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Consistency of defoliation data of the national training courses for the forest condition survey in Germany from 1992 to 2012

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Abstract The consistency of visual assessment of tree defoliation, which represents the most widely used indicator for tree condition, has frequently been in the focus of scientific criticism. Thus, the objective of the present study was to examine the consistency of the defoliation data from the annual national training courses for the forest condition survey in Germany from 1992 to 2012. Defoliation assessments were carried out in stands of beech (*Fagus sylvatica*), oak (*Quercus robur* and *Quercus petraea*), Norway spruce (*Picea abies*), and pine (*Pinus sylvestris*). Among the observer teams, the absolute deviation from the observer mean of all years was ±4.4 % defoliation and the standard deviation of defoliation was ±5.5 %. On average, 94 % of the assessments were located within the ±10 % interval of deviation from the mean. Tree species-specific differences did not occur when all years were considered. A trend towards increasing consistency was observed from 1992 to 2012, in particular for oak and spruce. The deviation of defoliation assessments depended nonlinearly on the level of defoliation with highest deviations at intermediate defoliations. In spite of high correlations and agreements among observers, systematic errors were determined in nearly every year. However, within-observer variances were higher than between-observer variances. The present study applied a three-way evaluation approach for the assessment of consistency and demonstrated that the visual defoliation assessment at the national training courses in general produced consistent data within Germany from 1992 to 2012.

Keywords Forest condition survey · Defoliation · Observer error · Harmonisation · Systematic error · Quality assurance

Introduction

In Europe, the issue of forest decline emerged as the major environmental concern of the 1980s (e.g. Innes 1993). As a consequence, the 'International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests' (ICP Forests) was established in 1985 by the Economic Commission for Europe of the United Nations under the Convention on Long-Range Transboundary Air Pollution (Innes 1993). Within the framework of the ICP Forests Programme, efforts were made to widely harmonise and standardise methods for forest monitoring throughout Europe. The methods were recorded in the ICP Forests manual (UNECE 2010) that was first published in 1985 and has continuously been subject to updates since its publication.

The forest condition survey represents an essential part of the forest monitoring, which was described in Part IV of the ICP Forests manual (Eichhorn et al. 2010) and became mandatory throughout the European Union in 1987 (Redfern and Boswell 2004; Solberg and Strand 1999). The survey on forest condition has been conducted annually on the systematic wide-scale monitoring plots (Level I), which were established wherever

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forest coincided with a 16 × 16 km grid over Europe, as well as on plots of the intensive monitoring programme (Level II; since the 1990s) (Eichhorn et al. 2010; Ferretti et al. 1999; Innes 1993). The forest condition survey according to ICP Forests, has been taken place annually in Western Germany since 1984 and in the whole Federal Republic of Germany since 1990 (BMELV 2012). The 16 German federal states (including three city states) are responsible for the field assessment of the forest condition survey and publish the results for the federal states annually. Within the federal states grid, densifications are common. The evaluation of the 16 × 16 km grid data for the whole of Germany (415 plots in 2012; ranging from 4 plots per state (Berlin) to 96 plots (Bavaria), and no plots for the city states Bremen and Hamburg) is carried out by the Thünen Institute of Forest Ecosystems and the results are finally published by the Federal Ministry for Food, Agriculture and Consumer Protection, which represents the National Focal Centre of Germany (BMELV 2012; Eichhorn et al. 2010).

The forest condition survey is based on the assessment of defoliation (e.g. Arbeitsgruppe AG Diagnose und Klassifizierung der neuartigen Waldschäden 1984; Eichhorn et al. 2010; Innes et al. 1993), which is the most widely used indicator for assessment of tree condition (Ferretti 1997; Ghosh et al. 1995; Innes et al. 1994). Defoliation is assessed visually using binoculars and a scoring system of 5 % classes (e.g. Durrant and Boswell 2002; Eichhorn et al. 2010). Consistency and reproducibility of defoliation data has frequently been in the focus of scientific criticism due to subjectivity in the visual assessment (Ferretti 1998; Innes 1988; Innes 1993; Schöpfer 1985a). Consistency of observations, however, is of major importance for spatial and temporal data evaluations. Several studies conducted in different European countries during the 1980s and beginning 1990s revealed a poor level of reproducibility and significant variations among observer teams (training courses) and between observer and control teams (field check) (Ferretti et al. 1999; Ghosh et al. 1995; Innes et al. 1993; Kandler and Innes 1995; Köhl et al. 2000; Solberg and Strand 1999). In addition, Klap et al. (2000) found the factor ‘country’ as the most statistically significant predictor for European defoliation data whereas Seidling (2004) detected the factor ‘federal states’ as the most significant predictor for defoliation data of the 89 German Level II plots. Despite criticism, an objective and feasible alternative method for the determination of defoliation is not yet available. The image analysis system CROCO has, however, been recommended for verification of visual assessments (Mizoue 2002; Nakajima et al. 2011). Hence, main emphasis has been placed on the quality assurance (QA) programme to improve and to document the consistency and reproducibility of visually assessed defoliation data (e.g. Ferretti et al. 1999). Regular training courses and further QA procedures (e.g. field checks) are believed to remove a great amount of subjectivity and variation among individual observers (Innes 1993; Köhl 1991; Schöpfer 1985b). For instance, a rapid and steady improvement of defoliation data consistency in Italy following the adoption of the QA programme was reported by Bussotti et al. (2009).

Thus, the present study investigated the defoliation data from the annual training courses in Germany from 1992 to 2012. The aim was (1) to evaluate the consistency of defoliation assessments over time and (2) to determine possible tree species-specific differences in the consistency.

Materials and methods

Procedure of the national training courses

The national training course has taken place annually in June since 1984 before the training courses of the federal states, which in turn have taken place immediately before the field surveys in July and August. The four most frequent tree species of Germany are investigated, namely, beech (*Fagus sylvatica*), oak (*Quercus robur* and *Quercus petraea*), Norway spruce (*Picea abies*), and pine (*Pinus sylvestris*). The participating observer teams consist of at least one representative who conducts the forest condition survey or who is responsible for the training course in its respective federal state. The training courses aim at eliminating differences in the assessments of defoliation among the observer teams of different federal states in order to obtain consistent data in terms of spatial and temporal comparability within Germany during the forest condition survey. Therefore, interfering factors such as the social position of trees, tree species, and visibility of the crown are kept constant during the course (Köhl 1993). Easily visible trees are generally chosen, although good visibility does usually not reflect the real condition during the forest condition survey. Moreover, the assessment occurs from a fixed observation point. Before the assessment, five trees of each species are jointly assessed and discussed. Subsequently, ten trees are independently assessed by the observer teams (first round). The results are recorded and distinct discrepancies among the teams are discussed following the first round. Finally, a second round where another ten trees are independently assessed is carried out. Discrepancies among the teams are discussed again. Over the years, the procedure of the training courses has changed. The second round including the discussion in between has been obligatory since 2011 but had already been performed in earlier years, e.g. in 2008 for beech and oak. In general, ten to twenty trees were assessed per tree species; however, the quantity of assessed trees ranged from ten to one hundred (Table 1). During the first years, assessment was not necessarily performed from the same observation point. In 1997, the guidelines for assessment (internal guideline of the AG Dauerbeobachtungsflächen – Waldschäden published in Dammann et al. 2001) as well as the reference book for defoliation 'Waldbäume – Bilderserien zur Einschätzung von Kronenverlichtungen bei Waldbäumen' (Arbeitsgruppe AG Diagnose und Klassifizierung der neuartigen Waldschäden 1984; Meining et al. 2007) were introduced. The age of trees was not recorded before 2011, but was over 60 years for most trees. Furthermore, the observer teams of the different federal states have partly changed over time; however, this was not recorded. In some cases, two separate persons representing two different federal states started as a joint team (Berlin and Brandenburg in most years, Bremen and Hamburg in earlier years, and Baden-Württemberg and Bavaria in 2003). The number of persons per team varied as well and was not noted before 2011. Generally, two persons built a team, but sometimes up to five persons or, in some cases, an individual person represented one federal state. Additionally, experience in defoliation assessment varied among the observers from persons being part of the courses since the beginning in the 1980s to inexperienced beginners. The annual training courses have usually taken place in one federal state for two consecutive years (Table 1). Sites are selected so as to reflect a large distribution of the defoliation levels, but the focus is on trees with intermediate defoliation because it has been reported that the defoliation assessment is more difficult than that of healthy or heavily damaged trees (e.g. Solberg and Strand 1999). For 1993, no data were available for oak due to strong pest infestation and for 1996 and 1997, data were unrecoverable.

Observer errors

Potential errors that may occur during surveys are sampling and non-sampling errors (Kish 1995). Sampling errors can be attributed to the fact that the sample does not represent the entirety of the population and can therefore be reduced by increasing the sample size provided that a probabilistic sampling design is adopted (Kish 1995; Schöpfer 1985b). Non-sampling errors include the observer error, which is the result of the visual assessment of defoliation (Kish 1995; Schöpfer 1985b) and the error which is addressed in the present study. The observer error has to be considered additionally to the sampling error when regarding errors of defoliation assessments during the forest condition survey (e.g. Gertner and Köhl 1995). According to Cochran (1977) and Kish (1995), the total error, which is usually given as mean-squared error (*MS*), is defined as the sum of variable (random) error and bias (systematic error):

$$MS = total\ error = (variable\ error)^2 + (bias)^2 \quad (1)$$

Precision refers to the random error (size of deviation of the estimated value from the sample mean value) whereas accuracy refers to the total error including the bias (size of deviation of the estimated value from the true mean value) (Cochran 1977; Kish 1995). Therefore, an estimate may be precise but biased. The observer error is defined as difference between the true value of defoliation and the assessed value (Gertner and Köhl 1995; Wulff 2002). Hence, random as well as systematic components can be included in the observer error (Köhl et al. 2000). Systematic errors can be ascribed to several sources of error such as different definitions of the assessable crown, weather conditions, flowering of pine trees, as well as the observer's style of assessment (Schöpfer 1985b; Solberg and Strand 1999). Calculation of the observer error is not trivial, since the true value of defoliation is unknown. In studies like the present one, it is not possible to estimate the true errors and the accuracy of defoliation assessments. When it is assumed that the arithmetic mean of defoliation assessments of all observer teams regarding an individual tree is the unbiased true value, then the mean absolute deviation of defoliation assessments represents an estimator for the observer error.

Table 1 Year, federal state, location, number of assessed trees (trees), and number of participating observer teams (observers) at the national training courses given for the main tree species

Year	State	Location	Beech		Oak		Spruce		Pine	
			Trees	Observers	Trees	Observers	Trees	Observers	Trees	Observers
1992	NW	Altenbeken	10	15	10	15	10	15	10	15
1993	TH	Schmiedefeld	10	14	–	–	10	13	10	14
1994	BY	Freising	10	15	15	15	15	13	10	15
1995	BY	Freising	20	16	20	16	20	16	20	16
1996	BB	Potsdam	–	–	–	–	–	–	–	–
1997	BB	Potsdam	–	–	–	–	–	–	–	–
1998	SH	Pronstorf	10	16	10	16	10	16	10	15
1999	SN	Graupa	20	15	20	15	20	16	20	16
2000	SN	Graupa	20	16	20	15	20	15	20	15
2001	SH	Pronstorf	90	17	10	17	10	16	10	16
2002	HE	Hann. Münden	95	14	10	13	10	14	10	14
2003	HE	Hann. Münden	20	13	18	13	100	13	15	13
2004	RP	Trippstadt	17	15	15	15	10	15	16	15
2005	RP	Trippstadt	15	15	10	15	15	15	10	15
2006	MV	Dümmer	15	13	15	12	15	13	30	13
2007	MV	Dümmer	15	14	15	14	15	14	20	14
2008	BY	Freising	20	13	20	13	10	13	10	13
2009	BY	Freising	10	12	10	12	10	12	10	11
2010	SL	Homburg	10	12	10	12	10	12	10	12
2011	SL	Bexbach	20	10	20	10	20	10	20	10
2012	HE	Witzenhausen	20	10	20	10	20	10	20	10

For 1993, no data were available for oak due to strong pest infestation, and for 1996 and 1997, data were unrecoverable. The observer teams generally represent the federal states, but Saxony-Anhalt started with two teams from 1993 to 2005, Berlin and Brandenburg started as joint team in most years, and in 2006, a cross-federal states institution was established comprising the states Hesse, Lower Saxony, and Saxony-Anhalt as well as Schleswig-Holstein (since 2011). The institution started with one to three observer teams.

Abbreviations: *BY* Bavaria, *BB* Brandenburg, *HE* Hesse, *MV* Mecklenburg-Western Pomerania, *NW* North Rhine-Westphalia, *RP* Rheinland-Palatinate, *SH* Schleswig-Holstein, *SL* Saarland, *SN* Saxony, and *TH* Thuringia.

Statistical analyses

In the present study, the consistency of defoliation data was evaluated. Therefore, deviations, correlations, and agreements among observer teams (federal states) were examined and variance components were estimated. The defoliation data are scored in 5 % classes and thus are pseudo-continuous.

The absolute deviation of defoliation assessments between the observer teams and the arithmetic mean of all observer teams was calculated as well as the standard deviation of defoliation assessments, which corresponded to the standard deviation of the deviation. At site level (one tree species per year), the number of degrees of freedom was corrected because the assessments of different teams on an individual tree were not independent.

A two-way analysis of variance (ANOVA) was performed in order to estimate the variance components as well as systematic and random errors (Wulff 2002). The observer teams were assumed to be a random selection of a population of possible observers, some of which will later carry out the forest condition survey (Bravo and Potvin 1991; Wulff 2002). Additionally, the precision of assessment was assumed to be the same for all k observer teams, i.e. $\sigma_1^2=\ldots=\sigma_k^2=\sigma_E^2$ (Köhl 1993;

Wulff 2002). The general model was described by Bravo and Potvin (1991) and Wulff (2002):

$$X_{ij} = \mu + S_i + O_j + E_{ij}, \tag{2}$$

where X_{ij} is the assessment by observer team j on tree i, μ is the grand mean of all estimations, S_i is the tree effect, O_j is the observer bias for observer team j, and E_{ij} is the random error of the assessment by observer team j on tree i. The bias is assumed to be the same on all kinds of trees. The term = μ + S denotes the true value. In practice, μ + S will be the arithmetic mean value of all assessments. The term = O + E denotes the error term, which is differentiated in systematic and random error components. The estimations for the corresponding variance (s^2) components are (Bravo and Potvin 1991; Wulff 2002):

$$s_E^2 = MS_E \tag{3}$$

$$s_O^2 = \frac{MS_O - MS_E}{n_i}, \tag{4}$$

where n is the number of trees. It was tested if observer teams differed significantly from the average defoliation assessment (H_0: $\sigma_o^2=0$).

Correlations between the observer teams were examined using the Pearson correlation coefficient r and agreements among observers were examined using the intraclass correlation coefficient (*ICC*) (Bravo and Potvin 1991):

$$ICC = \frac{n(MS_S - MS_E)}{nMS_S + kMS_O + (nk - n - k)MS_E}, \tag{5}$$

where k is the number of observer teams.

Furthermore, analysis of variance combined with Tukey's HSD test was used for multiple comparisons of means. In the case of non-normality of data, the non-parametric Kruskal–Wallis H test combined with the multiple comparison test by Castellan and Siegel (1988) were used. The non-parametric Mann–Whitney U test was used for comparison of two means. In addition, simple linear regressions were performed. In the case of heteroscedasticity of variances the generalised least squares method with a variance function was applied. Normality of residuals and homogeneity of variances were tested prior to all statistical analyses. Statistical significance was stated at $P \leq 0.05$. The whiskers of the boxplots correspond to 1.5 times the interquartile distance. Evaluation and visualisation of data were performed using R 2.15.1 (R Development Core Team 2012).

Results

The absolute deviation from the arithmetic mean at site level averaged 4.4 % defoliation (3.2–7.1 %) from 1992 to 2012, and no significant differences were observed among the tree species. The absolute deviations of oak (P=0.015) and spruce (P=0.017) decreased from 1992 to 2012 (Fig. 1). In 2011 and 2012, for example, the mean absolute deviations for all tree species were 3.5 and 3.6 %, respectively. The highest absolute deviations were observed in 2008 (7.1 %) and 2009 (5.8 %) at pine sites. On average, 93.4 (spruce) to 95.2 % (oak) of the assessments from 1992 to 2012 were located within the ±10 % interval of deviation from the mean (Fig. 2). Assessments outside this interval were detected at all sites in every year. The proportion of assessments within the interval increased over the years for oak (P=0.001) and spruce (P=0.02). In 2011, 94.0 (beech) to 99.5 % (spruce) and in 2012, 96.0 (pine) to 99.0 % (oak) of the assessments lay within this interval. Moreover, 72.0 (beech) to 86.6 % (pine) of the assessments were located within the ±5 % interval of deviation in 2011 and 70.5 (pine) to 84.0 % (oak) of assessments in 2012. The lowest proportion of assessments within the ±5 % interval (48.5 and 56.4 %) and ±10 % interval of deviation (78.5 and 85.5 %) were observed at the pine sites in 2008 and 2009. The introduction of two rounds during the training courses had no significant effect on the error of assessment in beech, oak, and spruce stands considering the years 2008 (only beech and oak), 2011, and 2012 (Fig. 3). The range of deviation even tended to increase from the first to the second round. For pine, the absolute deviation, however, decreased from the first to the second round (P<0.001) (Fig. 3). This decrease occurred in 2011 as well as in 2012.

The maximal positive and negative deviations at individual trees were 34.7 and −47.8 % defoliation both of which were observed at the pine sites in 1995. The maximal deviations at individual oak (−25.0 %) and spruce (32.3 %) trees were also found in 1995 whereas the maximal deviation of beech trees (30.7 %) was observed in 2004. Deviations greater

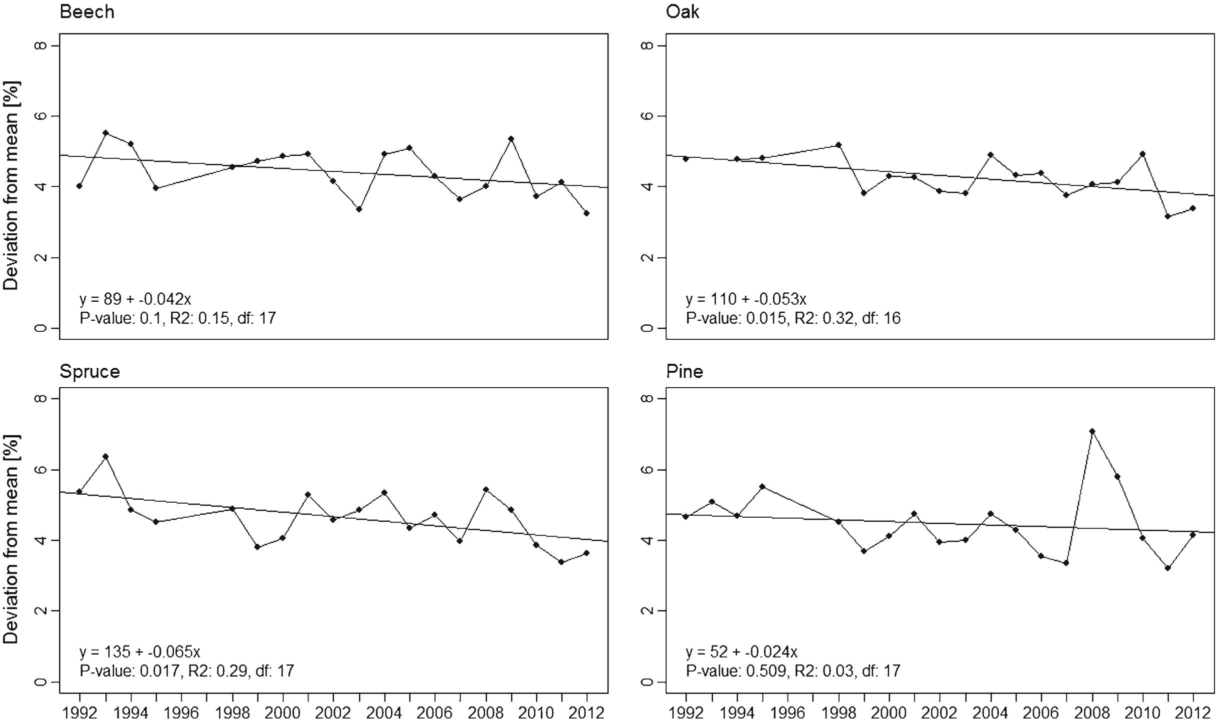


Fig. 1 Mean absolute deviation of defoliation assessments from the arithmetic mean given for the beech sites (top, left side), the oak sites (top, right side), the spruce sites (bottom, left side), and the pine sites (bottom, right side) for the years 1992 to 2012. The lines and parameters of significant (oak, spruce) and insignificant (beech, pine) linear regressions are indicated

than ±20 % were rarely observed and accounted for less than or equal to 1 % of the total assessments of one site except for the pine sites in 1995 and 2008 and the oak site in 1995 where these deviations accounted for up to 3 % of the total assessments.

The average standard deviation at site level was 5.5 % defoliation ranging from 3.9 to 8.6 %. As with the absolute deviation, no significant differences occurred among tree species and the standard deviation of oak ($P<0.005$) and spruce ($P<0.026$) decreased from 1992 to 2012 (Fig. 4). Mean standard deviations for all tree species in 2011 and 2012 were 4.4 and 4.5 % defoliation, respectively.

Systematic errors in assessed defoliations that were attributed to the observer teams were detected at all tree species and in nearly every year (Table 2). However, few consistent temporal or species-specific patterns regarding systematic errors among observer teams were determined. The variance among observers of oak decreased from 1992 to 2012 ($P=0.036$, $R^2=0.26$). The variance among observers (systematic error) was approximately one fifth of the variance of the random error regarding every year between 1992 and 2012 (Table 2). The average *ICC* was 0.83 and ranged from 0.52 (pine 1994, spruce 2001) to 0.97 (pine 2005, oak 2012) (Table 2). No temporal or species-specific trends were observed. In 2011 and 2012, the mean *ICC* were 0.89 and 0.91 and the Pearson correlation coefficients *r* were 0.91 (0.71–0.98) and 0.93 (0.73–0.99), respectively. For both years, *ICC* and *r* displayed the highest values for oak trees. The Pearson correlations were significant among all combinations of observer teams ($P<0.001$).

The four tree species differed in the frequency of the level of defoliation (Fig. 5). Beech trees showed the highest mean defoliation with 37 % whereas pine trees showed the lowest mean defoliation with 25 %. The frequency distributions of defoliation of all tree species displayed a distinct skewness to the right and defoliations more than 60 % were rarely present. The absolute deviation from the mean significantly and non-linearly depended on the defoliation level ($P>0.001$) (Fig. 6), being highest at intermediate levels of defoliation.

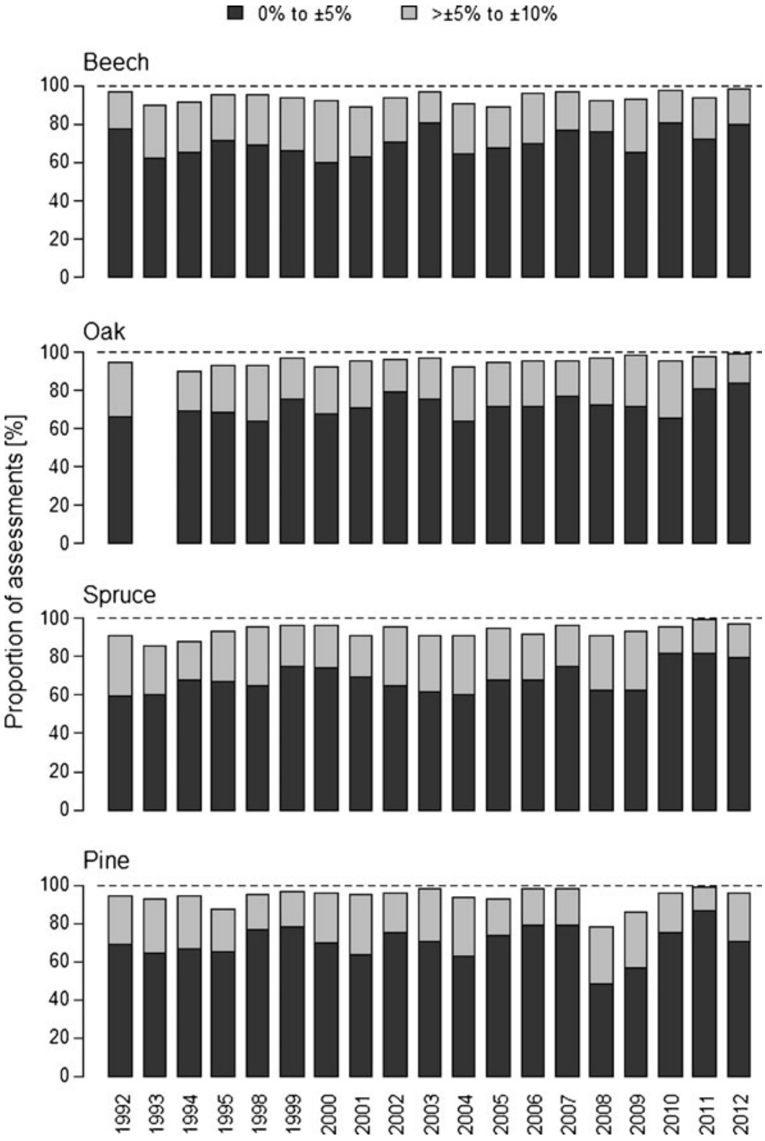


Fig. 2 Proportion of defoliation assessments that was within the 0 to ±5 % interval of deviation from the arithmetic mean of all assessments of an individual tree (0 to ±5 %) and within the interval of more than ±5 to ±10 % deviation (> ±5 to ±10 %). The proportions are representative for beech (top), oak (upper middle), spruce (lower middle), and pine (bottom) from 1992 to 2012. For 1993, no data were available for oak due to strong pest infestation, and for 1996 and 1997, data were unrecoverable

Discussion

Temporal changes in the observer error

The mean absolute deviation of 4.4 % defoliation, which may be used as estimate for the observer error, assuming that the arithmetic mean of all assessments of an individual tree represents the unbiased true value, as well as the mean standard deviation of 5.5 % defoliation were comparable or lower than deviations reported in the literature. Additionally, both measures displayed a decreasing trend from 1992 to 2012 for the four tree species, which was statistically significant for oak and spruce sites. In comparison, Schöpfer (1985b) estimated a higher observer error of ±8 % defoliation at the national training courses in 1983 and 1984. The mean deviation that was calculated among three European countries at a training course in 1989 was higher as well (deviation between two countries) (Innes et al. 1993). Standard deviations of single observations of control surveys (field checks) in Sweden amounted to 4.7–12.6 % defoliation between 1995 and 1999 (Wulff 2002). Solberg and Strand (1999) estimated a standard deviation of 10 % for single trees and of 5 % for plot means from field checks in Norway between 1990 and 1995. The reported standard deviations are similar but

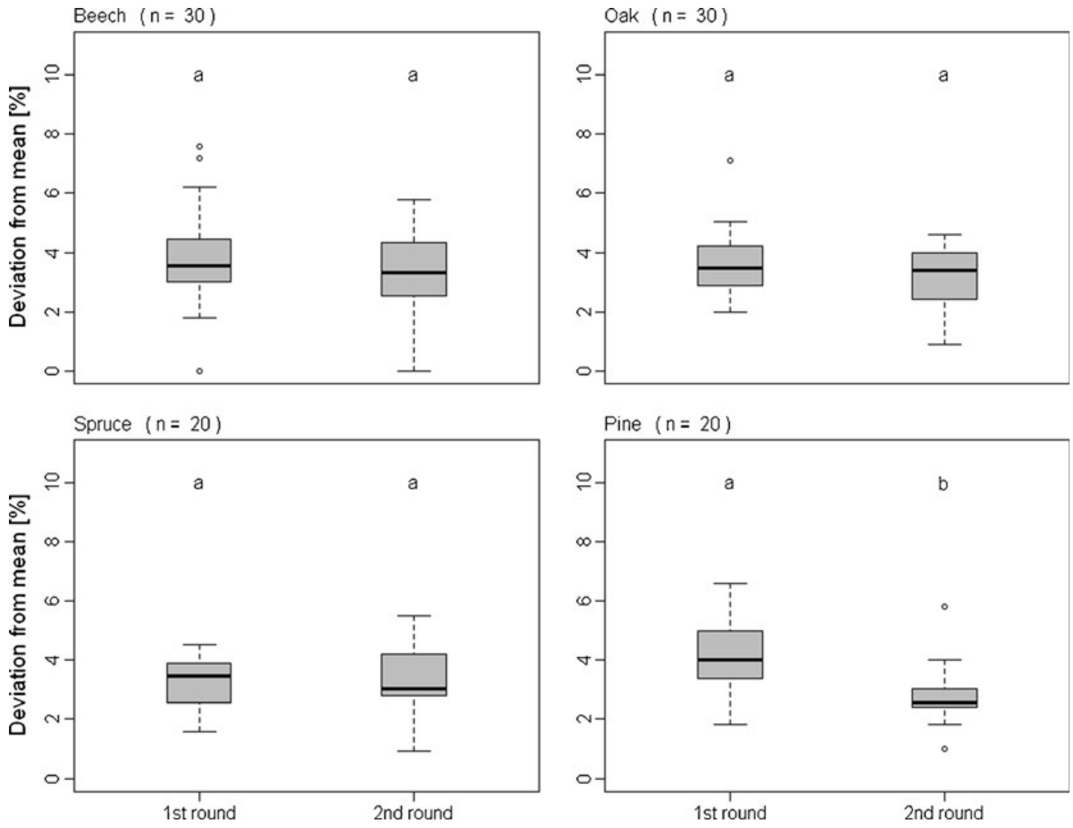


Fig. 3 Absolute deviation of defoliation assessments from the arithmetic mean of individual trees given for the first and second round during the training courses in 2008 (beech, oak), 2011, and 2012. Data are presented separately for beech (top, left side), oak (top, right side), spruce (bottom, left side), and pine (bottom, right side). The number of trees per round is indicated by 'n'. Significant differences between the first and second round are represented by different letters (Mann–Whiteny U test)

not directly comparable to our results since the reported ones were derived from pairwise assessments. In general, a deviation of ±10 % defoliation from a reference value is an acceptable limit of deviation (e.g. Innes 1988; Köhl 1991). In the present study, 94 % of the assessments were located within these limits and the proportion of assessments within the limits displayed an increasing trend, which was significant for oak and spruce. In fact, pronounced deviations (more than ±20 % defoliation) from the mean were not observed during the last three years. Proportions determined during the national training courses in Italy and the South European training courses between 1996 and 2004 were slightly lower ranging from 80 to 90 %, and a marginal increase in the proportion was observed over time (Bussotti et al. 2009). The proportions calculated in the present study are high in comparison to those reported in the literature from the second assessments by a control team during field checks. Innes et al. (1994) reported from a field check in Switzerland in 1993 that the quality limits had to be broadened to ±15 % defoliation to achieve an acceptable result with more than 90 % of the assessments lying within this interval. Innes (1993), Ferretti et al. (1999), and Solberg and Strand (1999) came to similar results during field checks in Great Britain (1988), Italy (1996), and Norway (1990–95), respectively. In contrast, Bussotti et al. (2009) found that more than or equal to 90 % of the assessments during the field control in Italy from 1999 to 2004 fell between ±10 % with respect to the reference team. In recent times, the prescribed aim (data quality limit) of ICP Forests for field checks during the forest condition survey was set to at least more than or equal to 70 % of assessments that must not deviate more than ±10 % from one another (Eichhorn et al. 2010). The results at hand suggest to introduce a data quality limit for national and international training courses requiring that 90 % of the assessments have to range within ±10 %

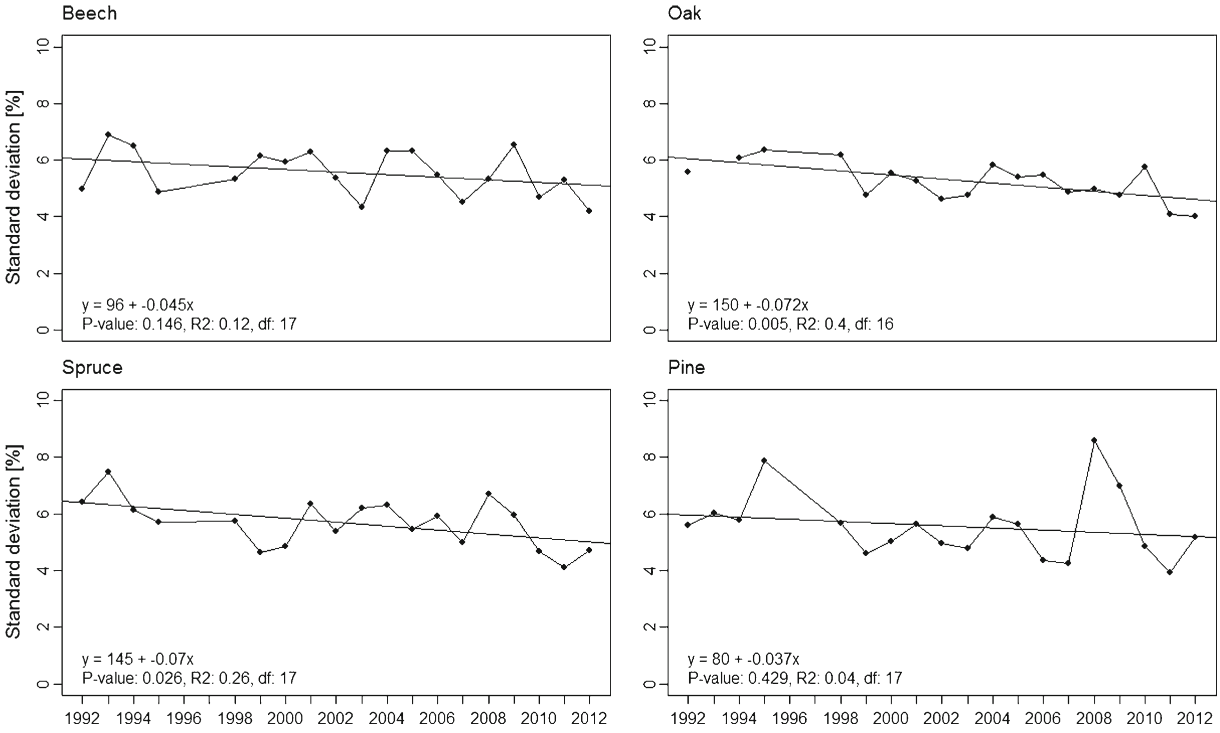


Fig. 4 Mean standard deviation of defoliation assessments given for the beech sites (top, left side), the oak sites (top, right side), the spruce sites (bottom, left side), and the pine sites (bottom, right side) for the years 1992 to 2012. The lines and parameters of significant (oak, spruce) and insignificant (beech, pine) linear regressions are indicated

from the reference value (here arithmetic mean of all assessments on an individual tree).

The observed trend towards more consistent assessments among observer teams may be ascribed to several changes over time. In particular, the introduction of the guidelines for assessment (internal guideline of the AG Dauerbeobachtungsflächen – Waldschäden published in Dammann et al. 2001) and the defoliation reference book in 1997 (Arbeitsgemeinschaft AG Dauerbeobachtungsflächen der Länder und des Bundes 1997; Meining et al. 2007) may have improved the assessments, although no abrupt improvement occurred following the introduction. Additionally, the definition of the observation point for assessment probably led to greater consistency. A positive effect of the introduction of two rounds was shown for pine. Maintenance of the achieved consistency during the forest condition survey, however, is of great importance. The positive effect was not observed for beech, oak, and spruce where the discussion in between possibly led to an increased uncertainty in the assessment. Since mandatory second rounds have been introduced only recently, no final conclusion can be made whether this implementation represents an improvement for harmonisation.

Explanation for outliers

Occasionally, deviations of more than ±20 % defoliation were determined at individual trees of all tree species but the cases where deviations of more than ±20 % accounted for slightly more than 1 % of total assessments occurred only at three sites and thus played a negligible role during the training courses. The most pronounced deviations and the highest proportion of deviations outside the ±10 % interval of deviation were observed at pine trees in 1995, 2008, and 2009. Innes et al. (1993) reported similar high deviations of ±45 % defoliation at individual trees, which were observed at a training course among three European countries in 1989. Innes et al. (1993) and Wulff (2002) also mentioned difficulties in the defoliation assessment of pine trees. However, despite difficulties in 1995, 2008, and 2009, pine trees did not differ from the other species over time in the present study. In these years, the training courses were carried

Table 2 Results of the two-way analysis of variance and the *ICC* for the defoliation assessments on beech, oak, spruce, and pine at the national training courses from 1992 to 2012

Year	Tree	Source of variance	*df*	*SS*	*MS*	s^2_O	F ratio	*P* value	*ICC*
2012	Beech	Tree	19	58,357	3,071				
		Observer	9	506	56	1.98	3.37	0.0008	0.94
		Error	171	2,851	17				
	Oak	Tree	19	111,053	5,845				
		Observer	9	488	54	1.96	3.60	0.0004	0.97
		Error	171	2,577	15				
	Spruce	Tree	19	35,297	1,858				
		Observer	9	857	95	3.79	4.88	0.0000	0.89
		Error	171	3,338	20				
	Pine	Tree	19	30,366	1,598				
		Observer	9	1,148	128	5.22	5.53	0.0000	0.85
		Error	171	3,945	23				
2011	Beech	Tree	19	37,154	1,956				
		Observer	9	236	26	−0.18	0.88	0.5440	0.87
		Error	171	5,082	30				
	Oak	Tree	19	50,997	2,684				
		Observer	9	454	51	1.73	3.17	0.0014	0.94
		Error	171	2,720	16				
	Spruce	Tree	19	23,198	1,221				
		Observer	9	348	39	1.09	2.29	0.0186	0.87
		Error	171	2,882	17				
	Pine	Tree	19	26,592	1,400				
		Observer	9	501	56	2.07	3.92	0.0002	0.89
		Error	171	2,431	14				
2010	Beech	Tree	9	29,872	3,319				
		Observer	11	848	77	6.17	5.01	0.0000	0.93
		Error	99	1,523	15				
	Oak	Tree	9	47,573	5,286				
		Observer	11	646	59	2.93	1.99	0.0368	0.93
		Error	99	2,915	29				
	Spruce	Tree	9	20,032	2,226				
		Observer	11	154	14	−0.83	0.63	0.8020	0.90
		Error	99	2,212	22				
	Pine	Tree	9	18,229	2,026				
		Observer	11	847	77	6.00	4.52	0.0000	0.88
		Error	99	1,688	17				
2009	Beech	Tree	9	20,096	2,233				
		Observer	11	1,692	154	12.45	5.25	0.0000	0.81
		Error	99	2,901	29				
	Oak	Tree	9	18,551	2,061				
		Observer	11	674	61	4.33	3.40	0.0005	0.88
		Error	99	1,784	18				
	Spruce	Tree	9	52,544	5,838				

Table 2 (continued)

Year	Tree	Source of variance	*df*	*SS*	*MS*	s^2_{O}	F ratio	*P* value	*ICC*
		Observer	11	552	50	1.71	1.52	0.1380	0.93
		Error	99	3,279	33				
	Pine	Tree	9	7,984	887				
		Observer	10	1,882	188	15.53	5.72	0.0000	0.62
		Error	90	2,964	33				
2008	Beech	Tree	19	30,192	1,589				
		Observer	12	1,374	115	4.48	4.62	0.0000	0.80
		Error	228	5,653	25				
	Oak	Tree	19	22,581	1,189				
		Observer	12	1,335	111	4.52	5.36	0.0000	0.78
		Error	228	4,734	21				
	Spruce	Tree	9	7,873	875				
		Observer	12	1,939	162	13.10	5.28	0.0000	0.60
		Error	108	3,307	31				
	Pine	Tree	9	20,878	2,320				
		Observer	12	3,433	286	23.77	5.92	0.0000	0.71
		Error	108	5,217	48				
2007	Beech	Tree	14	29,775	2,127				
		Observer	13	829	64	3.09	3.67	0.0000	0.88
		Error	182	3,159	17				
	Oak	Tree	14	11,890	849				
		Observer	13	935	72	3.42	3.50	0.0001	0.71
		Error	182	3,737	21				
	Spruce	Tree	14	17,305	1,236				
		Observer	13	1,021	79	3.83	3.73	0.0000	0.78
		Error	182	3,835	21				
	Pine	Tree	19	27,055	1,424				
		Observer	13	688	53	1.81	3.17	0.0002	0.84
		Error	247	4,121	17				
2006	Beech	Tree	14	29,528	2,109				
		Observer	12	1,822	152	8.69	7.07	0.0000	0.84
		Error	168	3,609	22				
	Oak	Tree	14	33,038	2,360				
		Observer	11	1,014	92	4.44	3.60	0.0002	0.87
		Error	154	3,942	26				
	Spruce	Tree	14	13,660	976				
		Observer	12	1,604	134	7.00	4.67	0.0000	0.67
		Error	168	4,804	29				
	Pine	Tree	29	24,311	838				
		Observer	12	936	78	2.00	4.37	0.0000	0.76
		Error	348	6,203	18				
2005	Beech	Tree	14	54,490	3,892				
		Observer	14	2,116	151	7.94	4.71	0.0000	0.87
		Error	196	6,287	32				

Table 2 (continued)

Year	Tree	Source of variance	*df*	*SS*	*MS*	s^2_O	F ratio	*P* value	*ICC*
	Oak	Tree	9	39,356	4,373				
		Observer	14	794	57	3.18	2.28	0.0083	0.91
		Error	126	3,139	25				
	Spruce	Tree	14	49,308	3,522				
		Observer	14	922	66	2.58	2.42	0.0037	0.89
		Error	196	5,322	27				
	Pine	Tree	9	155,058	17,229				
		Observer	14	1,229	88	6.34	3.60	0.0001	0.97
		Error	126	3,074	24				
2004	Beech	Tree	16	55,109	3,444				
		Observer	14	1,812	129	5.57	3.72	0.0000	0.85
		Error	224	7,785	35				
	Oak	Tree	14	49,436	3,531				
		Observer	14	1,473	105	5.09	3.64	0.0000	0.87
		Error	196	5,670	29				
	Spruce	Tree	9	60,938	6,771				
		Observer	14	1,703	122	9.25	4.17	0.0000	0.92
		Error	126	3,680	29				
	Pine	Tree	15	89,670	5,978				
		Observer	14	1,546	110	5.03	3.68	0.0000	0.92
		Error	210	6,294	30				
2003	Beech	Tree	19	109,002	5,737				
		Observer	12	959	80	3.19	4.95	0.0000	0.96
		Error	228	3,679	16				
	Oak	Tree	17	58,100	3,418				
		Observer	12	977	81	3.42	4.09	0.0000	0.92
		Error	204	4,061	20				
	Spruce	Tree	99	192,840	1,948				
		Observer	12	15,657	1,305	12.76	45.63	0.0000	0.78
		Error	1,188	33,970	29				
	Pine	Tree	14	45,055	3,218				
		Observer	12	1,095	91	4.87	5.02	0.0000	0.91
		Error	168	3,055	18				
2002	Beech	Tree	94	241,307	2,567				
		Observer	13	5,927	456	4.52	17.37	0.0000	0.85
		Error	1,222	32,085	26				
	Oak	Tree	9	45,882	5,098				
		Observer	12	525	44	2.56	2.42	0.0082	0.95
		Error	108	1,956	18				
	Spruce	Tree	9	7,155	795				
		Observer	13	1,227	94	7.35	4.52	0.0000	0.66
		Error	117	2,442	21				
	Pine	Tree	9	47,666	5,296				
		Observer	13	672	52	3.09	2.48	0.0050	0.94

Table 2 (continued)

Year	Tree	Source of variance	*df*	*SS*	*MS*	s^2_O	F ratio	*P* value	*ICC*
		Error	117	2,437	21				
2001	Beech	Tree	89	183,824	2,065				
		Observer	16	14,313	895	9.58	27.84	0.0000	0.74
		Error	1,424	45,751	32				
	Oak	Tree	9	23,414	2,602				
		Observer	16	1,415	88	6.91	4.56	0.0000	0.85
		Error	144	2,791	19				
	Spruce	Tree	9	6,226	692				
		Observer	15	1,464	98	6.54	3.03	0.0003	0.52
		Error	135	4,354	32				
	Pine	Tree	9	15,091	1,677				
		Observer	15	934	62	3.51	2.29	0.0063	0.77
		Error	135	3,669	27				
2000	Beech	Tree	19	69,070	3,635				
		Observer	15	1,972	131	5.05	4.32	0.0000	0.86
		Error	285	8,676	30				
	Oak	Tree	19	184,565	9,714				
		Observer	14	1,100	79	2.49	2.74	0.0009	0.95
		Error	266	7,634	29				
	Spruce	Tree	19	21,455	1,129				
		Observer	14	1,575	113	4.69	6.04	0.0000	0.76
		Error	266	4,955	19				
	Pine	Tree	19	30,674	1,614				
		Observer	14	1,587	113	4.62	5.40	0.0000	0.81
		Error	266	5,589	21				
1999	Beech	Tree	19	56,770	2,988				
		Observer	14	1,611	115	4.02	3.33	0.0001	0.84
		Error	266	9,202	35				
	Oak	Tree	19	178,749	9,408				
		Observer	14	952	68	2.37	3.29	0.0001	0.96
		Error	266	5,491	21				
	Spruce	Tree	19	20,805	1,095				
		Observer	15	1,141	76	2.85	4.00	0.0000	0.75
		Error	285	5,417	19				
	Pine	Tree	19	37,445	1,971				
		Observer	15	1,044	70	2.53	3.67	0.0000	0.85
		Error	285	5,402	19				
1998	Beech	Tree	9	44,195	4,911				
		Observer	15	1,312	87	6.68	4.23	0.0000	0.92
		Error	135	2,792	21				
	Oak	Tree	9	81,787	9,087				
		Observer	15	1,809	121	9.34	4.43	0.0000	0.94
		Error	135	3,678	27				
	Spruce	Tree	9	24,765	2,752				

Table 2 (continued)

Year	Tree	Source of variance	*df*	*SS*	*MS*	s^2_O	F ratio	*P* value	*ICC*
		Observer	15	2,008	134	11.34	6.56	0.0000	0.84
		Error	135	2,755	20				
	Pine	Tree	9	5,587	621				
		Observer	14	942	67	4.03	2.50	0.0037	0.56
		Error	126	3,398	27				
1995	Beech	Tree	19	45,508	2,395				
		Observer	15	687	46	1.14	1.99	0.0159	0.86
		Error	285	6,560	23				
	Oak	Tree	19	21,651	1,140				
		Observer	15	2,385	159	6.20	4.55	0.0000	0.63
		Error	285	9,959	35				
	Spruce	Tree	19	22,363	1,177				
		Observer	15	972	65	1.91	2.44	0.0023	0.72
		Error	285	7,562	27				
	Pine	Tree	19	103,759	5,461				
		Observer	15	2,422	161	5.18	2.79	0.0005	0.84
		Error	285	16,506	58				
1994	Beech	Tree	9	15,217	1,691				
		Observer	14	1,307	93	5.83	2.66	0.0020	0.73
		Error	126	4,423	35				
	Oak	Tree	14	14,546	1,039				
		Observer	14	2,453	175	9.88	6.49	0.0000	0.65
		Error	196	5,287	27				
	Spruce	Tree	14	9,583	685				
		Observer	12	2,406	201	11.61	7.62	0.0000	0.57
		Error	168	4,421	26				
	Pine	Tree	9	4,856	540				
		Observer	14	874	63	3.38	2.18	0.0118	0.52
		Error	126	3,609	29				
1993	Beech	Tree	9	38,176	4,242				
		Observer	13	1,689	130	9.31	3.52	0.0001	0.87
		Error	117	4,314	37				
	Spruce	Tree	9	27,588	3,065				
		Observer	12	1,424	119	7.48	2.71	0.0031	0.82
		Error	108	4,737	44				
	Pine	Tree	9	18,906	2,101				
		Observer	13	1,244	96	6.73	3.37	0.0002	0.81
		Error	117	3,324	28				
1992	Beech	Tree	9	14,323	1,591				
		Observer	14	726	52	3.12	2.51	0.0035	0.81
		Error	126	2,607	21				
	Oak	Tree	9	65,228	7,248				
		Observer	14	923	66	4.00	2.54	0.0031	0.94
		Error	126	3,270	26				

Table 2 (continued)

Year	Tree	Source of variance	*df*	*SS*	*MS*	s^2_{O}	F ratio	*P* value	*ICC*
	Spruce	Tree	9	48,061	5,340				
		Observer	14	1,232	88	5.35	2.55	0.0030	0.90
		Error	126	4,344	34				
	Pine	Tree	9	39,984	4,443				
		Observer	14	1,292	92	6.91	3.98	0.0000	0.91
		Error	126	2,921	23				

Negative variances should be interpreted as zero. For 1993, no data were available for oak due to strong pest infestation and for 1996 and 1997, data were unrecoverable

out in Bavaria. According to the participants, the selected pine trees showed an uncommon type of growth for pine trees in Germany. It was not possible to classify the defoliation using the reference book due to the special type of growth. However, these errors are negligible for the forest condition surveys where this growth type is very rare.

Common reasons for frequent occurrence of deviations of more than ±10 % on individual trees were difficulties in setting the assessable crown or anomalies such as crown damages, substitution crowns, and uncommon growth types (the information was derived from participants but was not recorded in the past). In spite of high consistencies among the observer teams

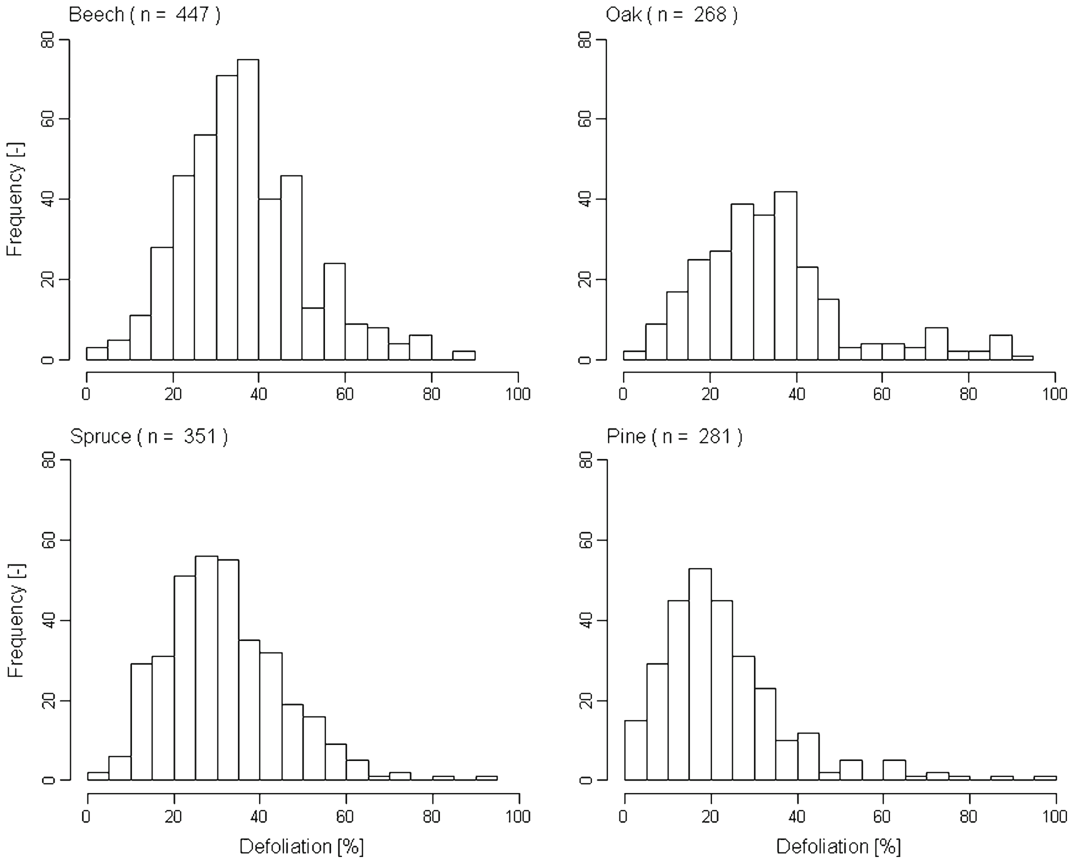
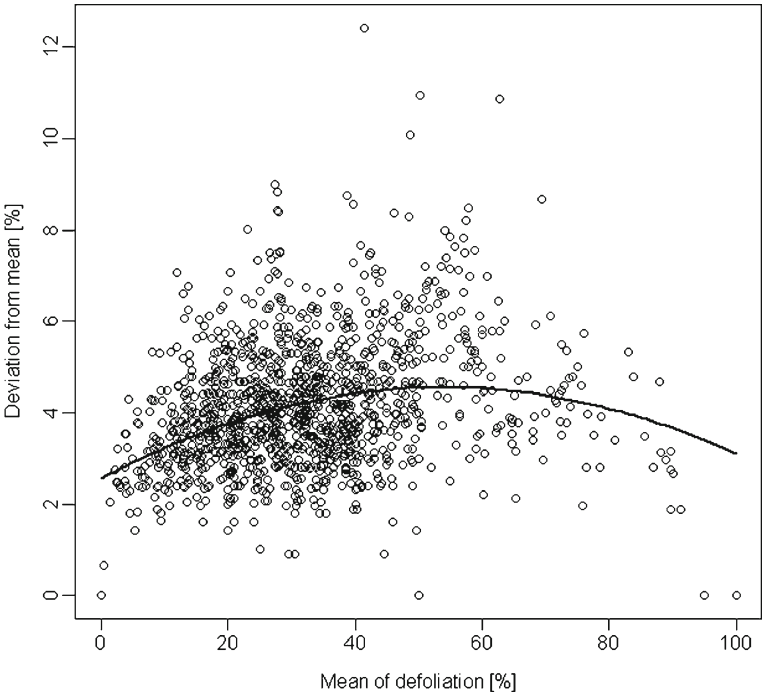


Fig. 5 Frequency distribution of defoliation levels for beech (top, left side), oak (top, right side), spruce (bottom, left side), and pine (bottom, right side) including all data from 1992 to 2012. The number of assessed trees is indicated by 'n'

Fig. 6 Relationship between absolute deviation of defoliation assessments and defoliation level of individual trees. The regression equation is $y=-0.00007\,x^2+0.074\,x+2.56$ ($P<0.001$; residual $df=1,344$) and was derived from generalised least squares using a variance function



in 2011 and 2012, the assessments on beech and pine displayed higher deviations compared to the other species in both years. The tree species showed an extraordinary fructification in 2011, which in case of beech was additionally accompanied by notably small-sized leaves, which caused the comparable high uncertainties in 2011. However, a systematic influence of fructification on defoliation assessment could not be observed between 1992 and 2012. In 2012, the actual needle set of the pine trees was still lacking, as the training course took place in early June. The absence of the actual needle set increased the level of error because the observers had to imagine the needle set. This error, however, is unimportant for the forest condition survey, which takes place later in the year when the actual needles are developed.

Systematic and random errors

Systematic errors among observer teams were found in nearly every year for the four tree species and have frequently been reported from studies investigating the quality of defoliation assessment (Ghosh et al. 1995; Innes 1993; Mues and Seidling 2003; Solberg and Strand 1999; Wulff 2002). Systematic errors resulting from different weather conditions could be excluded because all assessments took place at the same time and were additionally conducted from the same observation point. Systematic temporal or species-specific patterns regarding significant differences among observer teams (federal states) were hardly observed due probably to changes in the assembling of observer teams over time. However, in several years, two of the federal states showed systematic deviations for one tree species each. In one case, the corresponding tree species is rarely represented in the respective federal state and plays no role for the forest condition survey. The federal state that deviated the most over the years and for the four tree species was meanwhile taken over by a cross-federal states institution, which is now responsible for the forest condition survey. Under the cross-federal states institution, the survey is conducted by the same teams as before but systematic errors have not been observed so far.

Between-observer variances were lower than variances of the random error (within-observer variances). The variances were comparable to variances given for observer teams at the national training courses in Sweden in 1995–1999 (Wulff 2002). In 2011 and 2012, variances were in general low as compared to earlier years. The fructification and small-sized leaves of beech in 2011 resulted in comparably high uncertainties in the assessments due to a relatively high random error whereas a systematic error was not observed.

In contrast, the absence of the actual needle set at pine trees in 2012 resulted in a comparably high systematic error, which however was not relevant to the survey as already mentioned.

In spite of significant systematic errors, correlations and agreements among the observer teams were extraordinarily high. Agreements were slightly higher for deciduous trees than for coniferous trees. To evaluate whether assessments of one year and one species were consistent, we applied a three-way evaluation approach. Assessments were considered inconsistent if (1) the mean absolute deviation from the mean was more than ±5 %, (2) less than 90 % of the assessment lay within the ±10 % interval of deviation from the mean, and (3) significant systematic differences among observer teams existed. The present study demonstrated that defoliation assessments at the national training courses were consistent with exception of the assessments at the beech site in 2005, at the spruce site in 1993, and at the pine sites in 1995, 2008, and 2009. The inconsistency at the pine sites in Bavaria can be attributed to the growth type (see above) whereas reasons for the inconsistency at the beech and spruce sites could not be reconstructed. Results from the international cross-comparison courses in Europe in 2001 and 2002 also indicated consistent assessments among teams from one country (Mues and Seidling 2003). Despite consistent defoliation assessments among the German federal states, temporal and spatial evaluations of defoliation data from the forest condition survey should focus on pronounced alterations due to between-observer variance and, particularly, due to often considerable within-observer variance. Solberg and Strand (1999) as well as Wulff (2002) made similar statements for the Norwegian and Swedish forest condition survey.

Dependence of the absolute deviation on the level of defoliation

The distribution of defoliations was right-skewed and displayed slightly higher mean defoliations for the four tree species compared to the nationwide distribution (BMELV 2012). The observed non-linear dependence of the absolute deviation on the degree of defoliation was expected for assessments within an interval and was in line with results from other studies (e.g. Solberg and Strand 1999). Although average defoliation levels of the deciduous tree species were slightly higher than those of the coniferous tree species and hence supposedly more difficult to assess, this did not have a great effect on the absolute deviation. The average deviations ranged within one ±5 % class for all defoliation levels, and therefore, the dependency of the deviation on the defoliation level does not appear to be of critical importance for the quality assessment within the framework of the training courses. It should be noted that the determined relationship between observer error and defoliation level in the present study was based on unbalanced data and it may be worthwhile to investigate this relationship using equal sample sizes of all defoliation levels.

Conclusions

The present study demonstrated that the visual defoliation assessment produced consistent results within Germany at the national training courses for the forest condition survey from 1992 to 2012. Significant tree species-specific differences in the deviations were not observed but the assessment of deciduous trees tended to be slightly more consistent than the assessment of coniferous trees. In large part, pronounced deviations that were observed at the courses (e.g. assessments on pine trees in 1995, 2008, and 2009) are probably of little relevance for the national forest condition survey. Assuming similar assessment behaviours of the observers, a similar distribution of defoliation levels, and that the mean value of all observations on an individual tree represents the unbiased true value, then an observer error of one ±5 % class (absolute deviation of ±4.4 % defoliation from the mean) has to be considered in addition to the sampling error during the forest condition survey. The true bias could, however, not be calculated in the present study. In order to ensure that assessment behaviours do not drift apart subsequent to the training course and that the results can be generalised to the forest condition survey, an intercomparison course during the forest condition survey at which the federal states have to assess trees without previous consultation may be an appropriate measure. In addition, considerable temporal and spatial alterations should be the main focus of interest of the national defoliation assessments rather than short-term trends due to random and systematic observer errors.

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