Reliability Assessment of Selected Indicators of Tree Health

Pawel M. Lech

Abstract.—The measurements of electrical resistance of near-cambium tissues, selected biometric features of needles and shoots, and the annual radial increment as well as visual estimates of crown defoliation were performed on about 100 Norway spruce trees in three 60- to 70-year-old stands located in the Western Sudety Mountains. The defoliation, electrical resistance, and length of an individual shoot were classified as least reliable and of lowest diagnostic usability out of 17 parameters tested as estimates of tree health. In contrast, coefficients such as dry mass of one needle and dry mass of needles next to last set (per one shoot, per 1 cm of shoot) were evaluated as the most credible indicators of tree health. The normative scale of health, as expressed by the values of selected reliable coefficients, was then determined to allow an objective assessment of Norway spruce tree health.

Forest monitoring is one of the essential sources of information about forest health. It has been providing data in a spatially, chronologically, and, what is most important, methodologically uniform order on the European level since 1980's. However, the results obtained within its frame don't allow a clear interpretation. This is particularly obvious in such cases as the crown status—environmental condition relationship and causes of observed damages or disease symptoms. Thus, it seems plausible to analyze the reliability of the methods and criteria currently used in the monitoring of forest health and to consider their modification or replacement.

In the European, transnational survey, visually estimated defoliation of tree crown and discoloration of leaves are practically the only parameters on which the estimation of forest health is based. Each of 20 trees located on the permanent sample plot is assessed in comparison to a reference tree of full foliage and no symptoms of discoloration. The photographs of a healthy tree suitable for the region under investigation may serve as an aid, especially when no reference tree can be found in the vicinity of the plot. The results of defoliation assessment are recorded in 5 percent steps. It is widely accepted to treat defoliation larger than 25 percent as damage and evidence of the decreased health status of a tree. Such a quantity of defoliation corresponds to defoliation class 2 and 3 in the UN/ECE and EU classifications.

Numerous researchers have confirmed the usability of defoliation as an indicator of tree health. A positive relationship has been found between defoliation and loss of tree volume increment (Waring 1983, Soderberg 1991, Trampler *et al.* 1992, Wilmot *et al.* 1995), but a negative dependence has been found between defoliation and leaf chlorophyll content or nutrient status (Stachurski *et al.* 1994). These relationships result from the inhibition of the intensity of basic physiological processes, such as photosynthesis, uptake and transport, and, in effect, a decrease in sugars and other energy substances in leaves. This leads to a reduction in growth rate and is a predisposing factor inhibiting natural resistance of an organism to diseases.

Despite the results of these investigations, there is still a controversy about using defoliation as one of or sometimes the only indicator of forest health, which has commonly happened in the European monitoring programs. Two basic critical approaches can be distinguished. The first one undermines the commonly accepted rule that "the greater degree of crown defoliation of individual trees, the worse health condition of or the greater damage to the forest." The second approach focuses on the accuracy of the method of defoliation assessment and, as a consequence, on the reliability of forest health estimates.

Based on the analysis of the available historical data, Kandler (1992) and Schweigruber (1989) stated that the degree of defoliation is not an adequate indicator of the tree health. They pointed out that the trees, which presently display a good health condition and vitality would, from the early-century crown photographs, have been classified as severely damaged. Mayer *et al.* (1980) and Mueller-Dombois (1987) analyzed a stand-level breakdown and recovery on a spatially rotating basis. They reported that the forest fractions, where a stand is in the phase of breakdown attributed to processes of generation or species succession, are the natural components of the virgin forest spatial structure. Unlike the managed forests, in which such a phenomenon is observed over

Research Assistant, Forest Research Institute, Department of Forest Phytopathology, ul. Bitwy Warszawskiej 1920r. 3, 00-793 Warszawa, Poland, e-mail: p.lech@ibles.waw.pl

large areas, these fractions are small and scattered within the forest complex and they form a spatial mosaic. Recovery (reintegration) of a forest ecosystem follows rapidly and creates an impression of internal harmony (stability) in an ecosystem and of the smoothness of changes. It also means that the dieback of individual trees or species on the ecosystem level is not the symptom of a total destruction but rather the manifestation of the succession dynamics and the adaptive ability of the forest (Mueller-Dombois *et al.* 1983).

The most controversial issue, however, is the estimation method of the degree of defoliation, which according to the ICP-Forest methodology is subjective and not repeatable. It has been stated that defoliation determined in this way does not reflect the true crown condition of a tree as described by biometric parameters of the assimilating apparatus (Sierota 1990, 1991) or by the electric resistance indices of near-cambium tissues (Rykowski 1984). Researchers have also pointed out the low precision of defoliation estimates. The reason for that has been sought in variations of light conditions, unclear assessment criteria, varying levels of observer experience as well as their predisposition to underestimation or overestimation (Lick and Krapfenbauer 1986, Skelly 1992, Innes *et al.* 1993, Ghosh *et al.* 1995, Vacek *et al.* 1996). The constraints question the reliability of defoliation (estimated according to the ICP-Forest methodology) as a reliable indicator of the health of an individual tree or, more so, the health of the entire forest ecosystem. It has been empirically confirmed that there are statistically significant variations in the estimates of defoliation of the same trees at the same time by different teams of observers at a similar experience level (Innes 1988). Similarly, statistically significant differences in average defoliation index of the individual regional directorates of State Forests (administrative units of state-owned forests) were found between two independent research projects performed in Poland in 1991: biological monitoring and large-scale inventory of forest health condition (Lech 1995).

OBJECTIVES AND SCOPE OF THE STUDY

The objectives of the study were as follows:

1. To distinguish the indicators unsuitable for estimating tree health
2. To select the indicators most reliable and of highest diagnostic usability for estimating tree health
3. Definition of a normative health scale in terms of indicator values

To meet these goals, the measurements and analyses of the following biometric characteristics were made:

- tree crown defoliation,
- electric resistance of near-cambium tissues,
- biometric parameters of shoots and needles,
- dendrometric parameters, such as dbh, height and annual radial increment.

METHODS

Assumptions and Hypothesis

Von Bertalanffy's organismal theory and Hippocrates's correlation principle were the logical foundations for the hypothesis formulation. An organism is an integrated structure whose growth happens with the pre-defined trend of proportion changes between individual organs. The proportions between tree components, and the resulting (from them) proportions between the intensity of life processes, are expressed by specific relationships (interactions) between the parameters describing these processes or properties. This statement refers to both "healthy" and "ill" plants, because it cannot be assumed that the pathological course of one process influences other processes or brings about the changes only in the very place of its occurrence. This means, that for randomly selected trees, a positive relationship can be expected between the indicators characterized by the similar dependence to tree health, while a negative relationship can be expected between the indicators characterized by the opposite type of dependence.

These assumptions allow the formation of the following hypothesis:

> ***reliability and diagnostic usability of tree health condition indicators, characterizing a tree is most essential processes and features, are the same***

which should be expressed by the occurrence of statistically significant correlation between the indicators (a small number of indicator statistically significant dependencies with other indicators means poor reliability) and by the compliance of the nature of the relationships between the empirically measured indicators with the nature of these relationships defined *a priori* (no such compliance accounts for the lack of reliability).

Characteristic of the Study Sites

The study plots were located in the Karkonosze Mountains, at Szklarska Poręba forest district. The region is characterized by extreme ecological conditions, such as harsh climate, strong winds, air pollution, and poor and acidic soils (Jadczyk 1994). Forests growing there are usually Norway spruce stands often of unknown origin and unsuitable for local conditions (Wilczkiewicz 1982). The study was performed in three 60- to 70-year-old pure spruce stands in forest compartments 328, 84, and 86, at elevations of 650 m, 850 m, and 950 m above sea level and characterized by eastern, southwestern, and southern exposition. Measurements and samples were collected on all plots from a total of 110 trees in the stands differing in stocking, average dbh, and height of trees as well as in mean crown defoliation (table 1). During field trials in the period 1991-1994, no significant changes in these characteristics were observed.

Indicators of Tree Health Estimation and the Methods of their Evaluation

Seventeen coefficients of biometric characteristics of trees were tested to fulfill defined goals. They were as follows:

- Electric resistance of near-cambium tissues (Imp)
- Visually assessed crown defoliation (Def)

Dendrometric parameters

- Dbh (DBH)
- Tree height (H)
- Mean annual radial increment in periods 1981-85 and 1988-92 (Inc85, Inc92)

Indices of radial increment dynamics (change over time):

- stability (Stab = Inc92/Inc65)
- recovery (Rec = Inc92/Inc85)
- decline (Dec = Inc85/Inc65)

Biometric features of assimilative apparatus

- Mean length of shoot of the 1991 and 1992 sets (L91, L92)
- Mean dry mass of one needle of the 1991 and 1992 sets (M1_91, M1_92)
- Mean dry mass of needles per 1 cm of shoot of the 1991 and 1992 sets (M/1cm91, M/1cm92)
- Mean dry mass of needles per one shoot of 1991 and 1992 sets (M/shoot91, M/shoot92)

These characteristics directly or indirectly reflect the most vital processes and condition of a living tree, i.e., photosynthesis, transpiration, moisture level of near-cambium tissues and their nutrient status, damage to assimilation apparatus. Low costs and feasibility of measurement and analysis, in regard to the application possibility in the forest monitoring, have been the basis for indicator selection.

To evaluate tree health, the expected relations between the indicators and health have to be established. The relationship between tree health and the biometric parameters of assimilative apparatus (L91, L92, M1_91, M1_92, M/1cm91, M/1cm92, M/shoot91, M/shoot92) and the dendrometric features (DBH, H, Inc85, Inc92, Stab, Rec, Dec) has been assumed to be positive. On the other hand, the relationship between tree health and near-cambium electric resistance (Imp) or defoliation (Def) should be negative. If the above assumptions are true, then the dependence between the indicators within each of the two groups will be positive while the dependence between the indicators from different groups will be negative.

Statistical Analyses

A correlation analysis was applied to distinguish the indicators unsuitable for estimation of tree health. Then the cluster analysis that included indicators not eliminated in the preceding step was used to group similar trees, in respect of indicator values. Next, the one-variable analysis of variance (ANOVA) was applied to determine cluster-differentiating indicators. It was assumed that these indicators represent the highest reliability and diagnostic usability for health estimation among all tested parameters. Finally, the Scheffy confidence intervals for means from the plots of ANOVA selected indicators were combined for definition of a normative scale of tree health in terms of indicator values. It was done by extending the interval extremes to obtain continuous scale for every coefficient from health class 1 to health class 4.

Table 1.—*Characteristics of the study sites*

Attribute		Plot	
	328	84	86
Altitude above SL [m]	650	850	950
Aspect	Northeastern	Southwestern	Southern
Slope [%]	5-10	0-5	0-5
Stand age [years]	60-70	60-70	60-70
Stand density	Fully-stocked	Loosen	Intermittent
Range of defoliation [%]	20 – 75	10 - 65	25 – 85
Range of DBH [cm]	16.0 – 42.5	13.25 – 27.5	15.25 – 29.5
Range of tree's height [m]	18.2 – 27.1	13.0 – 21.4	12.6 – 16.8

RESULTS

The character (sign) of correlation between measured parameters, in most cases, agreed with the expected one. The only indicators of a greater number of contrary to assumption signs of correlation were the mean length of shoot of the 1992 set (L92) (6 cases on the plot 86 and 7 cases on the plot 328) and crown defoliation (Def) (5 and 1 such cases accordingly). Correlation signs different from the expected were also occasionally found for such indicators as M/shoot92, M/1cm92, M1_92, L91, and dbh. The signs of correlation of the remaining variables corresponded 100 percent to the assumptions. Contrary to assumption, character of dependence between indicators did not concern the pairs of indicators for which the correlation was statistically significant. It means that this discordance may be accidental and indicates the insufficiency of this criterion for the selection of reliable indicators of tree health.

The second criterion of the indicator selection was the number of statistically significant correlations between them (table 2). All indicators for which the average (of all the plots) number of statistically significant correlation dependencies was smaller than 8[1] (half of possible cases), or for which the number of these dependencies on any plot did not exceed 5.33[2], were subject to elimination.

These were:

- Crown defoliation (Def)
- Mean length of shoot of the 1992 set (L92)
- Radial increment recovery index (Rec)
- Electric resistance of near-cambium tissues (Imp)
- Radial increment decline index (Dec)
- Dbh (DBH)
- Tree height (H)
- Mean annual radial increment in period 1981-1985 (Inc85)
- Mean length of shoot of the 1991 set (L91)
- Mean dry mass of needles per shoot of the 1992 set (M/shoot92)

Visually assessed defoliation, average shoot length of the 1992 set, radial increment recovery index, and electric resistance in near-cambium tissues were the variables for which the number of statistically significant correlation dependencies with other variables was smallest—equaled adequately 2.00, 3.33, 4.33, 4.67. On the other hand, the average annual radial increment in 1988-1992 (11.00), radial increment stability index (10.00), mean needle dry mass per 1 cm of the 1991 shoot (9.33), and the mean needle dry mass on the 1991 shoot (9.00), were the variables for which the number of statistically significant dependencies with other variables was greatest.

---

[1] For Inc85, Dec, L91, L92, M/shoot91 and M/shoot92 it was 7.50 and for Rec – 7.00.

[2] For Inc85, Dec, L91, L92, M/shoot91 and M/shoot92 it was 5.00 and for Rec – 4.6.

Table 2.—*The results of the correlation analyses*

Indicators	Number of significant dependencies between indicators: Plot 328	Plot 84	Plot 86	Average	Result of selection
Imp	9	2	3	4.67	-
Def	3	0	3	2.00	-
DBH	12	5	4	7.00	-
H	9	5	7	7.00	-
Inc85	12	5	4	7.00	-
Inc92	15	9	9	11.00	+
Stab	12	9	9	10.00	+
Rec	3	5	5	4.33	-
Dec	10	4	5	6.33	-
L92	2	5	3	3.33	-
L91	11	4	9	8.00	-
M1_92	11	7	8	8.67	+
M1_91	12	7	7	8.67	+
M/1cm92	11	6	9	8.67	+
M/1cm91	12	8	8	9.33	+
M/shoot92	9	7	7	7.67	-
M/shoot91	10	10	10	10.00	+

In the succeeding step, the cluster analysis was applied to group trees in respect to the similar health status, as expressed by values of remaining indicators: Inc92, Stab, M1_92, M1_91, M/cz92, M/cm91, and M/shoot91. To be in accordance with EC-UN/ECE classification, division on four clusters (health classes) was adopted. On plot number 84, due to obtained distances between clusters in the sequential steps, trees were arranged only into three groups. Then, the result of this classification served as a basis for one-way analysis of variance (ANOVA). It was performed to select the variables that determined the division of trees into health classes (clusters) (table 3).

Among seven indicators selected previously and used in this step, three did not differentiate trees between clusters. They were as follows: Inc92, Stab, and M1_92. The remaining four coefficients (M1_91, M/cm92, M/cm91, and M/shoot91) were characterized by statistically significant variability between almost all clusters and were acknowledged as most reliable among indicators tested in the study.

In the last step, the combination of Scheffy confidence intervals for means of four reliable indicators from the plots served as a basis for determining ranges of indicator values for health classes (table 4). Because only one tree

Table 3.—*Indicators differentiating clusters (health classes)*

Indicator	Plot data ANOVA			All data ANOVA	Reliability
	328	84	86		
Inc92	-	+/-	-	-	-
Stab	+/-	+/-	-	-	-
M1_92	+	+/-	+/-	+/-	-
M1_91	+	+/-	+	+	+
M/cm92	+	+	+/-	+	+
M/cm91	+	+	+	+	+
M/shoot92	+	+	-	-	-
M/shoot91	+	+	+	+	+

Reliability of a given indicator was assigned due to the ANOVA results:
"-" means lack of statistically significant differences between means from clusters
"+/-" means occurrence of statistically significant differences between means from some clusters
"+" means occurrence of statistically significant differences between means from all clusters

Table 4.—*Norway spruce health scale as expressed by indicators' value ranges*

Indicator	Health class	Plot 328 MIN	Plot 328 MAX	Plot 84 MIN	Plot 84 MAX	Plot 86 MIN	Plot 86 MAX	All data MIN	All data MAX	Scale MIN	Scale MAX
	1			5.51	6.44	4.82	5.89	5.68	6.41	**> 5.0**	
M1_91	2	4.37	5.02	4.02	4.42	4.12	4.65	4.25	4.55	**4.1**	**5.0**
[g/1000]	3	3.45	4.23	3.17	3.57	3.69	4.14	3.49	3.79	**3.1**	**4.0**
	4	1.96	2.78			2.39	2.81	2.31	2.69	**≤ 3.0**	
	1			8.889	10.56	9.12	10.77	9.46	10.76	**> 9.0**	
M/cm92	2	8.16	8.94	7.41	8.14	7.98	8.81	7.88	8.423	**7.5**	**9.0**
[g/100]	3	5.97	6.90	5.45	6.18	6.38	7.08	5.97	6.514	**5.5**	**7.5**
	4	3.37	4.16			6.01	6.66	4.88	5.549		**≤ 5.5**
	1			10.36	12.05	11.10	12.96	11.54	12.76	**>10.0**	
M/cm91	2	9.11	9.96	8.44	9.17	8.43	9.36	8.79	9.27	**8.1**	**10.0**
[g/100]	3	6.73	7.74	6.38	7.11	6.87	7.66	6.76	7.27	**6.1**	**8.0**
	4	3.62	4.47			4.89	5.62	4.42	5.04		**≤ 6.0**
	1			0.857	1.027	0.795	0.926	0.877	0.970	**>0.70**	
M/shoot91	2	0.502	0.566	0.494	0.568	0.506	0.572	0.514	0.553	**0.46**	**0.70**
[g]	3	0.318	0.395	0.332	0.406	0.345	0.401	0.348	0.387	**0.31**	**0.45**
	4	0.157	0.221			0.233	0.285	0.205	0.252		**≤ 0.30**

was assigned to health class 1 on the plot number 328, the confidence intervals for this class were excepted. Similarly, the confidence intervals were omitted for the fourth health class on plot number 84 because of the three-class division of trees on this plot. As one may have noticed, in most cases the confidence intervals for respective health classes on plots overlap. Only for M1_92 was there a difference of values for the third health class between plots number 84 and number 86; for M/cm92 such a divergence was found for the second class between plots number 328 and number 84 and for the fourth class between 328 and 86. Other confidence intervals of indicator means for health classes were in a similar range, which enabled the grading of tree health as expressed by the values of selected indicators of a tree's biometric features.

DISCUSSION

The performed statistical analyses showed that the indicators tested in the study were characterized by different levels of reliability and diagnostic usability for estimating tree health. Crown defoliation appeared to be the least reliable indicator. The smallest number of statistically significant correlation dependencies with other indicators as well as the highest amount of discordance (with the assumptions) in sign of the relationship with other indicators manifested it. The highest reliability of assimilative apparatus biometric features indicates that the low reliability of defoliation is caused more by the method of its assessment than by a low diagnostic meaning of the symptom. Such an interpretation corresponds to the opinion of some authors (Innes 1988, Innes *et al.* 1995, Lech 1995), that the "weakness" of visually assessed defoliation is seen in the subjectivity of the way it is determined. On the other hand, among all indicators tested in the study, the most reliable and diagnostically usable were four parameters of assimilative organ features: M1_91, M/cm92, M/cm91, and M/shoot91. High numbers of statistically significant correlation dependencies with other indicators characterized them. In addition, the clusters' means from plots differed for them significantly.

It is interesting to note why the indicators referring to the 1991 set dominated among those selected as most reliable. From four such indicators, only one – average dry mass of needles per 1 cm of shoot of the 1992 set (M/cm92)—referred to the last set of needles and shoots. Explanation of that might be seen in strong juvenile shoot and needle growth dependence, especially in the early phase, on the status and photosynthetic effectiveness of the older needles. In Scots pine, it was found that the last but one set of needles participates in the tree high increment in 51 percent and in radial increment in 70 percent (Meixner and Wozniak 1981). For Norway spruce, similar values might be expected.

According to the results of the study, reliability and diagnostic usability of tested dendrometric parameters differed significantly. Two indicators—Inc92 and Stab—were the variables of the highest number (average for the plot) of statistically significant correlation dependencies with other variables among all those tested (11 and 10, respectively). However, as found in the analysis of variance performed after grouping trees into health classes (clusters), those indicators did not determine the division of trees. As such, both Inc92 and Stab were evaluated as inappropriate for estimating Norway spruce health. Other dendrometric parameters were found unreliable because of the low number of correlation dependencies with other indicators. Such a result is not surprising in the case of DBH, H, or Inc85. However, the low number of dependencies for Rec (Rec=Inc92/Inc85) – average for plot equal to 4.33, was not expected. It was assumed that this index should express the current vitality of the tree, as a manifestation of the ability to overcome the dramatic decline of growth observed in the Western Sudety during the first half of the 1980's. The increase of the radial increment rate in the second half of the 1980's and during the 1990's, which occurred in the stands where study plots were located, might not be an effect of the vitality and recovery ability of an individual tree. A favorable change in environmental conditions – reduction of stressing factor pressure (decrease in air pollution deposits) or the increase in insulation of needles, caused by lower density of crowns and stand stocking—can also serve as a probable explanation. The classification of dendrometric parameters as not reliable and of low diagnostic usability for evaluating tree health requires a comment. As a 5-year means, these parameters do not reflect the current status of a tree (i.e., from the moment other parameters were measured or assessed), but rather an averaged one. In the best case, for the mean year radial increment in the period 1988-1992 (Inc92), it was the 5 years preceding the collection of foliage, impedance, and defoliation data. The other dendrometric coefficients were even more outdated.

A similarity of value intervals of needle biometric parameters for almost all health classes on plots may be evidence of the existence of the universal scale of Norway spruce health condition. Such a scale might serve as a classification tool for estimating tree health and be applicable for all forest sites, climatic conditions, altitudes, etc. It should also be stressed here that the correctness of proposed coefficient value ranges for health classes needs to be tested in the next studies, performed in other places, in stands influenced by different stressing agents. If the values are confirmed, the scale will be ready for application in the monitoring of Norway spruce health.

CONCLUSIONS

1. The indicators used in the experiment are not of equal reliability and diagnostic usability for tree health estimation.

2. Least reliable variables were:
   - defoliation estimated according to the ICP Forest methodology
   - electrical resistance of near-cambium tissues
   - length of shoot of the last year set
   - DBH
   - tree height
   - average radial increment in the periods other than the last one.

3. The indicators of highest reliability and diagnostic usability for estimating of tree health were as follows:
   - mean dry mass of one needle, needles per 1 cm of shoot or needles per shoot of the last but one set (1991)
   - mean dry mass of needles per 1 cm of shoot of the last set (1992).

4. Establishment of a normative scale of tree health seems to be promising, but needs to be verified in additional studies.

ACKNOWLEDGMENT

The following people reviewed this manuscript: Professor Kazimierz Rykowski, Forest Research Institute, Department of Forest Ecology, Warsaw, Poland, and Dr. Jaroslaw Nowak, Philadelphia, MS, USA.

LITERATURE CITED

Ghosh, S.; Innes, J.L.; Hoffmann, C. 1995. Observer variation as a source of error in assessments of crown condition through time. Forest Science. 41(2): 235-254.

Innes, J.L. 1988. Forest health surveys: problems in assessing observer objectivity. Canadian Journal of Forest Research. 18: 560-565.

Innes, J.L.; Landmann, G.; Mettendorff, B. 1993. Consistency of observation of forest tree defoliation in three European countries. Environmental Monitor. Assessment. 25: 29-40.

Jadczyk, P. 1994. Przyczyny zniszczenia lasów w Górach Izerskich i Karkonoszach. I. Warunki środowiska i czynniki antropogeniczne. Sylwan. 12: 39-47.

Kandler, O. 1992. Historical declines and diebacks of Central European forests and present conditions. Environmental Toxicology Chem. 11: 1077-1094.

Lech P. 1995. Przydatnosc szacunkowej metody okreslania defoliacji drzew do badan stanu zdrowotnego lasu. Sylwan. 8: 99-109.

Lick, E.; Krapfenbauer, A. 1986. Terrestrische Waldzustandisinventuren und Probleme einer Objektivierung. Centralbl. Gesamte. Forstwes. 103.

Mayer, H.; Neumann, M.; Sommer, H.G. 1980. Bestandesaufbau und Verjüngungsdynamik unter dem Einfluss natürlicher Wilddichten im kroatischen Urwaldreservat Corkova Uvala/Plitvicer Seen. Schweiz. Z. Forstwes., Jg. 131: 45-70.

Meixner, J.; Wozniak, A. 1981. Przyrost wysokosci i grubosci mlodnika sosnowego przy zmniejszonym aparacie asymilacyjnym. Prace Kom. Nauk Roln. Lesn., T. 52: 109-113.

Mueller-Dombois, D. 1987. Natural dieback in forests. BioScience. 8: 575-583.

Mueller-Dombois, D.; Canfield, J.E.; Holt, R.A.; Buelow, G.P. 1983. Tree-group death in North American forests: a pathological problem or a new problem for vegetation ecology? Phytocoenologia. 11(1): 117-137.

Rykowski, K. 1984. Elektrometryczna metoda oceny stanu fizjologicznego sosny porazonej przez Armillaria mellea w warunkach nawozenia mineralnego. Prace IBL. 635: 81-103.

Schweingruber F.H. 1989. Lasst sich fechlends Datenmaterial zur Waldschadenssituation anhand von Postkarten erganzen? Allg. Forstz. 44: 266-268.

Sierota, Z. 1990. Biometrical features of needles of Scotch pine and Norway spruce under air pollution - a trial of verification of field assessment of crown transparency. Expertentagung Waldschadensforschung im Ostlichen Mitteleuropa und in Bayern. 13-15.11.1990, Schloss Neuburg/Inn bei Passau.

Sierota, Z. 1991. Biometryczne cechy aparatu asymilacyjnego jako posrednie kryterium oceny kondycji zyciowej sosny rosnacej w warunkach stresu. Sylwan. 4-6: 51-62.

Skelly, J.M. 1992. A closer look at forest decline: a need for more accurate diagnostics. In: Manion, P.D.; Lachance, D., ed. Forest decline concepts. American Phytopathological Society Press.

Soderberg, U. 1991. The relation between increment and defoliation for Scots pine and Norway spruce in Sweden. In: Proceedings of the IUFRO & ICP-Forests workshop on monitoring air pollution impact on pernament sample plots, data processing and results interpretation; 1991 September 2-6; Prachatice: 119-127.

Stachurski, A.; Zimka, J.R.; Kwiecien, M. 1994. Forest decline in Karkonosze (Poland). I. Chlorophyll, phenols, defoliation index and nutrient status of the Norway spruce (*Picea abies* L.). Ekol. Pol. 42(3-4): 289-316.

Trampler, T.; Dmyterko, E.; Kliczkowska, A.; Kludka, J. 1992. Wpływ stanu uszkodzenia na produkcyjnosc drzewostanów swierkowych. Project report (manuscript), IBL Warszawa.

Vacek, S.; Leps, J.; Stefancík, I.; Cicák, A. 1996. Precision of visual estimates of tree defoliation. Lesnictví-Forestry. 2: 49-53.

Waring, R.H. 1983. Estimating forest growth and efficiency in relation to canopy leaf area. Advanced Ecology Research. 13: 327-354.

Wilczkiewicz, M. 1982. Rys historyczny gospodarki w lasach sudeckich. Sylwan. 6: 49-54.

Wilmont, T.R.; Elsworth, D.S.; Tyree, M.T. 1995. Relationships among crown condition, growth and stand nutrition in seven northern Vermont sugarbushes. Canadian Journal of Forest Research. 25(3): 386-397.