Indicators of crown and their application in forest health monitoring

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Growth and productivity of forests are considered to be very important indicators reflecting a general condition and health of forests. It is very important that indicators used for monitoring purposes provide an opportunity for direct or indirect evaluation of forest productivity and its natural and anthropogenic changes. Analysis of the FHM crown indicators has shown, that the primary crown indicators, which are presently measured and evaluated, are not sufficient for biological interpretation of the collected data and estimation of potential tree growth. Crown length is necessary for calculation of the meaningful composite crown indicators and, consequently, the measurements of tree height should also be included into FHM sampling protocol. Statistically reliable tree height measurements as well as basal area estimation are necessary for estimation of tree stand volume and biomass.

A new composite crown quality indicator - total crown losses has been developed on the basis of primary FHM crown quality indicators (crown density, foliage transparency, crown dieback). For determination of crown losses very important is what can be considered as normal density, normal dieback or normal foliage transparency. Based on four years of the FHM data, normal (maximal) crown density for Scots pine was assessed 70 per cent; normal (minimal) crown dieback-zero and normal (minimal) foliage transparency - 5 per cent. Crown surface area was used as a composite crown quantity indicator. Multiple regression model for assessment of potential productivity of trees on the basis of qualitative and quantitative crown indicators is being developed. Five years' basal area increment was found to be a mostly suitable tree increment indicator related to the FHM Crown indicators.

Key words: monitoring, crown indicators, crown losses, productivity.

Introduction

Increasing anthropogenic pressure, especially by environmental pollution emphasizes the environmental role of forests. Forest vegetation, and particularly trees, as a basic component of the forests ecosystems, 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 about 60 per cent of Lithuanian forests, are sensitive to air pollution in particular. The health and structure of the forest ecosystems worsen, biodiversity and productivity decrease and aging processes accelerate in the polluted environment.

Because of their longevity, forests have an important effect on various processes in the entire biosphere. Their sensitivity to anthropogenic influence, integrally reflects past and current environmental situation and is one of the most suitable objects to environmental monitoring. Long range transboundary pollution and environmental acidification effects are considered as the main reason for wide range of forest decline over the last decade. Lithuania has been participating 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. Average defoliation of the main tree species, according to the data of Lithuanian National survey has increased during 1989- 1995. Some stabilization and even a decrease in defoliation for pine and birch was recorded from 1996 (Ozolinčius, Stakėnas,1996) (Table 1), can hopefully be considered as the first signs of positive biological reaction to the improved environmental situation, took place during transitional period because of economy decline and reconstruction (Juknys, 1995).

Much more significant improvement of the state-of-art and productivity of forests is observed locally, in the surrounding forests of industrial centers (Jonava Mineral Fertilizers plant, Mažeikiai Oil refinery, etc.), where

Table 1. Average defoliation of different tree species

Tree species	Average defoliation, %								
	1989	1990	1991	1992	1993	1994	1995	1996	1997
Scots pine	22.8	23.3	25.5	23.6	25.2	24.2	24.0	19.3	21.1
Norway spruce	15.6	16.5	17.9	17.5	23.1	21.7	28.6	21.2	21.3
Birch	19.3	21.7	23.3	19.7	23.8	20.7	20.5	16.6	19.5
Total	**18.8**	**19.7**	**21.3**	**21.0**	**23.4**	**23.0**	**24.2**	**19.1**	**21.1**

forest decline was especially heavy over the last decade of the soviet times. Decrease in the production and reconstruction of these factories are the main reason for the mentioned positive environmental processes.

As an example of such general pattern, the actual and estimated width of annual rings for affected Scots pine trees in the surroundings of Jonava Mineral Fertilizers plant, are presented in Figure 1 (Juknys, 1995). In this case "normal" width of annual tree rings is calculated on the basis of so called Climate Response models (Cook, 1987; Becker, 1989) (Fig. 1).

Growth and productivity of forests are one of the main indicators reflecting a general condition and health of forests monitored. 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 the main components of the forest ecosystems, growth, productivity and mortality of trees are very important indicators of Forest Monitoring. Since direct measurements and estimation of tree growth and productivity, as a rule, is very time consuming and

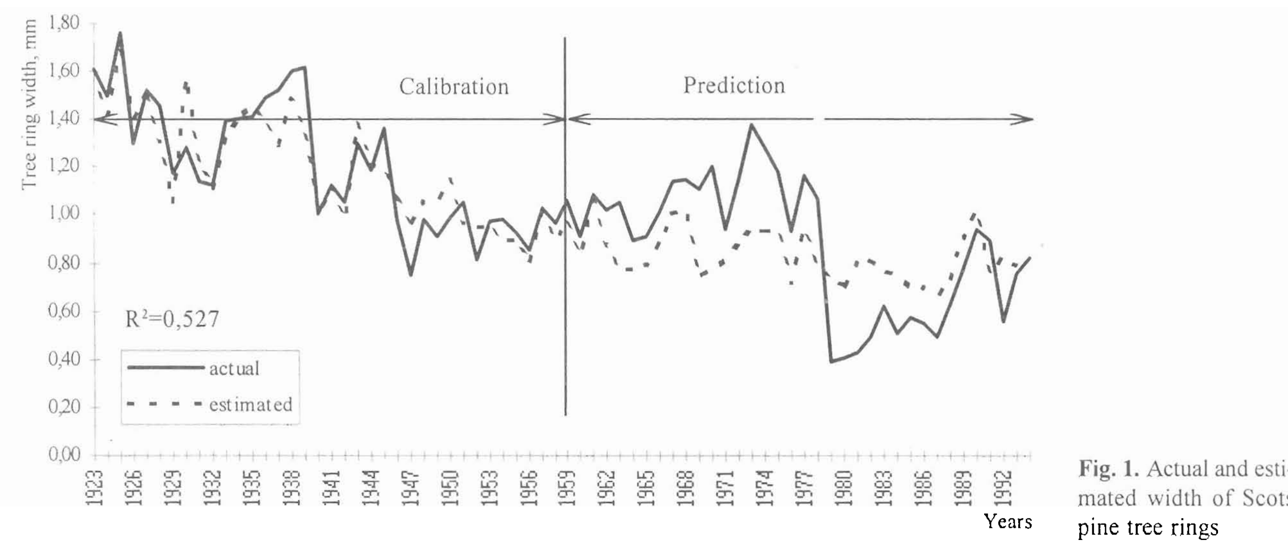

Fig. 1. Actual and estimated width of Scots pine tree rings

It can be seen, that three different periods in reaction of surrounding forests' could be singled out after construction of Jonava Mineral Fertilizers plant in 1965. The first one (1966-1978) could be called as fertilization (stimulation) period, with faster growth of Scots pine. Second - depression period started in 1979 and exclusively cold winter of 1978/79 was an additional unfavourable external factor in this case. The third period - recovering of damaged stands started in 1989, when the production of this factory was considerably reduced and different environmental impact mitigation measures were implemented. As mentioned above, rather significant recovery of damaged forests was noticed in the surroundings of other local pollution sources as well.

usually destructive sampling procedures are needed, indirect methods based on easily detected external indicators are highly preferred.

Different crown indicators are usually used to evaluate potential growth of forest trees. Many investigations were conducted over last decades in order to evaluate the relations between the crown indicators (mainly defoliation of trees) and tree increment. Rather different results were obtained by different authors. Some of them (Kohler, Stratman, 1986) did not find any consistent relations between crown defoliation and tree increment. After others, a more obvious decrease in the tree increment usually starts only in the case, when defoliation exceeds 20-30% (Schweingruber 1985; Krause e.a., 1986; Braker, Gaggen, 1987) or even 50% (Franz, Preuhsler, Rohle, 1986). More complicated treshold effects were presented by R. Ozolincius (Ozolinčius, 1996).

Oposite results were presented by S.O.Philips e.a., R. Kontic and others (Philips, Shelly, Burkhardt, 1977; Kontic, 1987). They found, that a decrease in the tree increment usually starts before the obvious signs of crown defoliation can be determined. Our investigations have shown (Juknys, 1991), that the correlation between the crown defoliation and radial increment of trees (width of annual rings) is not very strong (coefficient of negative correlation usually does not exceed 0.3-0.5), but statistically mostly significant (α=0.05). H.Kramer in his investigations (Kramer 1986) showed that for assessment of potential tree growth both crown quantity and crown quality should be considered.

Forest Health Monitoring activities in Lithuania, and other Baltic countries, were started in 1993, the first field training with participation of specialists from USA and all three Baltic countries was held in Birstonas (Lithuania). Real field works according to the FHM program (Forest Health Monitoring Field Method Guide 1994) were started in 1994.

From the very beginning of the FHM methodology implementation in national Environmental Monitoring practice, we paid special attention to the analysis and biologically meaningful interpretability of collected data. Special additional investigations were conducted, and necessity to make some changes in the methodology of field works in order to enhance interpretability of the data was recognized. Our results and proposals are presented in this article.

Materials and methods

Investigation of relations between the growth (increment) of trees and the FHM crown indicators was caried out in 1994-1995. Crown defoliation according to the European Forest Monitoring system was assessed parallely. Primary proposals to improve interpretability of the FHM data were presented during the Baltic countries-USA FHM meeting, which was held in Kaunas in December, 1994.

The investigation was conducted on Scots pine forests in the surroundings of Jonava Mineral Fertilizer plant. The plant was run in 1965. The main emissions consist of sulphuric oxide, nitric oxides, ammonium and some organic compounds (methanol, formaldechid, etc.). In 1978 the biggest and mostly polluting - Nitrophosca department was run and air pollution had increased essentially. In 1979, after very cold winter very heavy damage of surrounding forests, which consist of Scots pine and Norway spruce mainly, became obvious at the distance more than ten kilometers. In the direction of prevailing winds forest completely died at the distance up to 2 -3 kilometers. In 1989, after very heavy accident in Nitrophosca department, this mostly polluting department was closed, emission was reduced almost three times and recovering processes in the surrounding forests started.

The main ojectives of this research were:

- To elaborate the methodology and models for assessment of potential productivity of trees on the basis of primary and composite crown indicators.
- To determine most suitable tree growth indicator as a response function to the indicators of crown quantity and quality.
- To develop new indicators and proposals to improve field work methodology in order to enhance interpretability of the FHM data.

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

The FHM field work program includes only two quantitative tree indicators - crown diameter, stem diameter (perimeter) and one semiquantitative indicator - the ratio of live crown.

Primary analysis of the FHM crown indicators has already shown, that the list of quantitative indicators, measured during FHM field works is not sufficient for biological interpretation of collected data and estimation of potential growth of trees. Crown length is absolutely necessary for calculation of meaningful composite crown indicators. Taking into account, that the ratio of live crown is evaluated according to the FHM field protocol, the height of trees should be measured for some subsample in order to have the data on crown length. Statistically reliable data on tree height are also necessary for determining stand productivity (m^3/ha, or in better case - m^3/ha/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)*; tree height (THG); height of crown base (HCB) and crown diameter (CRD)*, as the average of maximal and perpendicular crown diameters.

Qualitative indicators (in pct) - crown density (CDN)*; foliage transparency (FTR)*; crown dieback (CDB)* and crown defoliation (DEF) according to European Forest Monitoring system.

* - included into the FHM program.

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) for different length of period - from 1 to 10 years. 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, as well as crown volume, usually are calculated on the basis of the data on crown diameter and crown length by data, considering that crown is cone or parabolia shaped. However investigations on the basis of extensive study of crowns of felled trees (Kravchenka, 1972) have shown, that such a strictly geometrical approach can give only rough approximation to crown surface area or crown volume. The shape of Scots pine crown essentially depends 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) varies 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:

$$CSA = CRD * CRL * p * K \qquad (1)$$

where: CRD - crown diameter, CRL - crown length.

Given the age of 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 as 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 per cent were calculated in the following way:

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

where: 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 very important is a question what is normal: what can we consider as normal density, normal dieback, normal foliage transparency? On the basis of our FHM data, obtained over four years survey, normal (maximal) crown density for Scots pine was set at 70 per cent; normal (minimal) crown dieback-zero and normal (minimal) foliage transparency - 5 per cent.

Tree crown density losses (DNL) in per cent were calculated:

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

where: NCD - normal crown density , per cent; CRD - crown density of tree, per cent.

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

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

where: NFT - normal foliage transparency, per cent; FTR - foliage transparency of tree, per cent.

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

And last composed crown indicator -relative crown amount (RCA) is considered as a mostly integrated crown indicator, which includes practically all quantitative and qualitative crown indicators:

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

where: 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, the correlation between radial tree increment (RI), and basal area increment (BI) for different duration (from 1 to 10 years) and the FHM crown indicators was analysed first. Correlation coefficients for stand No.1 are presented in Table 2.

As seen from Figure 2, up to five-six years, the correlation between the tree increment with crown indicators increases rather essentially, but further an increase in duration usually causes stabilization or even a decrease in correlation coefficient. From the data presented, five year basal area increment can be considered as mostly suitable tree increment indicator relating to FHM crown indicators.

Table 2. The correlation between the radial and basal area increment in different periods and primary FHM crown indicators

Crown indicator	Length of period, years									
	1	2	3	4	5	6	7	8	9	10
	Correlation coefficient / Significance level									
Radial Increment										
Density	**0.296**	**0.260**	**0.302**	**0.363**	**0.417***	**0.439***	**0.434***	**0.426***	**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	**-0.368**	**-0.300**	**-0.370**	**-0.473***	**-0.578***	**-0.623***	**-0.628***	**-0.624***	**-0.618***	**-0.541***
	0.076	0.154	0.074	0.019	0.003	0.001	0.001	0.001	0.001	0.007
Dieback	**-0.036**	**-0.174**	**-0.128**	**-0.137**	**-0.148**	**-0.173**	**-0.223**	**-0.236**	**-0.247**	**-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	**0.451***	**0.446***	**0.489***	**0.541***	**0.555***	**0.554***	**0.532***	**0.517***	**0.507***	**0.491***
	0.027	0.029	0.015	0.006	0.005	0.005	0.007	0.010	0.011	0.012
Transparency	**-0.533***	**-0.495***	**-0.569***	**-0.665***	**-0.710***	**-0.726***	**-0.706***	**-0.616***	**-0.688***	**-0.623***
	0.007	0.013	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Dieback	**-0.057**	**-0.240**	**-0.202**	**-0.242**	**-0.251**	**-0.269**	**-0.323**	**-0.374**	**-0.349**	**-0.320**
	0.791	0.245	0.315	0.243	0.273	0.210	0.123	0.072	0.095	0.126

* statistically significant ($\alpha=0.05$)

A couple of primary conclusions can be made from data, presented in Table 2.

- The correlation between crown indicators and the radial tree increment is essentially weaker than correlation between crown indicators and basal area increment. A reason for that is rather obvious, because the basal area increment reflects biomass production by far better than linear increment. The same linear increment can result in very different biomass increment for trees with different diameter.

- Foliage transparency is mostly related to tree increment among qualitative Scots pine indicators. The correlation between crown dieback and tree increment is weak and usually statistically insignificant ($\alpha = 0.05$) for Scots pine.

Average coefficients of the correlation between the tree increment indicators of different duration and foliage transparency for all three investigated stands is presented in Figure 2.

The data on the correlation between FHM the qualitative crown indicators and crown defoliation according to the European forest monitoring system are presented in Table 3

As seen from Table 3, the closest correlation with crown defoliation (according to European system) was detected for foliage transparency. The correlation between the crown defoliation and crown dieback is weak and statistically most insignificant ($\alpha = 0.05$).

The data on the correlation between the basal area increment over five years and different crown indicators are presented in Figure 3. As shown in this figure, crown length is closer related to the tree increment than crown

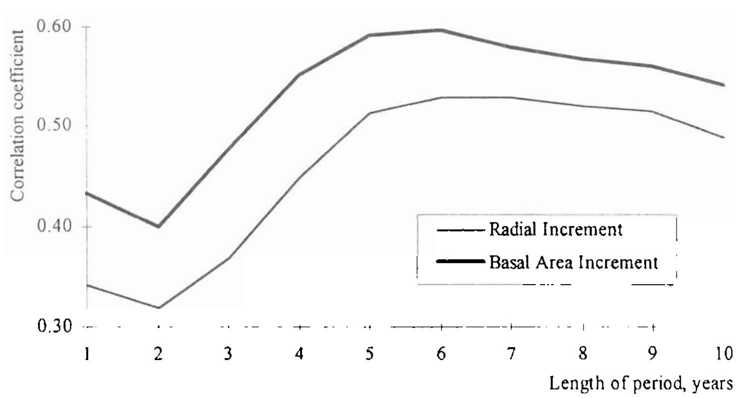

Fig. 2. The correlation between the tree increment of different periods and foliage transparency

Table 3. The correlation between the qualitative FHM crown indicators and crown defoliation.

No. of sampled stand	Crown density, pct	Foliage transparency, pct	Crown dieback, pct	Total crown losses, pct
1	-0.813*	0.878*	0.215	0.801*
2	-0.830*	0.931*	0.404*	0.818*
3	-0.781*	0.823*	0.206	0.789*

* statistically significant (α = 0.05)

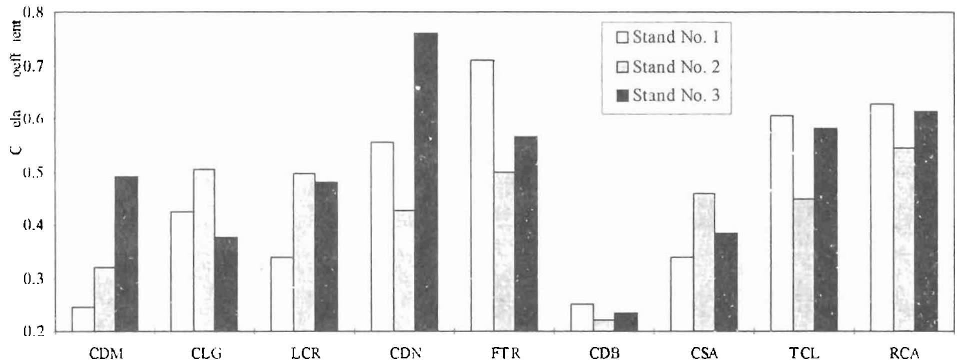

Fig. 3. The correlation between the basal area increment over five years and different crown indicators

where: 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. (Horizontal line – significance level, α = 0.05)

diameter. Foliage transparency, and crown density area are most closely related to the tree increment from primary crown qualitative indicators. Foliage transparency is also most closely correlated with crown defoliation according to the European forest monitoring system.

Relative crown amount, which integrates into quantitative and qualitative crown indicators, is most closely correlated with tree increment from composite crown indicators. The correlation between the total crown losses, as a composite qualitative crown indicator and tree increment is closer then that between the crown surface area, which integrates into quantitative crown indicators. As seen from the same Figure, the correlation between the primary qualitative crown indicators (with exception of crown dieback) and tree increment in general is closer than correlation between quantitative primary crown indicators.

Finally, the influence of crown quality on the growth of trees with a different crown quantity (crown surface area) has been investigated. The results of multiple regression analysis has shown (Figure 4), 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 (large crown surface area). Multiple regression coefficient equals about 0.7, consequently, almost one half of basal area increment variation can be explained on the basis of composed qualitative and quantitative crown indicators.

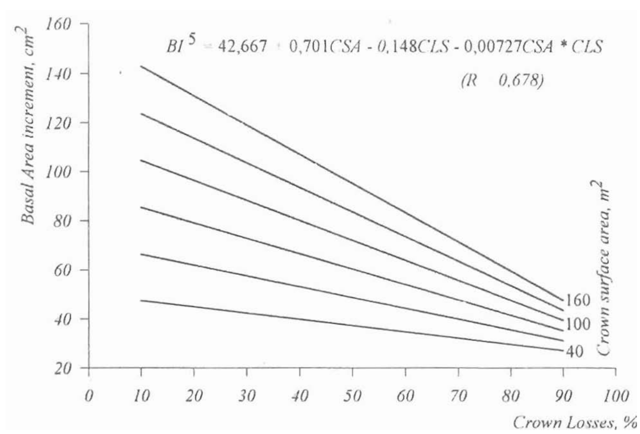

Fig. 4. The influence of qualitative and quantitative composed crown indicators on the tree increment.

Discussion

For meaningful interpretation of forest monitoring data, the possibility to assess such general features of forests, as productivity, sustainability etc., on the basis of easily detected external indicators is very important. Analysis of Forest Health Monitoring indicators has shown, that the list of primary indicators measured and evaluated during field works is not sufficient for biological interpretation of collected data and estimation of potential tree growth and its anthropogenic 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 semiquantative - 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.

The basal area increment determined over five years can be considered as mostly suitable tree increment indicator, relating to the FHM crown indicators. The correlation between the radial (linear) increment and crown indicators is essentially weaker, because the same linear increment can result in different biomass increases. Composed tree crown indicator - total crown losses integrates into 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 composed crown quantity indicator - crown surface area. A constructed multiregresional model has shown, that on the basis of qualitative and quantitative crown indicators reliable assessment of tree growth is feasible.

Along with the productivity (increment) of an individual tree, assessment of the productivity of entire monitored stands in terms of biomass, volume, basal area per unit of area is absolutely necessary. In accordance with the FHM field work program, basal area measurement is included into the list of site tree measurements and really is not statistically based. It would be more appropriate to calculate basal area of monitored stands on the basis of measured tree diameters on subplots. Tree height measurements should be adapted to tree diameter measurements on subplots as special subsamples. Simplified methodology for minimal statistically reliable tree height measurements is developed by the Lithuanian FHM project and will be presented in the report for the field season in 1996.

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

European International Cooperative Program on Assessment and Monitoring of Air Pollution Effects of Forests (ICP-Forests) was joined from 1987, and information on condition of Lithuanian forest is presented every year. This very simple and operative method was supplemented by 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 International Integrated Monitoring Program on Small Catchments. 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, 2-3 very good equipped Integrated Monitoring Stations were established on afforested background areas in each Baltic countries during 1993-1995.

Forest Health Monitoring Program with sound ecologically based methodology and emphasis on biodiversity of forest ecosystems may be very good extension of Forest Monitoring System. It may help in filling a gap between very simple European Forest Monitoring system on one side and very sophisticated and expensive Integrated Monitoring system on the other side.

Better coordination and coadaptation between these three systems are necessary. Baltic countries could be very good case for such international and interprograme activities.

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ПОКАЗАТЕЛИ КРОН ДЕРЕВА И ВОЗМОЖНОСТИ ИХ ИСПОЛЬЗОВАНИЯ ПРИ МОНИТОРИНГЕ ЛЕСОВ

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Резюме

Рост и продуктивность лесов является важным показателем, отражающим общее состояние и здоровье лесов. Очень важно чтобы показатели, определяемые в лесу, создавали возможности прямой или косвенной оценки продуктивности лесов и неё антропогенных изменений. Анализ показателей кроны, определяемых при проведении Мониторинга здоровья лесов, показал что они недостаточны для оценки потенциальной продуктивности деревьев. Длина кроны необходима для более полной количественной характеристики кроны, следовательно высота деревьев должна определяться во время полевых работ. Статистически обоснованное определение высоты деревьев и сумы площадей сечений необходимо и для определения запаса и биомассы древостоев.

Новый интегральный показатель состояния кроны - общие потери кроны (Total Crown Losses), был разработан обощая все три первичные показатели состояния кроны (густота (Density), прозрачность (Transparency), усыхание (Dieback)). При определении потерь кроны очень важен вопрос нормы - нормальной густоты кроны, прозрачности листвы и нормального (естественного) усыхания побегов. На основе накопленных полевых материалов для сосны обыкновенной в качестве нормальной (максимальной) густоты кроны принято 70%, в качестве нормальной (минимальной) прозрачности листвы - 5% и в качестве нормального (минимального) усыхания побегов - 0%. Поверхность кроны принята в качестве интегрального количественного показателя кроны. На основе проведённых исследований разработана множественная регресионная модель для косвенной оценки потенциальной продуктивности деревьев на основе качественных и количественных показателей кроны. Пятилетний прирост по площади сечения был принят в качестве показателя роста деревьев, наиболее тесно коррелирующего с показателями кроны.

Ключевые слова: мониторинг, показатели кроны, потери кроны, продуктивность.