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Assessment of crown condition in forest trees: comparison of methods, sources of variation and observer bias

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Abstract

In Britain, as part of an annual survey of forest 'health' conducted throughout Europe, the condition of trees is assessed visually by comparing the transparency of crowns when viewed against the sky with standard photographs. Two standards of comparison have been used: (1) an 'ideal' or 'perfect' tree for each species carrying the maximum possible amount of foliage, and (2) a tree with the maximum amount of foliage under local growing conditions. These are referred to as the absolute and local reference trees respectively. Results are expressed as a percentage reduction in either absolute or local crown density. Annual assessments of ~8500 trees based on these two standards were compared for the period 1995–2000.

Reductions in crown density were smaller when trees were compared with a local reference tree than when they were compared with an absolute reference tree. Differences between results obtained by the two methods over the 6-year survey period were smaller for conifers (Scots pine 11.3%, Norway spruce 9.3%, Sitka spruce 8.0%) than for broadleaved species (oak 16.0% and beech 13.1%). Assessments were carried out by regionally-based assessors, and a proportion of plots was re-assessed by a 'standard observer' to check the consistency of scoring. A mean bias of >5% on a single 24-tree plot was significant but affected <10% of plots. There was little difference in performance by assessors on the two types of assessment.

For broadleaved trees reductions in absolute crown density were significantly greater in the west of Britain than in the east and differences between results obtained by the two methods were also greater in the west than in the east. It is suggested that this may be associated, among other things, with increased exposure to wind in the west, resulting in greater crown transparency. The use of absolute reference trees enabled geographical differences in crown transparency to be detected more frequently than was possible using local reference trees.

It is concluded that assessments based on an absolute (fixed) standard for each species offers the best means of detecting changes in crown condition with time and of identifying geographical differences. A relationship established between crown transparency scores based on absolute and local reference trees offers a means of adjusting scores from one basis to the other only in limited circumstances. It might not be appropriate to do this in order to facilitate international comparisons.

Keywords: Forest condition; Assessment methods

1. Introduction

A national programme to assess crown condition began in Germany in 1982 following concern about

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the possibility of widespread damage to forests by air pollution. An increasing number of countries became involved in such assessments in the next few years. Throughout Europe forest condition is now monitored annually under the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests. This programme was established in 1985 under the auspices of the Convention on Long-range Transboundary Air Pollution. In 1987 annual assessment became mandatory throughout the European Union. The results for 36 countries are now published jointly by the United Nations Economic Commission for Europe and the European Commission. In 1997 the results from 10 years of monitoring were published (Anon., 1997).

In Britain monitoring began in 1984 (Binns et al., 1985). Methods followed those used in Germany, with some modifications to suit the type of forest found in Britain. Methods were sufficiently standardised by 1987 to permit a time-series to be established for the crown condition of five species (Redfern et al., 2000).

The condition of trees in sample plots is assessed by estimating the degree of defoliation compared to the amount of foliage on a standard reference tree. Defoliation may be assessed directly, for example by counting the number of needle-years held by a tree and comparing this figure with the number a fully foliated tree might be expected to carry (Anon., 1994a). Alternatively, defoliation may be assessed indirectly by comparing the degree of transparency of the crown when viewed against the sky with standard photographs of trees with full foliage (this can also be referred to as a reduction in crown density). Neither method provides a completely objective estimate of defoliation. The latter integrates branching frequency with the amount of foliage. This is the method used in Britain. Until 1993 the basis for comparison was an 'ideal' or 'perfect' tree for each species carrying the maximum possible amount of foliage under ideal growing conditions. In essence this is a tree with a totally opaque crown. Assessment gives rise to a score for each tree referred to as the 'absolute reduction in crown density' (ARCD) for that tree. However, in other countries comparisons are made with reference to a tree with the maximum amount of foliage under the conditions obtaining locally. Under most circumstances, and especially in exposed conditions, it could be expected that this method would provide a higher baseline from which to make a comparison than the absolute tree method, i.e. the score for reduction in crown density would be lower. Results obtained using this method are referred to here as the 'local reduction in crown density' (LRCD). It can be seen that the spatial distribution of damage reported throughout Europe is therefore affected by differences in the assessment methods used and by the type of reference tree adopted (Innes et al., 1993; Dobbertin et al., 1997). Reference standards may also change over time (Landmann et al., 1999).

While the principle of a local reference tree is easily understood, the precise definition has varied. For use as a standard when assessing the so-called Level I (wide-scale monitoring) plots it was defined in manuals produced in 1989, 1994, 1998 and 2001 as follows: "the reference tree could be either a healthy tree in the vicinity (of the same crown type), a photograph, locally applicable, or the sample tree itself with imagined full foliage... Observers should be provided with locally applicable, standard photographs of trees of each species and of different crown types with which to compare the trees to be assessed" (Anon., 1989, 1994b, 1998, 2001). However, in connection with the assessment of Level II (intensive monitoring) plots the local reference tree was further defined, as "the best tree with full foliage that could grow at a particular site, taking into account factors such as altitude, latitude, tree age, site conditions and degree of dominance. It has 0% defoliation. This tree should represent the typical crown morphology and age of trees in the plot. In all cases it is conceptual (imaginary)" (Anon., 1998).

In order to harmonise results with those obtained in most other countries, since 1993 crown transparency estimates in Britain have been made using the local tree method. However, in order to maintain the existing time-series of figures, parallel assessments continued using the previous absolute standard for each species. The purpose of this paper is to compare the results obtained by these two methods and examine the feasibility of adjusting scores to permit more realistic geographical comparisons throughout Europe.

2. Methods

2.1. Absolute and local reductions in crown density, 1995–2000

Reductions in crown density were assessed annually on approximately 8500 trees of five species distributed over the following numbers of permanent plots: 70 Sitka spruce (*Picea sitchensis* (Bong.) Carr.), 60 Norway spruce (*P. abies* (L.) Karst.), 80 Scots pine (*Pinus sylvestris* L.), 85 oak (*Quercus* spp.) and 60 beech (*Fagus sylvatica*). The number of trees and plots varied slightly from year to year due to differences between losses (due to windthrow or clear-felling) and the recruitment of new plots. Plots were distributed throughout Britain. When assessment was first instituted in Britain, in 1984, species choice was restricted to the three conifers and plots were stratified by geographical region, altitude, rainfall and sulphur deposition. Tree age was restricted to 30–45 years (Binns et al., 1985). Subsequent changes in the criteria used to select additional plots and to replace losses have blurred the original stratification. In particular, the minimum age for qualification has been reduced from 30 to 5 years and there is no upper age limit. The locations of plots in the most recent assessment are shown in Redfern et al. (2000).

Plots consist of 24 trees, located in four sub-plots of six trees. In open crops in which individual crowns can be seen clearly from a viewpoint within the stand, the sub-plots are located within the stand in a cruciform pattern (Anon., 1998). In dense stands, where visibility is impaired, the four sub-plots are located in openings within the stand or on stand margins nearest

Fig. 1. Examples of reference trees used to assess absolute reductions in crown density for oak, showing (a) a 10% reduction in density and (b) a 55% reduction in density. From Innes (1990). Assessment of tree condition. Forestry Commission Field Book No. 12. HMSO, London.

to the plot centre and approximately at the cardinal points. In this case, edge trees fulfilling certain criteria are chosen for assessment at random (Binns et al., 1985). Durrant and Boswell (2002) found no significant difference in crown transparency between trees in plots located on stand edges within the forest, and those in plots within stands.

Crown transparency was assessed between the beginning of July and the end of August by 15–20 regionally-based assessors. Inconsistencies in scoring were minimised by training conducted prior to each annual assessment by an experienced supervisor. For each plot tree the reduction in crown density was estimated in 5% classes by comparing the upper two-thirds of the live crown with photographs of either absolute or local reference trees. The lower crowns of trees were excluded to avoid the effects of suppression. Examples of absolute reference photographs for use in Britain are available in Innes (1990). This booklet contains several photographs for each species showing trees with a range of crown transparencies (Fig. 1). A local reference tree was chosen for each plot in the first year of assessment. This was a tree of the appropriate species with the greatest amount of foliage from among those in the general vicinity of the plot (Fig. 2): it could have been a plot tree. Most plots contained only one species, but for those with mixed species two or more local reference trees were required. An ''instant'' photograph was used for comparison with the plot trees. The same photograph was used in subsequent years if it continued to represent the best tree. In each plot LRCD was assessed first, followed by a number of assessments not related to crown density and finally ARCD was assessed. Data were collected on hand-held computers and checked for consistency and departures from expected values both in the field and before analysis.

2.2. Bias

In order to check the consistency of scoring among assessors, approximately 25% of plots were reassessed each year by one experienced supervisor (the standard observer). This was done on a sub-set of plots located on, or close to, a 16 km × 16 km trans-European grid (Anon., 2000). For the majority of plots, both assessments were done at the same time but occasionally there was an interval of some days. In 1999 and 2000 the absolute crown density data were analysed for evidence of bias. The analysis assumed that differences could be treated as continuous variables (Ghosh et al., 1995), and the model tested for the main effects of species and assessor, and the interaction between them. The main effects were

Fig. 2. Example of a 'local' reference tree for a plot of 130-year-old oak growing at an altitude of 100 m.

tested against a pooled estimate of the variation present in the plots stratum. This variance was then used to create approximate standard errors for each assessor/species cell, based on the number of comparisons, and to calculate 'significant' assessor bias at a probability of $P = 0.05$.

2.3. Factors affecting the relationship between ARCD and LRCD

Crown transparency is affected by a number of biotic and climatic factors such as droughts and attacks by fungi and insects (Redfern et al., 2000). The effects are often localised and of short duration, but other adverse factors such as exposure to wind have widespread effects that may persist for the life of the crop. The effect of exposure, which is particularly important in Britain, is greatest in the north and west. In these locations, sensitive species could be expected to have more transparent crowns than elsewhere. Because the local reference tree would be affected similarly, LRCD would not reflect the difference, whereas the reduction in absolute crown density would be greater than elsewhere. Accordingly, the difference between crown densities derived from absolute and local reference trees would be greater. This hypothesis was tested for oak, beech and Scots pine, the three species most uniformly distributed in Britain, by analysing the difference between ARCD and LRCD for plots west and east of a line from Plymouth (50°15′N, 4°W) to Newcastle (55°N, 1°40′W). This line approximately bisects the country from north to south. The distribution of differences in the two populations of plots was tested using the non-parametric Kolmogarov–Smirnov two-sample test.

3. Results

3.1. Absolute and local crown density reductions, 1995–2000

Reductions in crown density determined by comparison with absolute and local reference trees for each of the six years 1995–2000 are shown in Fig. 3. The corresponding standard errors are shown in Table 1. For all species the mean reduction in crown density was smaller using a local tree rather than an ideal tree as the basis for comparison. Mean differences between results obtained by the two methods were smaller for the conifers (Scots pine 11.3%, Norway spruce 9.3%, Sitka spruce 8.0%) than for the broadleaved species (oak 16.0% and beech 13.1%). Standard errors were smaller for the LRCD estimates than for the ARCD estimates.

Fig. 4 shows the distribution of trees in 10% crown density classes when assessed by comparison with absolute and local reference trees. It can be seen from this that the difference between results obtained using the two methods (Fig. 3) largely reflects changes in the proportions of trees recorded in the lowest crown density classes.

The 'local' reference tree shown in Fig. 2 was selected to assess a plot in southwest Scotland. Fig. 5 shows the assessment results for 1999 for all 24 trees in this plot using both this reference tree and

Table 1
Standard errors associated with the reductions in crown density shown in Fig. 3[a]

Year	Scots pine		Norway spruce		Sitka spruce		Oak		Beech	
	A	L	A	L	A	L	A	L	A	L
1995	0.696	0.574	1.135	0.739	1.232	0.846	1.100	0.786	0.876	0.639
1996	0.654	0.617	1.146	0.903	1.028	0.709	1.139	0.768	0.851	0.702
1997	0.700	0.700	1.196	0.933	1.037	0.711	0.987	0.983	1.011	0.660
1998	0.695	0.655	1.124	0.989	1.118	0.962	0.906	0.875	1.026	0.755
1999	0.749	0.709	0.988	0.951	1.075	0.853	0.844	0.764	0.968	0.718
2000	0.807	0.708	1.133	0.971	0.961	0.843	0.866	0.832	0.809	0.715
Number of plots	79–84		55–70		69–81		83–85		59–62	

[a] The number of plots shown is the maximum and minimum for each species during the period 1995–2000. A: ARCD; L: LRCD.

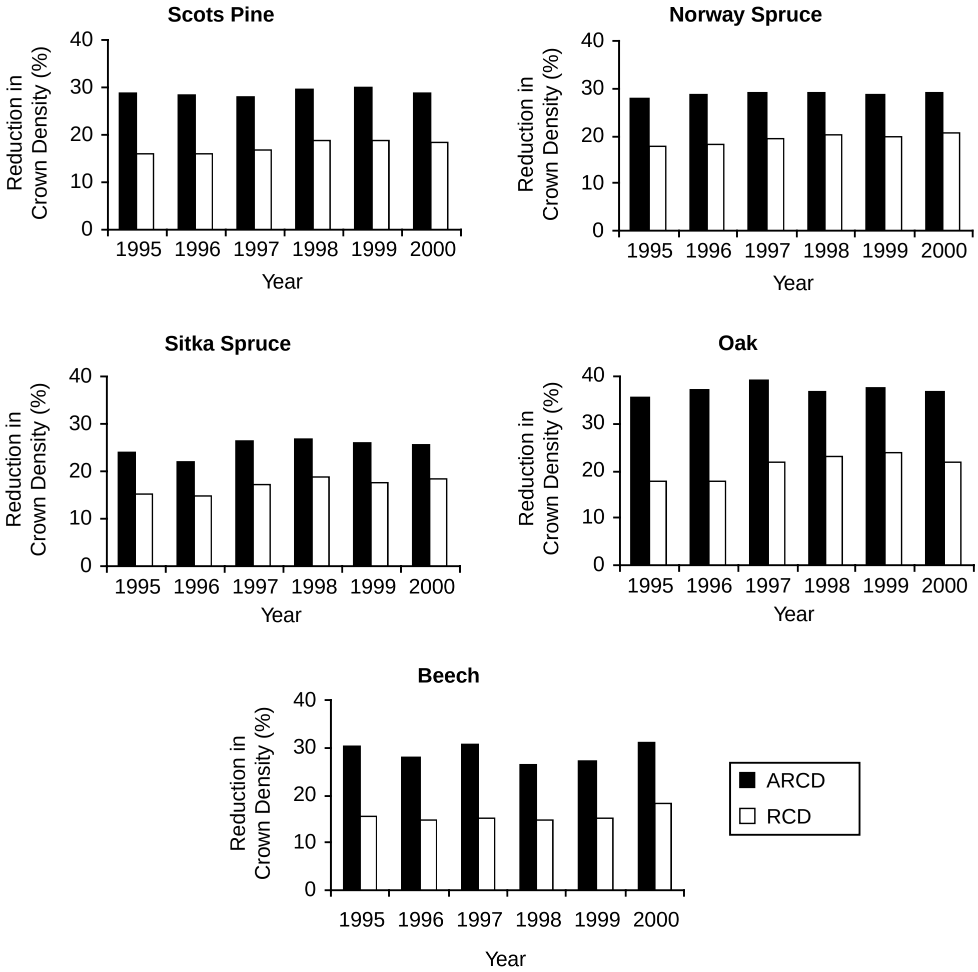

Fig. 3. Mean percent reductions in crown density for five species for the years 1995–2000 determined by comparison with either an 'ideal' tree, i.e. a tree with the maximum possible amount of foliage, or with a 'local' tree, i.e. a tree with full foliage under local conditions. Reductions in crown density determined by reference to these two standards are referred to as the absolute reduction in crown density (ARCD) and the local reduction in crown density (LRCD) respectively.

the absolute reference trees illustrated in Innes (1990), examples of which are shown in Fig. 1.

3.2. Bias

Fig. 6 shows an example, for 1999, of differences in scoring between 16 individual assessors and the standard observer (number 12) for both LRCD and ARCD for each species. Not all the 80 combinations of species and assessor could be compared but in 47 of them at least one plot was available for comparison, and in 21 instances there were two or more. The figure suggests that overall there was little difference in the performance by assessors on the two types of assessments and there was little evidence of bias in scoring individual species. One assessor (11) apparently showed consistent bias in scoring LRCD across several species (Fig. 6b), but only the largest difference was likely to be significant (see later). Analysis of the ARCD data suggested that there were no effects of species or any species/assessor interaction. In Fig. 6a bias was highly significant ($P < 0.001$) in three combinations of assessor and species, i.e. beech 4, oak 9 and Sitka spruce 16. In these instances differences ranged from 6.53 to 8.54% and there were 48 trees or more (two or more plots) in the comparison. The

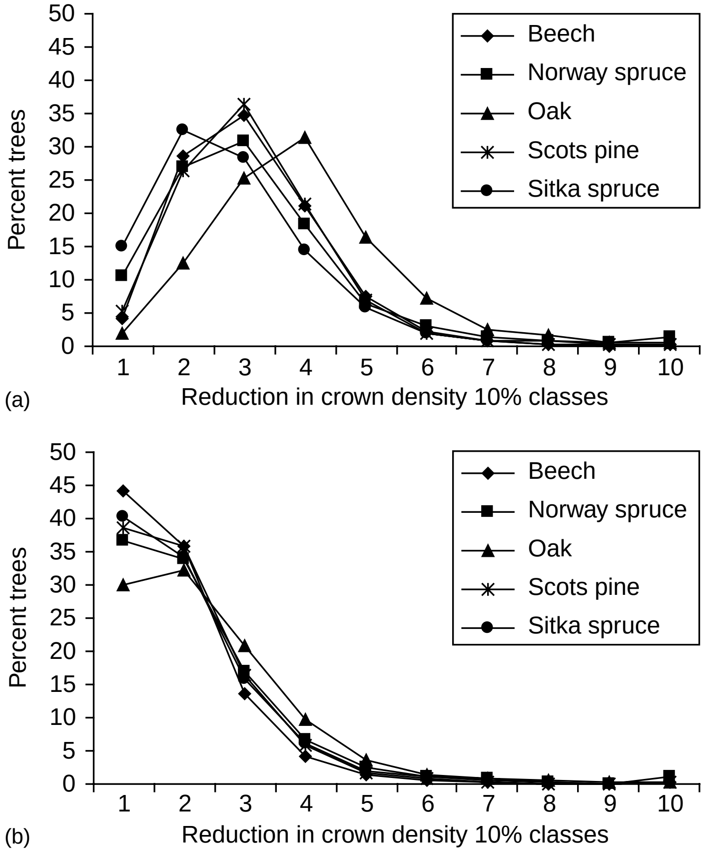

Fig. 4. Mean percentages of trees of five species in 10% crown density reduction classes for the period 1995–2000. Each class represents a reduction in crown density compared (a) with an 'ideal' tree, i.e. a tree with the maximum possible amount of foliage (ARCD) or (b) with a 'local' tree, i.e. a tree with full foliage under local conditions (LRCD).

corresponding differences in LRCD assessments (Fig. 6b) were also quite large and were also overestimates. Biases exceeding 4.25% were significant at $P = 0.05$. For comparisons on single plots of 24 trees a bias of 5% (one class interval) was considered significant. Fig. 6a therefore suggests that there was significant bias in four combinations of species and assessor. This represents 8.5% of the 47 combinations tested. In 2000, comparisons were made over more trees and three more assessors were involved. The precision of the analysis was accordingly greater. In contrast to the previous year it revealed significant assessor/species interaction and a greater number (nine) of significant differences from the standard observer. This suggests that a difference of 5% on a single 24-tree plot is a good guide to a statistically significant bias ($P = 0.05$).

3.3. Factors affecting the relationship between ARCD and LRCD

Mean differences between ARCD and LRCD for plots in the east or west of Britain are shown in Table 2. For beech and oak, differences were significantly greater in the west than in the east for 4 and 3 years, respectively, out of the 6 years tested. Although differences for Scots pine were also consistently greater in the west none of them was significant.

4. Discussion

The results from crown condition surveys are often expressed as the proportion of trees in which crown

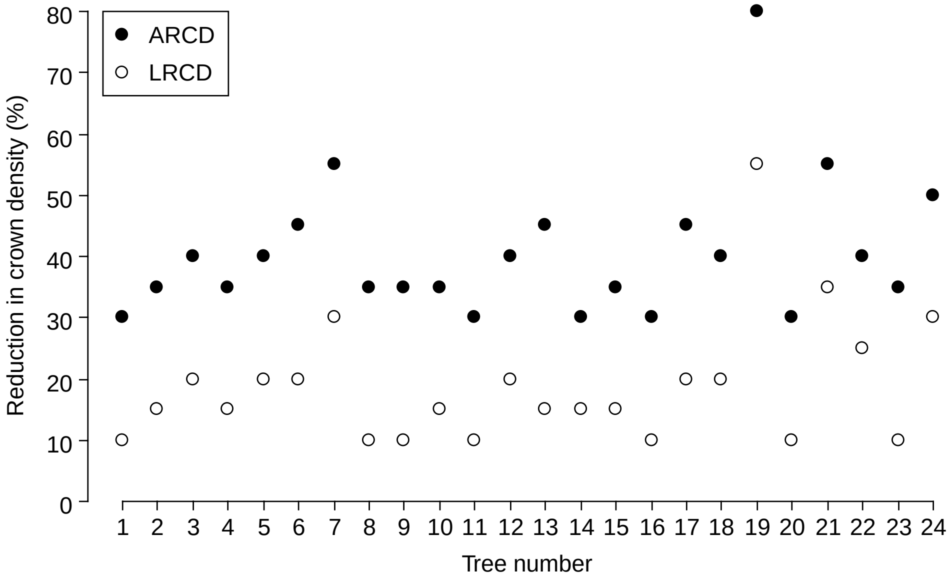

Fig. 5. An example of reductions in crown density for 24 trees in a single plot of oak assessed by comparison with absolute reference trees (closed circles) and the local reference tree (open circles) shown in Fig. 2. The reduction in crown density is shown as a percentage compared with the reference tree.

density is reduced by more than 25% compared to either a local or absolute reference tree (Redfern et al., 1998; Anon., 2000). Thus in the last year (1992) in which figures reported to the EU-UN/ECE by the UK were based on the assessment of ARCD, the mean proportion of trees in which crown density was reduced by >25% was 58.3% for all species combined. In 1993, the corresponding figure based on LRCD was 16.9%. This greatly exceeds the reduction implied by the differences between ARCD and LRCD shown in Fig. 3, but it can be attributed to the disproportionately large differences in the numbers of trees in the lowest crown density classes shown in Fig. 4.

The relationship between ARCD and LRCD for the trees in any plot is given by the formula: $\mathrm{LRCD\%} = 100(\mathrm{ARCD\%} - \mathrm{ARCD\%\ of\ local\ reference\ tree})/(100 - \mathrm{ARCD\%\ of\ local\ reference\ tree})$. It can be seen that it is not a simple difference equal to the ARCD of the local reference tree. The difference becomes smaller as both values approach 100% for trees that

Table 2
Difference (%) between the ARCD and the LRCD for three species in plots located in the west and east of Britain

	Beech			Oak			Scots pine		
	West	East	*P*-value and significance of difference	West	East	*P*-value and significance of difference	West	East	*P*-value and significance of difference
1995	17.2	13.8	0.040 *	18.4	17.0	0.441 ns	13.5	12.2	0.320 ns
1996	14.4	12.6	0.258 ns	25.3	15.3	<0.001***	13.5	11.5	0.151 ns
1997	17.0	14.7	0.143 ns	18.7	16.6	0.210 ns	11.2	11.1	0.999 ns
1998	14.9	10.4	0.001**	16.5	12.1	0.001**	11.2	10.7	0.585 ns
1999	16.4	10.0	<0.001***	16.8	12.8	0.002**	12.2	10.8	0.172 ns
2000	15.5	11.8	0.002**	16.2	13.9	0.104 ns	11.4	9.8	0.111 ns
Mean number of trees	980	468		1200	816		992	943	

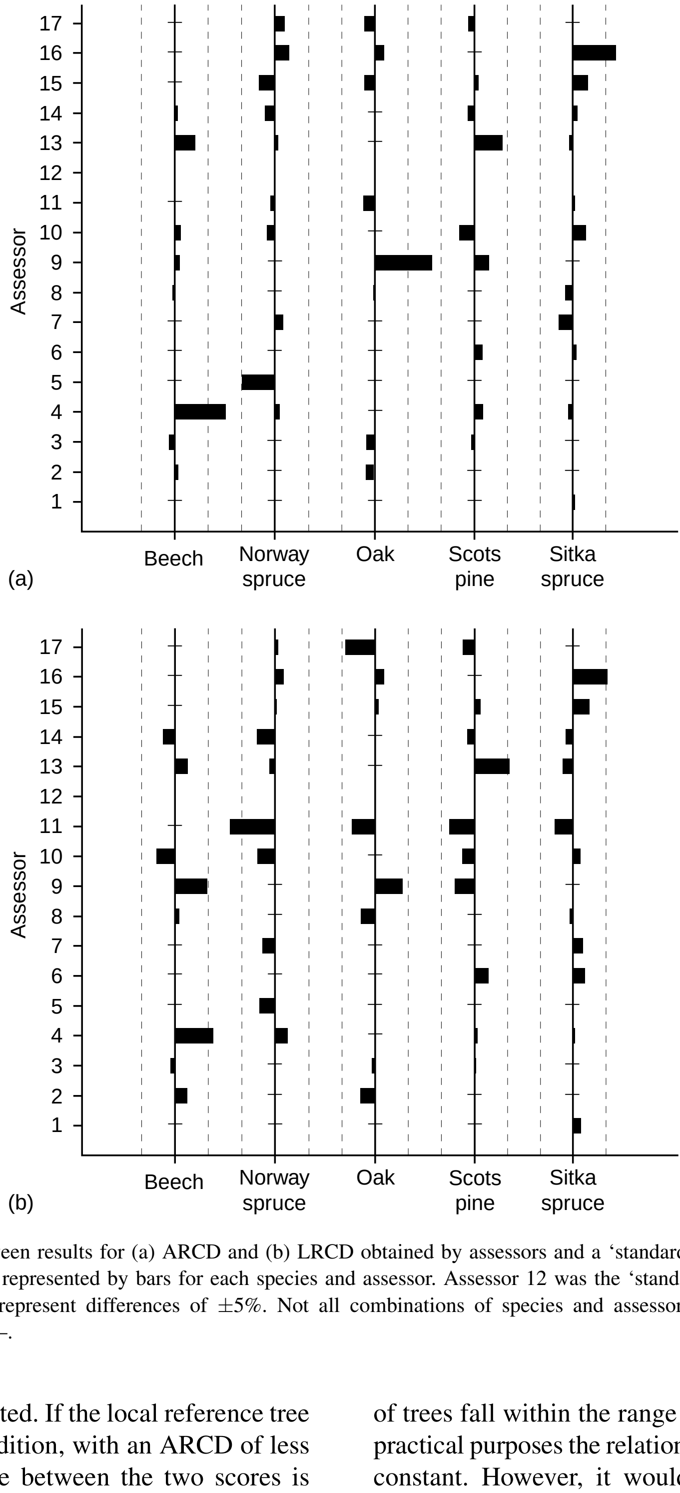

Fig. 6. Mean differences between results for (a) ARCD and (b) LRCD obtained by assessors and a 'standard observer' on a sub-sample of plots in 1999. Differences are represented by bars for each species and assessor. Assessor 12 was the 'standard observer'. The dotted lines parallel to each species line represent differences of ±5%. Not all combinations of species and assessor could be compared. Missing comparisons are indicated by –.

are almost totally defoliated. If the local reference tree is in relatively good condition, with an ARCD of less than 20%, the difference between the two scores is relatively constant up to 45% ARCD. More than 90% of trees fall within the range 0–50% for ARCD so for practical purposes the relationship might be considered constant. However, it would be less appropriate to make this assumption for local reference trees in poorer condition, i.e. with an ARCD $> 20\%$. While this work establishes a broad relationship between results obtained using the two methods, it might not be appropriate to alter scores on this basis in an attempt to facilitate international comparison: the local reference tree is only loosely defined and there are other methodological differences between countries (Innes, 1993).

During the 6-year survey period, the difference between ARCD and LRCD for all plots was greater in oak and beech than in the conifers (Fig. 3). Local reference trees chosen for the broadleaved species must therefore have been in poorer condition compared to the absolute reference trees than those chosen for the conifers. Thus, compared with these local standards the assessed trees would appear to be in much better condition than when compared to the absolute reference trees, and the difference between the two scores would be greater. Correspondingly the difference between the two scores would be smaller for conifers. This suggests that the crowns of broadleaved trees tend to be affected by factors that affect a high proportion of the trees over a large area, effectively leaving no 'good' local reference trees. By contrast, in conifers sufficient trees may remain unaffected to provide well-foliated reference trees.

The data in Table 2 suggest that larger differences between ARCD and LRCD are associated with a westerly location of plots for both oak and beech. This was entirely due to higher ARCD values in the west. In 5 out of 6 years for beech and in all 6 years for oak transparency (ARCD) was significantly greater ($P < 0.05$) in westerly plots than in those in the east. Scots pine also had thinner crowns in the west but differences were smaller and were significant in only 3 years. By contrast, LRCD scores revealed fewer geographical effects: differences were detected on four occasions for oak, two for Scots pine and none for beech.

Greater wind exposure in the west may be one factor increasing the difference between ARCD and LRCD, but other factors such as tree age (Solberg, 1999), growth habit, insect attack and fruiting in beech, may also be involved. Young trees tend to have more open crowns than old trees. This effect may be particularly important in Scots pine in which the mature crown forms shown by the reference trees illustrated in Innes (1990) are not exhibited for 30 or 40 years (Binns et al., 1986). A greater difference between ARCD and LRCD might therefore be anticipated for young trees compared to old trees. However, no significant age effect was revealed by analysis, probably because of the relatively small number of young trees in the plots assessed. In oak, age seems to have less effect on crown form, and most of the plots were in mature stands. On the other hand, there were differences in growth habit. On some plots, tree crowns were much branched, with dense crowns, resembling *Quercus robur* L., whereas elsewhere trees were more like *Q. petraea* (Mattuschka) Lieblein having relatively few, radiating, major branches, with few subordinate branches in the inner crown, creating an umbrella-like crown and an open appearance. The former crown type was similar to the standard reference photographs in Innes (1990). No attempt was made to identify plot trees to species since the origin of most stands was unknown and the two species hybridise. However, the open-crowned *Q. petraea* is more common in the north and west of Britain so that both crown form and exposure may contribute to the greater difference between ARCD and LRCD in the north and west. Growth habit may also have an important influence on crown density. In Sitka spruce, trees grow faster under high rainfall conditions in the west, increasing internode length and creating a more open crown. ARCD would therefore be greater in such trees simply by virtue of their faster growth rate. Insect attacks may also have contributed to the greater difference between ARCD and LRCD in the west. Scotland lies west of the line chosen to bisect the country from north to south, and here attacks by both winter moths and *Rhynchaenus fagi* were more severe than elsewhere (Redfern et al., 1998, 2000).

Standard errors for estimates of LRCD were lower than those for ARCD estimates. This was a surprise since it might be anticipated that estimates of LRCD based on comparisons with a single photograph of relatively poor quality would be more difficult than estimates of ARCD based on comparisons with high quality photographs showing a range of crown densities. A possible explanation is that while both scores are 'limited' by zero, local scores are generally lower than absolute scores and often have a smaller range (Fig. 4). Assessors may also find it easier to compare trees to a 'mental' image of the local tree than to the photographs used to assess ARCD. Alternatively, assessors may sub-consciously restrict their scores to a narrower range than for ARCD.

In Switzerland, Ghosh et al. (1995) found significant differences between field teams and control teams in the assessment of defoliation. The analysis presented here suggests that a mean bias of >5% in scoring crown density on a single 24-tree plot is significant when using standard errors based on the results of all comparisons between an assessor and a standard observer. The amount of bias detected was relatively low, affecting <10% of plots tested, and in general these findings confirm those of an earlier study of British data which found that bias between individual surveyors and a check team was insignificant (Innes and Boswell, 1991).

Despite the effects of tree age and growth habit on crown form, assessments based on absolute (fixed) reference standards for each species provide the best means of detecting changes in crown condition with time, which is the principal objective of the monitoring programme. Geographical differences can also be detected. Whilst assessments based on local standards may appear to give a more realistic impression of tree condition locally, the information obtained is less useful. The main drawback is that without knowledge of the condition of local reference standards geographical comparisons are invalid.

The higher estimates of transparency obtained using a fixed standard do not provide prima facie evidence of poorer 'health' if compared to estimates obtained using local reference trees. Such an interpretation could only be supported by specific health assessments and by analysis of other variables that affect crown density. Some of the non-pathological factors affecting the assessment of transparency could be addressed by extending the range of reference photographs to include examples of the effect of tree age or growth rate.

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