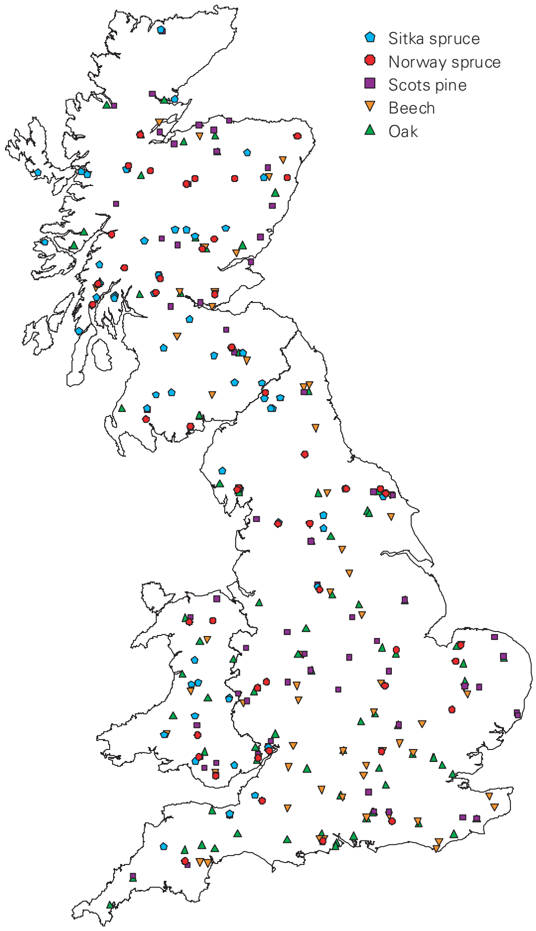
Overview of the Forest Condition Survey

The current Forest Condition Survey is based upon the assessment of five tree species: Norway spruce, Sitka spruce, Scots pine, oak and beech. Each year, between late June and September, the condition of approximately 8400 trees distributed across a network of 350 permanent monitoring plots is determined (Figure 1). Plots consist of 24 trees located in four sub-plots of six trees and, depending upon the species assessed, between 29 and 33 features indicative of condition are scored for each tree. The feature of greatest interest is an assessment of crown density: an estimate of the degree of transparency of the crown which is used as an index of tree condition. Reductions in crown density are estimated in 5% classes by reference either to a standard set of photographs of 'ideal' trees (Innes, 1990) or to 'instant' photographs of individual local reference trees (Anon., 1998). Data are collected on hand-held computers and are checked for consistency and departures from expected values both in the field and before analysis.

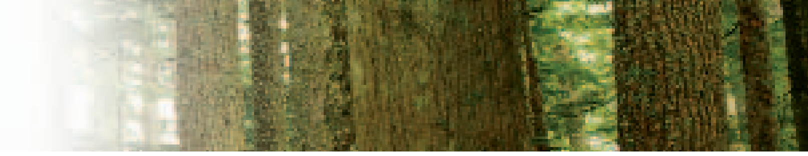
The assessments are carried out by between 15 and 20 regionally based surveyors (Figure 2). Although all of the surveyors participating in the programme receive a week of training prior to the start of each year's survey, between a quarter and a third of all plots are reassessed by one experienced supervisor to check the consistency of assessments. At the conclusion of the survey, the data from both the main and check survey are verified and loaded onto a dedicated Oracle database containing the results of all of the surveys conducted since 1987. Following analysis, the data are reported both nationally and internationally (Hendry *et al.*, 2003; Lorenz *et al.*, 2003).

Figure 1

Distribution of Forest Condition Survey plots in Britain: 2003.



Surveyors record FCS assessments using hand-held computers which provide context-sensitive help and carry out data consistency checks in the field.



Box 1

Two sampling strategies for the assessment of forest condition.

Systematic sampling involves the establishment of monitoring plots at the intersection points of a regularly spaced grid overlaid on the area of interest. Given an appropriate sampling intensity the design benefits from:

- Reflecting the relative abundance and geographical distribution of the surveyed tree species.
- Reflecting the age structure of the wider populations of the surveyed species.

But the design suffers from the disadvantages that:

- Plot numbers will be low for particular species and the condition of plot trees may therefore be unrepresentative of condition at a wider scale.
- The statistical sensitivity of the survey for under-represented species will be poor.
- Geographical coverage may be patchy, negating the possibility of spatial analysis of condition.
- It may not be possible to analyse condition data for the effects of potentially significant co-variables such as pollution deposition or soil moisture deficit.

Stratified sampling involves the identification of a limited number of particular (usually site-related) variables of importance and establishing plots at locations where differences in these variables exist. The design benefits from:

- Allowing the effects of the stratified variables (e.g. pollution deposition, soil moisture deficit) to be tested.
- Ensuring geographical coverage for the species which are assessed and therefore allowing spatial analysis of condition.
- Ensuring that appropriate numbers of plots are present to attain the required statistical sensitivity for all of the species included in the survey.

But the design suffers from the disadvantages that:

- The number of species which can be incorporated into the survey is limited.
- The distribution of plots may not reflect the locations in which the species are numerically important, or the age structure of the wider populations of the surveyed species.

Survey and plot design

The majority of forest condition monitoring programmes in Europe employ survey designs which are based upon either systematic or stratified sampling. Each of these strategies has attendant strengths and weaknesses (see Box 1), and the choice between them depends both upon the key aims of the survey and the nature and distribution of the forests to be assessed.

The Forest Condition Survey was established to a stratified sampling design (Binns *et al.*, 1985; Innes and Boswell, 1989; Mather *et al.*, 1995) with two levels (high and low) of three variables: altitude, rainfall and sulphur deposition. The country was divided into six different regions and, within each of these, plots displaying all possible combinations of level and variable (eight combinations in total) were established for each of the assessed species. Contrastingly, the Level I survey to which the UK contributes, is based upon systematic sampling from a 16 x 16 km grid covering the British Isles and Continental Europe (Regulation EEC No. 1696/87). The differing requirements of these two sampling strategies were reconciled by establishing a specific subset of Level I plots in the UK in 1987 (Innes and Boswell, 1987).

Table 1

Numbers of Forest Condition Survey (FCS) plots by type and species in 2003.

Species		Number of plots	
	FCS + Level I	FCS only	FCS total
Beech	12	53	65
Norway spruce	12	42	54
Oak	18	68	86
Scots pine	15	66	81
Sitka spruce	23	37	60
Mixed (Sitka spruce & Scots pine)	3	0	3
Total	86	266	349

By their inclusion in the Forest Condition Survey, the Level I plots have blurred the original stratification of the sampling design but this effect is limited since they constitute less than 25% of plots which are assessed each year (Table 1).

The non-systematic design of the FCS allows the condition of a limited number of key species to be assessed efficiently across their entire range in Britain. Although less-common tree species are not represented, the quantity of data gathered for those species which are included in the survey increases its statistical sensitivity to any changes in their condition. The range of locations at which plots have been established, and the associated variety of site conditions which are sampled, also allows sufficient flexibility for unforeseen stratification of the survey data to be carried out (Mather *et al.*,1995). This not only makes the analysis of existing data in the light of new findings possible but also demonstrates that the survey is capable of responding to unforeseen circumstances – a key requirement for any long-term monitoring programme (Skalski, 1990).

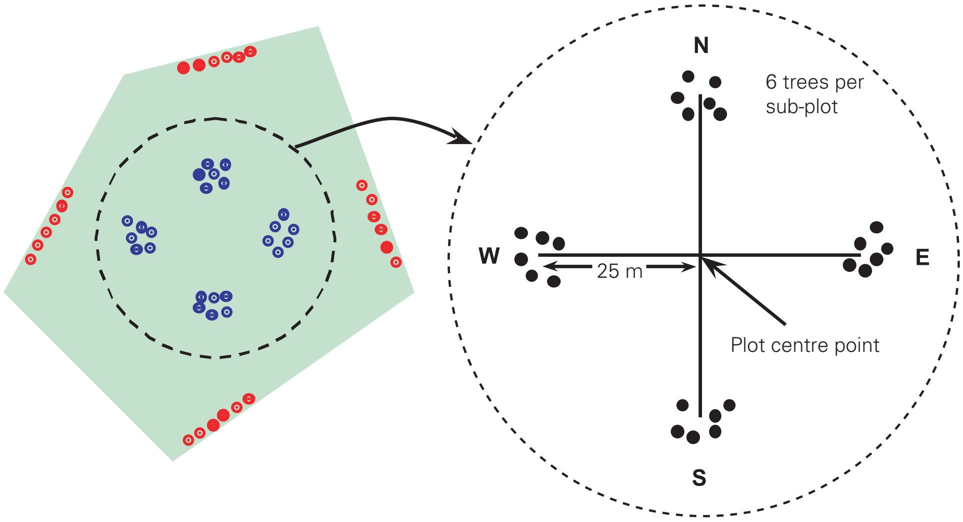
Plot design

All Forest Condition Survey plots, barring three which have been established in mixed crops, are located in even-aged stands of a single tree species. The plot design employed in the FCS follows the recommendations for the Level I survey (Anon., 1998) and consists of 24 dominant or co-dominant trees located in four sub-plots of six trees. Adaptation of the standard cross-cluster design for survey plots is, however, frequently required in Britain (Binns *et al.*, 1985). In dense crops, where the crowns of trees located within the stand are not clearly visible from the ground, sub-plots are established in openings within the crop or on the stand margins closest to the plot centre (Figure 3). Although previous work from the Republic of Ireland and elsewhere has suggested that there may be differences in crown density between edge trees and those within stands (Moffat and Durrant, 1998), the edge trees assessed in the FCS are located along internal boundaries within forests and are unlikely to be exposed to the weather, pollution levels and light conditions experienced by trees at forest margins. A recent study conducted on FCS plots found no significant difference in crown density between plots of trees located on stand edges and plots established inside the same crops (Durrant and Boswell, 2002).

To ensure that the survey plots are truly representative of normal forest crops, no management restrictions are placed upon the stands which contain them, and both sample trees and entire plots can therefore be lost as a result of thinning or clearfelling operations.

Figure 3

Forest Condition Survey plot designs for dense crops (red circles) and open crops (blue circles).



Lost trees are replaced by selecting suitable replacements located as close to any remaining sub-plot trees as possible, whilst plot losses are generally made good by the establishment of new plots in similar crops nearby.

Forest Condition Survey assessments

A record of site history and physical characteristics, including soil type, is maintained and updated annually for each FCS plot. Assessments carried out on individual trees vary according to species, with the number of variables recorded currently ranging from 29 for oak and beech to 33 for Sitka and Norway spruces (Table 2). Basic mensurational data are also collected via an assessment of diameter at breast height for each tree. Tree heights are measured when plots are first established but are only recorded at irregular intervals thereafter. In addition, all assessors are trained to identify common types of biotic and abiotic damage and these are recorded as comments which qualify certain damage scores (Figure 4).

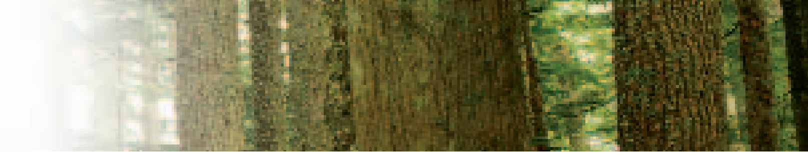
The assessment which is most widely reported from both the FCS and Level I surveys is that of crown density. This is an indirect assessment of defoliation which compares the opacity of the crown of the subject tree with that of a standard reference tree bearing full foliage. Two estimates of crown density are possible: absolute crown density which compares the subject tree with an ideal reference tree with a totally opaque crown, and local crown density which compares the subject tree with a local reference tree (the most densely foliated tree of the same species and age as the subject tree growing under local conditions). Under most circumstances, and particularly in exposed

Mining by larvae of the weevil *Rhynchaenus fagi* results in damage and discoloration of beech leaves.

Table 2

Variables assessed for FCS sample trees by species.

Variables		Sitka spruce	Norway spruce	Scots pine	Beech	Oak
1	Diameter at breast height	✔	✔	✔	✔	✔
2	Height	✔	✔	✔	✔	✔
3	Dominance	✔	✔	✔	✔	✔
4	Canopy closure	✔	✔	✔	✔	✔
5	Crown density – local	✔	✔	✔	✔	✔
6	Crown density – absolute	✔	✔	✔	✔	✔
7	Branch pattern	✔	✔			
8	Crown form			✔		✔
9	Defoliation type	✔	✔	✔	✔	✔
10	Shoot death (crown)	✔	✔	✔		
11	Shoot death (branches)	✔	✔	✔		
12	Shoot death extent	✔	✔	✔		
13	Dieback type				✔	✔
14	Dieback location				✔	✔
15	Dieback extent				✔	✔
16	Location of secondary shoots	✔	✔			
17	Abundance of secondary shoots	✔	✔			
18	Epicormics					✔
19	Flowering			✔		
20	Fruiting	✔	✔	✔	✔	✔
21	Needle retention	✔	✔	✔		
22	Browning – current	✔	✔	✔	✔	✔
23	Browning – current type				✔	✔
24	Browning – old	✔	✔	✔		
25	Yellowing – current	✔	✔	✔	✔	✔
26	Yellowing – current type	✔	✔	✔	✔	✔
27	Yellowing – old	✔	✔	✔		
28	Yellowing – old type	✔	✔	✔		
29	Overall discoloration	✔	✔	✔	✔	✔
30	Leaf rolling				✔	
31	Premature leaf loss				✔	
32	Mechanical damage type 1	✔	✔	✔	✔	✔
33	Extent of mechanical damage type 1	✔	✔	✔	✔	✔
34	Mechanical damage type 2	✔	✔	✔	✔	✔
35	Extent of mechanical damage type 2	✔	✔	✔	✔	✔
36	Butt and stem damage	✔	✔	✔	✔	✔
37	Game damage	✔	✔	✔	✔	✔
38	Insect damage	✔	✔	✔	✔	✔
39	Fungal damage	✔	✔	✔	✔	✔
40	Abiotic damage	✔	✔	✔	✔	✔
41	Anthropogenic damage	✔	✔	✔	✔	✔
42	Fire damage	✔	✔	✔	✔	✔
43	Pollution damage	✔	✔	✔	✔	✔
44	Other damage	✔	✔	✔	✔	✔
45	Comments	✔	✔	✔	✔	✔



areas, the local reference tree does not possess a totally opaque crown and therefore represents a less stringent standard for comparison than an ideal reference tree. Between 1984 and 1992 only absolute crown density was assessed as part of the Forest Condition Survey but since 1993 local crown density has also been determined to harmonise with the survey protocols employed by most other countries contributing to the Level I monitoring programme.

A local crown density assessment might be seen as providing a more realistic impression of a tree's condition because it takes into account factors such as tree age and exposure which will affect the crown condition of even the healthiest trees in a particular locality. However, because trees in different areas of the country are being compared with reference trees in different states of defoliation, direct comparisons of local crown density scores between plots can be misleading. The relative condition of trees in different localities can only be determined if the condition of the local reference trees for each plot are known (Redfern and Boswell, 2004). Absolute crown density scores do not suffer from similar problems of interpretation because all trees are assessed with reference to a common standard. The condition of trees in different locations or at different times can therefore be directly compared.

The function of many of the FCS assessments is to qualify the crown density scores which are obtained for each tree. In some cases, low crown density scores can be directly attributed to certain causes, e.g. to mechanical damage such as breakage of branches by wind or snow, resulting in gaps within the tree's crown. In many instances, however, it is necessary to examine the change in crown density of a species, plot or individual tree and to relate this to changes in other attributes in order to identify potential cause(s) of defoliation. For example, a decrease in the mean crown density of a species between one year and the next may be related to an increase in damage from defoliating insects (Box 2).

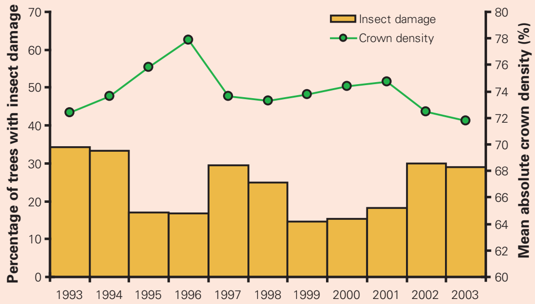
Box 2

Crown density and insect damage in Sitka spruce.

In Britain, Sitka spruce is occasionally subject to severe defoliation by the green spruce aphid *Elatobium abietinum*. In winter, spring and early summer the aphid feeds on mature needles which become discoloured and quickly fall. In certain years, outbreaks of the insect are widespread and Sitka spruce is defoliated over large areas of the country. The Forest Condition Survey results for the period 1993–2003 clearly show two occasions on which the crown density of Sitka spruce has deteriorated markedly: between 1996 and 1997, and between 2001 and 2002 (Figure 5). On both of these occasions, the proportion of trees in the sample population which was recorded as being damaged by insects increased notably. With few exceptions, the insect damage which occurred in 1997 and 2002 was identified by the FCS surveyors as being caused by *Elatobium abietinum* (Redfern *et al.*, 1998; Hendry *et al.*, 2003).

Figure 5

Mean absolute crown density and percentage of trees recorded as insect-damaged for Sitka spruce in the period 1993–2003.



The connectivity survey

The assessments which are made during forest condition monitoring exercises are subject to human error. Appropriate checking of the quality of survey assessments is therefore essential if recorded differences in crown density and other variables are to be ascribed to differences in the condition of the assessed trees rather than differences in the accuracy and consistency of the assessments themselves.

The importance of quality assurance was recognised at the inception of the FCS (Binns *et al.*, 1985) and the first check or 'connectivity' survey to determine the nature and extent of any assessor bias was implemented in 1985 (Binns *et al.*, 1986). Considerable differences were initially detected between the scores which different surveyors allocated to the same trees and improvements in both survey procedures and surveyor training were instigated to address this problem (Innes, 1993). Greater accuracy was also introduced into the connectivity survey by comparing the surveyors' results with those of a single experienced assessor rather than relying upon the inter-comparison of scores obtained by the surveyors themselves (Innes and Boswell, 1987).

Since 1995, the FCS connectivity survey has involved the re-assessment of between a quarter and a third of all survey plots by a single experienced assessor (the standard observer). Individual plots are assessed simultaneously but independently by both the standard observer and the surveyor being tested, thus ensuring that the appearance of the trees and the conditions under which they are viewed are the same for both assessors. Differences in the scores obtained by the standard observer and the surveyor therefore reflect differences only in their respective assessments of the condition of the trees.

For crown density assessments, surveyor bias is detected by calculating the average difference between the scores of the assessor and the standard observer (Figure 6). For comparisons conducted on a single plot of 24 trees, a difference of 5% or more has been found to provide a reliable indication of the presence of statistically significant bias (Redfern and Boswell, 2004). While a small number of comparisons usually reveal differences of this magnitude each year, e.g. in 4 of the 47 combinations of surveyor and species shown in Figure 6, consistent bias (i.e. bias affecting several species for an individual surveyor) has only been detected on two occasions during the past 10 years of the survey (Redfern *et al.,* 1996; 1998).

Survey results

Detailed data on the condition of each tree in the Level I subset of survey plots, and summary data for the entire Forest Condition Survey, are provided by Forest Research to ICP-Forests each year in fulfilment of the UK's obligations under EU regulations and CLRTAP. This information contributes to a joint EC/UNECE annual report on forest condition which informs policy decisions on forest health at a European scale (Anon., 2003a). Further dissemination of the Level I data also occurs through the Statistical Office of the European Communities (EUROSTAT, 2003) and the UNECE (Anon., 2003b).

At a national level, the results of each survey since 1984 have been published annually by the Forestry Commission (e.g. Binns *et al.*, 1985; Hendry *et al.*, 2003) in order to highlight any short-term or long-term changes in the condition of the surveyed species. Short-term changes in crown density, and geographical variations in the condition of the species in particular years, are attributed where appropriate to the action of particular damaging agents (see Box 2 and

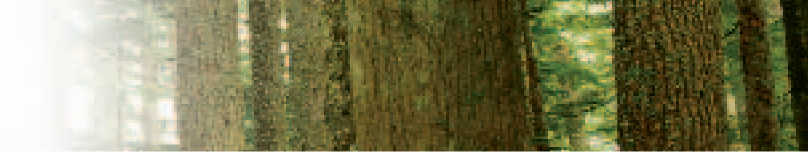


Figure 6

Mean differences between the absolute crown density results obtained by the surveyors and the 'standard observer' on a sample of 88 plots in 1999. Differences are represented by bars for each surveyor/species combination tested. Assessor 12 was the 'standard' observer.

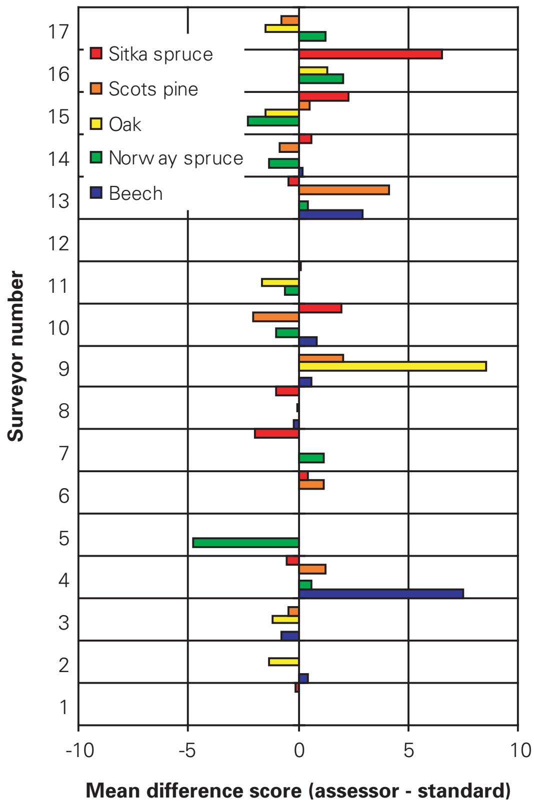


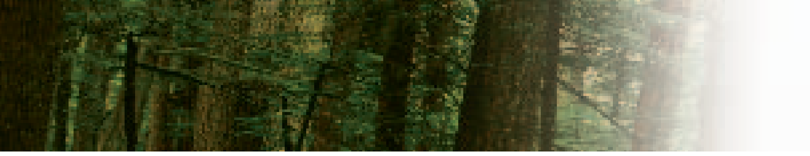
Figure 7

Bud blight of Norway spruce caused by the fungus *Cucurbitaria piceae* leads to death and distortion of shoots and can reduce the crown density of heavily infected tress.

Figure 7). Although statistically significant long-term trends in the crown density of particular species can also be detected, these are difficult to interpret since the time-series is of relatively short duration and the trends can be negated by relatively small changes in tree condition from year to year (Hendry *et al.*, 2002).

Analysis of the FCS dataset to identify correlations between tree condition and other factors has indicated that soil moisture deficit and potential evapotranspiration are significant explanatory variables with respect to changes in crown density for all of the surveyed species. Other indices recorded as part of the Forest Condition Survey which have been found to be strongly correlated with environmental variables include: masting in beech, flowering in Scots pine, shoot death in Scots pine, insect damage in all species except oak, and fungal damage in oak (Mather *et al.*, 1995).

It is important to note that correlations may suggest but do not establish the existence of causal links between variables. Environmental variables in particular display strong correlations with each other and, as a result, a significant relationship between crown condition and any particular environmental factor cannot be interpreted with certainty as demonstrating cause and effect. However, the assessments of tree condition obtained via the Forest Condition



Survey can provide compelling evidence that certain factors are not responsible for changes in tree condition and can indicate those variables which may be influencing long-term trends in forest health and which therefore require further study. In order to establish cause–effect relationships in such cases, a different and more intensive approach to forest monitoring is required. Such an approach is adopted in the EU Level II programme established in 1994 (EC Regulation 1091/94), which consists of a restricted network of plots across Europe, including 20 in Great Britain, at which detailed tree condition and environmental monitoring is conducted (Durrant, 2000). Thus, a complementary system of extensive monitoring via the Forest Condition Survey/Level I network and intensive monitoring via the Level II network ensures that changes in the condition of British forests are both detected and investigated at appropriate scales

Conclusions

The Forest Condition Survey, including its Level I component, provides a national overview of forest health in Great Britain. Focussing on a key selection of forest tree species over a wide geographical range, the survey continues to gather a unique time series of forest health data. This information not only fulfils the UK's international obligations to provide data on forest condition and indicators of sustainable forestry (Anon., 2001) but also supports national forestry policy, the UK Forestry Standard (Anon., 2004) and the UK Woodland Assurance Scheme (Anon., 2000). Whilst originally established to address the potential effects of air pollution on forests, the Forest Condition Survey remains responsive to changing requirements for data on tree health.

References

Anon. (1998). *Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests*, 4th edn. UNECE/EC, Hamburg and Brussels.

Anon. (2000). *Certification Standard for the UK Woodland Assurance Scheme.* UKWAS Steering Group. Forestry Commission, Edinburgh.

Anon. (2001). *UK indicators of sustainable forestry.* Forestry Commission/Northern Ireland Forest Service. Forestry Commission, Edinburgh.

Anon. (2003a). *The condition of forests in Europe - 2003 executive report.* UNECE/EC, Geneva and Brussels.

Anon. (2003b). *State of Europe's forests 2003.* MCPFE/UNECE. Ministerial Conference on the Protection of Forests in Europe. Liaison Office, Vienna.

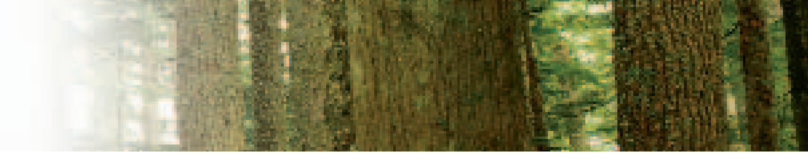
Anon. (2004). *The UK Forestry Standard - the government's approach to sustainable forestry.* Forestry Commission, Edinburgh.

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.

Binns, W.O., Redfern, D.B., Boswell, R. and Betts, A.J.A. (1986). *Forest health and air pollution 1985 survey.* Forestry Commission Research and Development Paper 147. Forestry Commission, Edinburgh.

Durrant, D. (2000). *Environmental monitoring in British forests.* Forestry Commission Information Note 37. Forestry Commission, Edinburgh.

Durrant, D. and Boswell, R. (2002). Comparison of crown density assessments on trees within the stand and on ride edges within the forest. *Forest Ecology and Management* **157**, 1–6.



EUROSTAT (2003). *Forestry statistics - data 1990-2002.* Publication no. KS-59-04-306-EN-N. Office for Official Publications of the European Communities, Luxembourg.

Hendry, S.J., Boswell, R.C. and Proudfoot, J.C. (2002). *Forest condition 2001.* Forestry Commission Information Note 46. Forestry Commission, Edinburgh.

Hendry, S.J., Boswell, R.C. and Proudfoot, J.C. (2003). *Forest condition 2002.* Forestry Commission Information Note 51. Forestry Commission, Edinburgh.

Innes, J.L. (1990). *Assessment of tree condition.* Forestry Commission Field Book 12. HMSO, London.

Innes, J.L. (1993). *Forest health: its assessment and status.* CAB International, Wallingford.

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. (1989). *Monitoring of forest condition in the United Kingdom.* Forestry Commission Bulletin 88. HMSO, London.

Lorenz, M., Mues, V., Becher, G., Müller-Edzards, C., Luyssaert, S., Raitio, H. Fürst, A. and Langouche, D. (2003). *Forest condition in Europe - results of the 2002 large-scale survey.* UNECE/EC, Geneva and Brussels.

Mather, R., Freer-Smith, P. and Savill, P. (1995). *Analysis of the changes in forest condition in Britain: 1989 to 1992.* Forestry Commission Bulletin 116. HMSO, London.

Moffat, A. and Durrant, D. (1998). European programme for the intensive monitoring of forest ecosystems - the Level II network. In: *Forest Research Annual Report and Accounts 1997–1998.* The Stationery Office, Edinburgh.

Redfern, D.B. and Boswell, R.C. (2004). Assessment of crown condition in forest trees: comparison of methods, sources of variation and observer bias. *Forest Ecology and Management* **188**, 149–160.

Redfern, D., Boswell, R. and Proudfoot, J. (1996). *Forest condition 1995*. Forestry Commission Research Information Note 282. Forestry Commission, Edinburgh.

Redfern, D.B., Boswell, R.C. and Proudfoot, J.C. (1998). *Forest condition 1997.* Forestry Commission Information Note 4. Forestry Commission, Edinburgh.

Regulation EEC No. 3528/86 (1986). Council Regulation (EEC) No. 3528/86 of 17 November 1986 on the protection of the Community's forests against atmospheric pollution. *Official Journal L* **326**, 21/11/1986, 2–4.

Regulation EEC No. 1696/87 (1987). Commission Regulation (EEC) No. 1696/87 of 10 June 1987 laying down certain detailed rules for the implementation of Council Regulation (EEC) No. 3528/86 on the protection of the Community's forests against atmospheric pollution (inventories, network, reports). *Official Journal L* **161**, 22/06/1987, 1–22.

Regulation EEC No. 1091/94 (1994). Council Regulation (EEC) No. 1091/94 of 29 April 1994 laying down certain detailed rules for the implementation of Council Regulation (EEC) No. 3528/86 on the protection of the Community's forests against atmospheric pollution. *Official Journal L* **125**, 18/05/1994,1–44.

Skalski, J.R. (1990). A design for long-term status and trends monitoring. *Journal of Environmental Management* **30**, 139–144.

Wachter, A. (1978). Deutschprachige Literatur zum Weißtannensterben (1930-1978). *Zeitschrift für Pflanzenpathologie und Pflanzenschutz* **85**, 361–381.