

Forest Health Monitoring Indicators and Their Interpretability: A Lithuanian Case Study¹

Romualdas Juknys,² Algirdas Augustaitis³

Abstract

Growth and productivity of forests are important indicators for understanding the general condition and health of forests. It is very important that indicators detected during monitoring procedures afford an opportunity for direct or indirect evaluation of forest productivity and its natural and anthropogenic changes. Analysis of the U.S. Forest Health Monitoring (FHM) crown indicators showed that primary crown indicators are not enough for biological interpretation of collected data and estimation of potential tree growth. The length of crown is necessary for calculating meaningful crown indicators; consequently, measurements of tree height should be included into a FHM sampling design. Statistically reliable tree height measurements as well as basal area estimation are necessary for evaluation of tree volume and biomass. Results of a pilot study on relationships between tree growth and crown indicators, and a multiple regression model for assessment of potential productivity of trees based on primary and composite crown indicators are presented in this paper. New composite crown indicators are developed to increase interpretability of FHM data. A modification of FHM tree height, basal area measurement and estimation procedures is proposed.

Introduction

Increased environmental pollution, especially from anthropogenic sources, emphasizes the importance of monitoring the environmental role of forests in Lithuania. Forest vegetation, especially trees, are a basic component of forest ecosystems and are characterized not only by their impressive dimensions and age, but also by their high sensitivity to environmental pollution. Main coniferous species (Scots pine and Norway spruce), which make up to about 60 percent of Lithuanian forests, are especially sensitive to air pollution. As the health and structure of forest ecosystems worsens, biodiversity and productivity decreases, and aging processes accelerate in this polluted environment.

Because of their longevity, forests have an important effect on various processes in the entire biosphere. Their sensitivity to anthropogenic influence integrates past and current environmental situations and is one of the most suitable objects for environmental monitoring. Long range transboundary pollution and environmental acidification affects are considered a main reason for the wide range of forest decline during the last decade. Lithuania has participated in the European Forest Monitoring program (International Cooperative Program on Monitoring and Assessment of Air Pollution Effects on Forests) since 1988. The main forest condition indicator in this program is the visually assessed crown defoliation. According to data of the Lithuanian National survey (Ozolincius 1996), defoliation of the main tree species has affected more than 80 percent of Lithuanian forests (table 1).

Defoliation of different tree species has increased rather substantially during the last several years. A significant increase in defoliation was registered for Norway spruce. Although there has been a significant decrease in air pollution in Lithuania and in Europe during the last 3-4 years (Juknys 1995), the increased defoliation can be explained as a result of the integrated effects of anthropogenic and natural stressors. Unfavorable climatic conditions of past years, especially extremely hot and dry summers in 1992 and 1994, and the invasion of insects have contributed to this negative process. Some stabilization and even decreased defoliation

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² Professor of Forestry, Vytautas Magnus University, S. Daukanto St. 28, 3000 Kaunas, Lithuania.

³ Forester, Lithuanian Agricultural University, 2434 Kaunas region, Lithuania.

for pine and birch recorded in 1994-1995 (*table 1*) can hopefully be considered a first sign of positive biological reaction to the improved environmental situation.

Forest Health Monitoring activities in Lithuania, as well as in other Baltic countries, were started in 1993 when field training with the participation of specialists from the U.S.A. and all three Baltic countries was begun in Birstonas (Lithuania). By following FHM protocol in the Forest Health Monitoring Field Method Guide (FHM 1994), field work started in 1994.

This paper discusses the beginning of the FHM methodology implementation in Lithuanian environmental monitoring procedures and the biological interpretation of the collected data; we also analyzed the necessity to change the field work methodology to enhance the interpretability of the data.

Table 1—Average defoliation of different tree species.

Tree species	Average defoliation (percent)						
	1989	1990	1991	1992	1993	1994	1995
Scots pine	22.8	23.3	25.5	23.6	25.2	24.2	24.0
Norway spruce	15.6	16.5	17.9	17.5	23.1	21.7	28.6
Birch	19.3	21.7	23.3	19.7	23.8	20.7	20.5
Total	18.8	19.7	21.3	21.0	23.4	23.0	24.2

Objectives and Methods

Growth and productivity of forests are one of the main indicators reflecting the general condition and health of monitored forests. Therefore, it is very important that indicators used during monitoring procedures allow for direct or indirect evaluation of forest productivity and its natural and anthropogenic changes.

Because trees are main component of forest ecosystems, growth, productivity, and mortality of trees are very important indicators for forest monitoring. Because direct measurements and estimation of tree growth and productivity is very time consuming and usually requires destructive sampling procedures, indirect methods based on easily detected external indicators are preferred.

Different crown indicators are usually used to evaluate potential growth of forest trees. Many investigations were performed during the last decade to evaluate relations between crown indicators (mainly defoliation of trees) and tree growth (Braker and Gaggen 1987, Juknys 1991, Kontic and Winkler-Seifert 1987, Kramer 1986, Schweingruber 1985). Different results were obtained, but the main conclusions were that correlation between crown defoliation and growth of trees (usually width of annual rings) is rather weak and the coefficient of negative correlation usually doesn't exceed 0.3-0.5.

Our investigation of relations between growth of trees and FHM crown indicators was performed during 1994-1995 using the European forest monitoring system. Crown defoliation was assessed at the same time. Primary proposals to improve interpretability of FHM data were presented during the Baltic countries-U.S.A. FHM meeting, which was held in Kaunas (Lithuania) in December 1994.

Investigations were performed in Scots pine forests surrounding the Jonava mineral fertilizer plant where nitrogen and sulfur compounds are the primary emissions.

The main objectives of this research were:

- To elaborate methodology and models for assessment of potential productivity of trees on the basis of primary and composite crown indicators.
- To define the most suitable tree growth indicator as a response function to crown quantity and quality indicators.

- To develop new indicators and proposals to improve field work methodology in order to enhance interpretability of FHM data.

During the investigation, all tree crown and stem indicators were separated a priori into **primary indicators** (measured or evaluated during field work) and **composite indicators** (secondary or tertiary, calculated on the basis of primary indicators). On other hand, for better understanding and interpretation, all (primary and composite) indicators were defined as **quantitative** or **qualitative** indicators.

Primary analysis of FHM crown indicators have already shown that the list of quantitative indicators measured during FHM field work is not sufficient for biological interpretation of collected data and estimation of potential growth of trees. Length of crown is absolutely necessary for calculation of meaningful composite crown indicators. For live crown ratio evaluated according to the FHM field protocol, height should be measured for some subsample of trees to have data on crown length. Statistically reliable tree height data are also necessary for determination of stand productivity (m^3/ha or $\text{m}^3/\text{ha}/\text{year}$).

Three semimature Scots pine stands were chosen for the investigation and 25 trees were systematically sampled in each of them. The following primary crown and stem indicators were measured for each sampled tree:

- **Quantitative indicators:** Stem diameter (DBH; average of maximal and perpendicular crown diameters); tree height (THG); height of crown bottom (HCB) and crown diameter (CRD; average of maximal and perpendicular crown diameters).
- **Qualitative indicators** (in percent): Crown density (CDN; included into FHM program); foliage transparency (FTR; included into FHM program); crown dieback (CDB; included into FHM program) and crown defoliation (DEF) according to the European forest monitoring system.

Additionally, increment cores were taken from each tree at breast height and two increment indicators were estimated — radial tree increment (RI) and basal area increment (BI) — from 1 to 10 years. Kramer (1986) showed that for assessment of potential tree growth both crown quantity and crown quality should be considered. The following composite tree crown indicators were used for further analysis:

- Crown surface area (CSA) as an integrated crown quantity indicator.
- Total crown losses (TCL) as an integrated crown quality indicator.

Crown surface area and crown volume usually are calculated on the basis of crown diameter and crown length data, and assume that the crown is cone or parabolic shaped. But more detailed investigations on the basis of extensive study of crown for felled trees (Kravchenka 1972) showed that such a strictly geometrical approach can give only a rough approximation to crown surface area or crown volume. Shape of Scots pine crown depends essentially on the age of tree and crown class. Crown shape coefficient (K) (ratio of crown surface area or crown volume to the surface area or volume of cylinder with the same diameter and length) varied from 0.530 for young and suppressed trees to 0.674 for mature dominant trees (Kravchenka 1972).

Crown surface area (CSA) was calculated as follows:

$$\text{CSA} = \text{CRD} * \text{CRL} * \pi * K \quad (1)$$

in which CRD — crown diameter, CRL — crown length.

For the investigated forest stands (70 years), the following crown shape coefficients (K) were used for different crown classes: 1 (open growth) — 0.660; 2 (dominant) — 0.630; 3 (codominant) — 0.600; 4 (intermediate) — 0.570; 5 (overtopped) — 0.550.

Reduced crown density and increased foliage transparency and dieback were considered crown losses (losses of branches, shoots, and foliage) because of the influence of different internal (competition) and external (environmental pollution, insects, diseases, etc.) factors. **Total crown losses** (TCL) in percents were calculated by using the equation:

$$TCL = 100 - ((100 - DNL) * (100 - DBL) / 100 * (100 - FTL) / 100) \quad (2)$$

in which DNL — crown losses because of decreased tree crown density (losses of branches, shoots, and foliage); DBL — crown losses because of increased dieback (losses of shoots and foliage); FTL — crown losses because of increased foliage transparency (losses of foliage).

For determination of crown losses, these questions were examined: what can be considered normal density, normal dieback, and normal foliage transparency? On the basis of 2 years of FHM data, normal (maximal) crown density for Scots pine was assessed as 70 percent, normal (minimal) crown dieback as zero, and normal (minimal) foliage transparency as 5 percent.

Tree crown density losses (DNL) in percent were calculated:

$$DNL = (NDN - CRD) / NCD * 100 \quad (3)$$

in which: NCD — normal crown density; CRD — crown density of tree.

Tree crown losses because of increased foliage transparency (FTL) in percent were calculated:

$$FTL = ((FTR - NFT) / 100 - NFT) * 100 \quad (4)$$

in which: NFT — normal foliage transparency; FTR — foliage transparency of tree.

Crown losses because of increased crown dieback should be assessed according to the analogous formula (4), given that normal dieback for Scots pine equals zero, DBL = CDB.

The composite crown indicator — relative crown amount (RCA) — is considered a mostly integrated crown indicator, which includes practically all quantitative and qualitative crown indicators:

$$RCA = CSA * NCD / 100 * (100 - TCL) / 100 \quad (5)$$

in which: CSA — crown surface area; NCD — normal crown density; TCL — total crown losses.

Results

In order to define the most suitable tree growth indicator as a response function to crown indicators, we correlated radial tree increment (RI) and basal area increment (BI) for different durations (from 1 to 10 years) with the FHM crown indicators (*table 2*). We found that correlation of crown indicators with radial tree increment is essentially weaker than with basal area increment because basal area increment reflects biomass production much better than ring-width increments. The same ring width increment can result in very different biomass increment for trees with different diameters. In addition, foliage transparency is mostly related to radial tree increment between qualitative Scots pine indicators. Correlation of crown dieback with radial tree increment is weak and usually statistically insignificant ($\alpha = 0.05$) for Scots pine.

Table 2 — Correlation of radial and basal area increments with primary FHM crown indicators for different periods.

Crown indicator	Length of period (years)									
	1	2	3	4	5	6	7	8	9	10
Radial increment										
Density	0.296	0.260	0.302	0.363	¹ 0.417	¹ 0.439	¹ 0.434	¹ 0.426	¹ 0.417	0.403
	0.159	0.220	0.151	0.085	0.043	0.032	0.034	0.038	0.042	0.056
Transparency	¹ -0.368	¹ -0.300	0.370	¹ -0.473	¹ -0.578	¹ -0.623	¹ -0.628	¹ -0.624	¹ -0.618	¹ -0.541
	0.076	0.154	0.074	0.019	0.003	0.001	0.001	0.001	0.001	0.007
Dieback	¹ -0.036	¹ -0.174	¹ -0.128	¹ -0.137	¹ -0.148	¹ -0.173	¹ -0.223	¹ -0.236	¹ -0.247	¹ -0.237
	0.867	0.417	0.548	0.519	0.489	0.416	0.295	0.266	0.244	0.261
Basal area increment										
Density	¹ 0.451	¹ 0.446	¹ 0.489	¹ 0.541	¹ 0.555	¹ 0.554	¹ 0.532	¹ 0.517	¹ 0.507	¹ 0.491
	0.027	0.029	0.015	0.006	0.005	0.005	0.007	0.010	0.011	0.012
Transparency	¹ -0.533	¹ -0.495	¹ -0.569	¹ -0.665	¹ -0.710	¹ -0.726	¹ -0.706	¹ -0.616	¹ -0.688	¹ -0.623
	0.007	0.013	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Dieback	¹ -0.057	¹ -0.240	¹ -0.202	¹ -0.242	¹ -0.251	¹ -0.269	¹ -0.323	¹ -0.374	¹ -0.349	¹ -0.320
	0.791	0.245	0.315	0.243	0.273	0.210	0.123	0.072	0.095	0.126

¹ Statistically significant ($\alpha=0.05$).

Coefficients of correlation were averaged between different durations of tree increment indicators and foliage transparency for all investigated tree stands (fig. 1). For 5 to 6 years the correlation of tree increment with crown indicators essentially increased, but further increase of duration usually caused stabilization or even decrease of correlation coefficient. Five-year basal area increment can be considered the most suitable tree increment indicator relating to FHM crown indicators.

FHM qualitative crown indicators and crown defoliation were correlated according to the European forest monitoring system (table 3). Closest correlation with crown defoliation (according to European system) was detected for foliage transparency. Correlation of crown defoliation with crown dieback is weak and statistically insignificant ($\alpha= 0.05$).

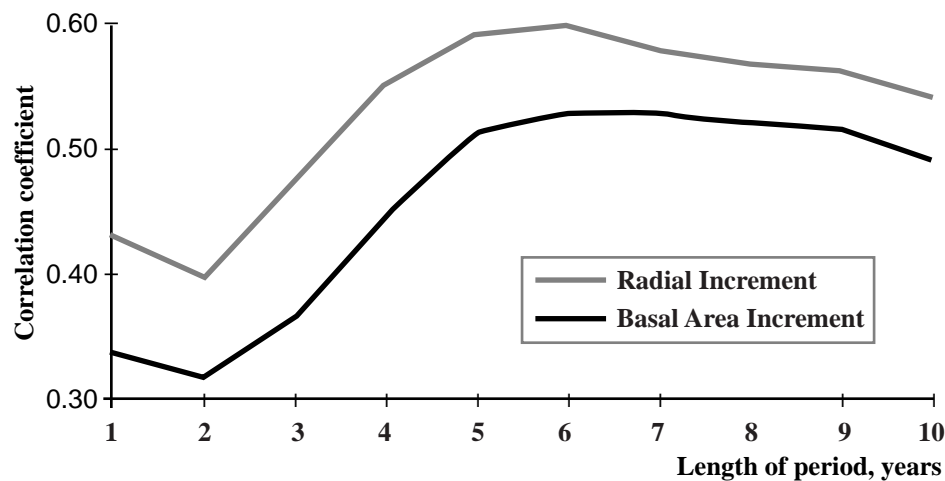


Figure 1 — Correlation of tree increment with foliage transparency for different periods.

Five-year basal area increment and different crown indicators were correlated (fig. 2). Crown length is more closely related to tree increment than crown diameter. Foliage transparency and crown density area are most strongly related to tree increment from primary crown qualitative indicators. Foliage transparency is also closely correlated with crown defoliation according to the European forest monitoring system (table 3).

Relative crown amount, which integrates quantitative and qualitative crown indicators, is most strongly correlated with tree increment from composite crown indicators. Correlation of total crown losses, as a composite qualitative crown indicator with tree increment is closer to that for crown surface area, which integrates quantitative crown indicators. Correlations of primary qualitative crown indicators (with the exception of crown dieback) with tree increment in general is larger than correlations of quantitative primary crown indicators (fig. 2).

Finally, the influence of crown quality on the growth of trees with a different crown quantity (crown surface area) was investigated. Results of multiple regression analysis showed (fig. 3) that for suppressed trees with small crowns the influence of crown quality (total crown losses) is much less than for trees with well developed crowns (big crown surface area). Multiple regression coefficient equal about 0.7; consequently, almost one-half of basal area increment variation can be explained on the basis of composite qualitative and quantitative crown indicators.

Figure 2 — Correlation between 5-year basal area increment and different crown indicators. Key: CDM - crown diameter, CLG - crown length, LCR - live crown ratio, CDN - crown density, FTR - foliage transparency, CDB - crown dieback, CSA - crown surface area, TCL - total crown losses, RCA - relative crown amount.

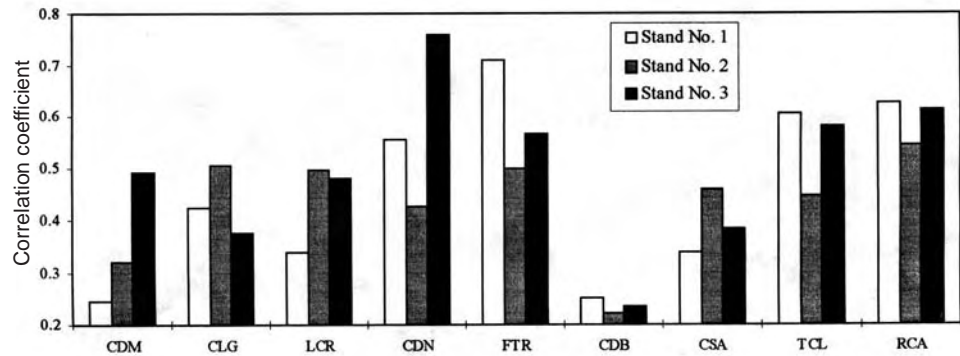


Figure 3 — Influence of qualitative and quantitative composite crown indicators on tree increment.

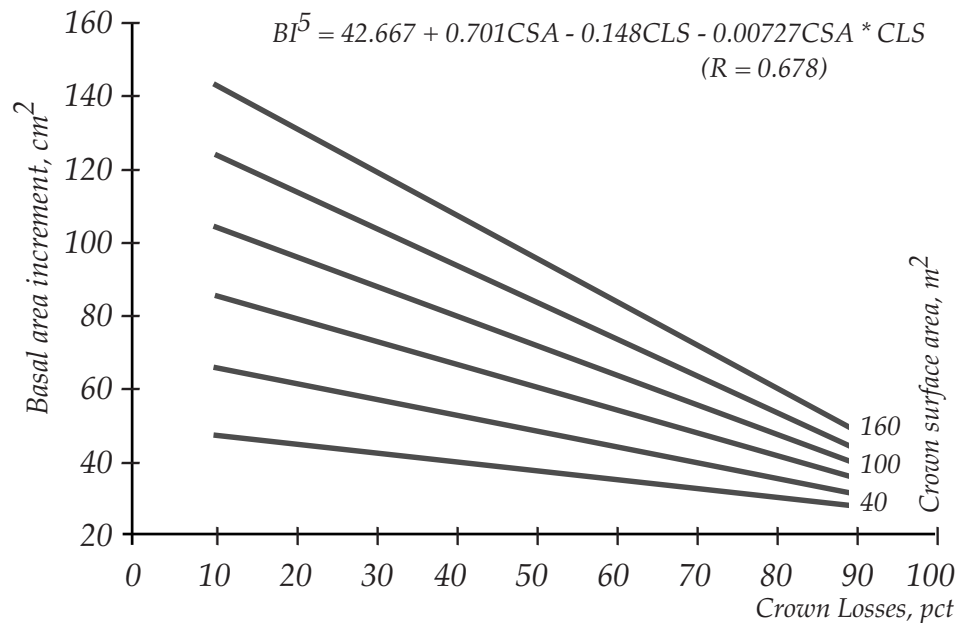


Table 3—Results of correlation of qualitative FHM crown indicators with crown defoliation (significance level).

Stand	Crown density (pct)	Foliage transparency (pct)	Crown dieback (pct)	Total crown losses (pct)
1	¹ -0.813 (0.000)	¹ 0.878 (0.000)	0.215 (0.314)	¹ 0.801 (0.000)
2	¹ -0.830 (0.000)	¹ 0.931 (0.000)	¹ 0.404 (0.049)	¹ 0.818 (0.000)
3	¹ -0.781 (0.000)	¹ -0.823 (0.000)	0.206 (0.334)	¹ -0.789 (0.000)

¹statistically significant ($\alpha = 0.05$)

Discussion

For meaningful interpretation of forest monitoring data, the possibility to assess general features of forests, such as productivity, sustainability, etc., on the basis of easily detected external indicators is very important. Analysis of FHM indicators showed that the list of primary indicators measured and evaluated during field work is not sufficient for biological interpretation of collected data and estimation of potential tree growth and its anthropogenical changes. For assessment of tree growth on the basis of crown indicators, both crown quality and crown quantity should be evaluated and measured. The FHM field work program includes only one quantitative tree crown indicator — crown diameter — and one semiquantitative — live crown ratio. On the basis of these two indicators it is impossible to assess crown quantity (crown surface area, crown volume). Tree height should be measured for some subsample of trees in order to have data on crown length. Statistically reliable tree height data are also necessary for determination of stand productivity.

Five-year basal area increment can be considered the most suitable tree increment indicator relating to FHM crown indicators. Correlation of radial (linear) increment with crown indicators is weaker because the same linear increment can result in different biomass increases. The composite tree crown indicator of total crown losses integrates all tree FHM crown qualitative indicators (crown density, foliage transparency, and crown dieback) and reflects general crown quality. Total crown losses correlates more closely with tree growth than the composite crown quantity indicator — crown surface area. An elaborated multiregional model showed that on the basis of qualitative and quantitative crown indicators, a reliable assessment of tree growth is possible.

Besides separate tree productivity (increment), assessment of productivity of entire monitored stands, such as biomass, volume, and basal area per unit of area, is absolutely necessary. According to the FHM field work program, basal area measurement is included in the list of tree site measurements, but really is not statistically based. Basal area of monitored stands calculated on the basis of measured tree diameters on subplots would be more appropriate. Tree height measurements should be adopted to supplement tree diameter measurements on subplots as special subsamples. Simplified methodology for minimally statistically reliable tree height measurements was developed by the Lithuanian FHM project and is presented in the report for 1995 field season.

In Lithuania, as well as in other Baltic countries, three different forest monitoring systems were introduced during the last decade:

- The European International Cooperative Program on Assessment and Monitoring of Air Pollution Effects of Forests (ICP-Forests) began in 1987, and information on the condition of Lithuanian forests is presented every year. This very simple and operative method was supplemented by the forest soil monitoring subsystem from 1993 and more sophisticated second-level forest monitoring methods from 1995.
- From 1993 Lithuania and other Baltic countries (Latvia and Estonia) joined the International Integrated Monitoring Program on Small Catchments. The pilot phase of this program (Integrated Monitoring in Terrestrial Reference Areas of Europe and North America) was started in 1988 within the UN/ECE Convention on Long-range Transboundary Air Pollution. On the basis of financial support from Nordic countries, two to three very well-equipped Integrated Monitoring Stations were established in afforested background areas in each Baltic country during 1993-1995.
- The Forest Health Monitoring Program, with sound ecologically based methodology and emphasis on biodiversity of forest ecosystems, may be a very good extension of the Forest Monitoring System. It may help in filling a gap between the very simple European Forest Monitoring System and the very sophisticated and expensive Integrated Monitoring System.

Better coordination and coadaptation between those three systems are necessary. Baltic countries could be a very good case study for such international and interprogram activities.

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