DENDROCHRONOLOGY FOR ENVIRONMENTAL IMPACT ASSESSMENT

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Abstract

Different methods for assessment of anthropogenical changes of tree increment are analysed in this article. According to the method of evaluation of normal tree increment, as a basis for assessment of anthropogenical changes, tree groups of methods were separated: methods of control communities (stands), methods of control individuals (trees) and methods of control periods. Methods of first group are recommended to use in the areas with well expressed pollution gradient with increase of distance from local pollution gradient with increase of distance from local pollution source. In the case of low level chronic environmental pollution of regional scale methods of control individuals and control periods preferable and are presented in more details in this article.

Keywords: normal increment, anthropogenical changes, climate response models, predictive capacity

INTRODUCTION

Relations between tree increment and different natural external factors is a key issue of dendroclimatology. But from the very beginning of eighties very important environmental problem has arose and forest decline of regional scale has started. Long range transboundary pollution and environmental acidification effects has became as a very powerful new external factor, which affects state and productivity of forests considerably. Assessment of anthropogenic transformations of different biological indicators, including tree increment, has became as very important scientific and practical task.

Taking into account, that productivity of forests is one of the main parameters. which reflects integrally a condition and health of forests, annual tree increment (width of annual tree rings) is one of the most acceptable biological indicators for environmental impact assessment.

Lithuania participating in the European Forest Monitoring program (International Cooperative Program on Monitoring and Assessment of Air Pollution Effects on Forests) since 1988. Average defoliation of main tree species, which occupy more than 80 percent of Lithuanian forests, according to data of Lithuanian national survey (Ozolincius, Stakenas, 1997) is presented in table 1.

As it is seen from table 1, defoliation of different tree species has increased rather substantially in first half of nineties. Mostly significant increase of defoliation was registered for Norway Spruce. Taking into account rather significant decrease of air pollution in Lithuania, as well as in whole Europe, from the beginning of nineties (Juknys 1995) such phenomena could be explained as a result of integrated effects of anthropogenic and natural stresses. Unfavourable climatic conditions of past years, especially extremely hot and dry

1992 and 1994 summers and following invasion of insects has made essential input to this negative process. Some stabilisation and even decrease of defoliation for pine and birch registered from 1994-1995 (table 1) can hopefully be considered as a first signs of positive biological reaction to the improved environmental situation.

Table 1. Average Defoliation of Different Tree Species

Tree species	Average defoliation, pct								
	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**

Much more significant improvement of forests state and productivity is observed locally, in surrounding forests of industrial centres (Jonava Mineral Fertilisers plant, Mazeikiai Oil refinery, etc.), where the decline of forests was especially heavy during the last decade of the soviet times. Decrease of production and reconstruction of these factories are the main reason for the mentioned positive environmental processes.

Main limitations for assessment of anthropogenical changes of different biological indicators could be listed as follows:

- sensitivity of indicators to anthropogenical impact;
- spatial and temporal variability of indicators;
- length of data time series.

Tree ring analysis provides very important long term data, are very useful for the assessment of environmental impact.

MATERIALS AND METHODS

Investigations of three injured Scots pine stands in different distances from source of pollution were carried out in the surroundings of Jonava Mineral Fertilizers plant, where nitrogen and sulphur compounds are emitted mainly. This plant was run at 1965 and was gradually extended up 1978, when most polluting Nitrophosca department was run. Extreme accident took place in this department at 1989 and it was closed. Production of factory was greatly reduced and environment pollution in the surrounding was essentially reduced consequently. Twenty five trees were sampled in each stand. Main stem and crown parameters (diameter, height) were measured and wood samples were taken for each tree.

Methodology of dendroecological investigations is rather different from that for traditional dendroclimatology. First of all, main object of investigations - tree rings should be taken from other positions. During dendroclimatological investigations there is not absolute values of annual increment but derivations from long term average (trend of age) - tree ring indices are mostly interesting and informative. From dendroecological point of view fluctuations of annual increment creates a big informational noise and main difficulties during assessment of anthropogenical changes of tree increment. Detection of anthropogenical signal on the background of natural quasiperiodical fluctuations is one of the most difficult tasks for environmental science.

The second essential difference from dendroclimatological tree ring analysis - length of tree ring series. For dendroecological purposes annual increment of mostly common tree species is mostly interesting and length of tree ring series, as a rule, do not exceed 100 years, and usually is essentially shorter (50-70 years).

For the quantitative assessment of anthropogenical changes of biological indicators and parameters problem of norm (normal growth in the case of tree ring analysis) is very important. A lot of different methods for the assessment of anthropogenical changes of tree increment were elaborated.

According to the method of evaluation of normal tree growth (normal increment, as a basis for assessment of anthropogenical changes), they could be classified into three main groups:

- Methods of control communities (stands);
- Methods of control individuals (trees);
- Methods of control periods.

Methods of first group are based on the comparison of tree increment or tree indices of injured stands with such of relatively healthy ones, are growing in the similar forest type and have approximately same dendrometrical characteristics (age, average height and diameter, density and so on). An increment of these control relatively healthy stands is considered as a normal to compare with injured stands (Bitvinskas, 1974; Liepa, 1980). The accuracy of assessment in this case is rather subjective and depends essentially on the successfulness of control stand choice. The method was improved essentially (Liepa, 1980) and could be recommended to use in the areas with a well expressed pollution gradient with increasing distance from the local pollution source.

In the case of low level chronic environmental pollution on a regional scale, the choice of control stands is difficult and really impossible, and methods of control individuals and control periods are usually used.

Methods of control individuals are based on two presumptions:

- interspecific variability of sensitivity to the impact of environmental pollution is significant;

- relation between tree growth (increment) and tree state (level of defoliation) is statistically significant.

Increment of relatively healthy individuals (trees) with a minimal defoliation is considered as a normal in this case and is compared with increment of more defoliated trees inside the same stand.

Methods of control periods are based on quantitative analysis of tree-ring series, and their relations with climatic factors. Increment of trees during the period before the essential environmental impact (pollution) was started, is considered as a normal, and prediction of normal growth for the period of injury is made on the basis of Climate response models (Cook, 1987; Becker, 1989).

Possibilities of two group of methods, are suitable for assessment of anthropogenical changes of tree growth on regional scale (methods of control individuals and methods of control periods), are analyzed in this paper.

RESULTS

As it was already mentioned, methods of control individuals are based on two main presumptions:

- interspecific variability of sensitivity to the impact of external factors is significant;
- relation between tree growth and tree state is statistically significant.

Regarding to the first presumption, usually there are no essential contradictions, because it is rather obvious, that individuals with very different level of injure (level of defoliation) can be found in the same stand.

Rather different results were obtained by different authors during investigations of relations between tree defoliation and increment. Some of them (Kohler, Stratman, 1986) did not find any consistent relations between crown defoliation and tree increment. According to others, more obvious decrease of 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% (Frantz, Preuhsler, Rohle, 1986).

Oposite results were presented by S.O.Philips e.a., R.Kontic e.a. (Philips, Shelly, Burkhardt, 1977; Kontic, Winkler-Seifert, 1987). They found, that decrease of tree increment usually starts before the obvious signs of crown defoliation can be determined. Rather sophisticated threshold effects for the relations of crown defoliation and radial increment were detected by R.Ozolincius (Ozolincius, 1996).

Our investigations showed (Juknys, 1991), that correlation between crown defoliation and radial increment of trees is not very strong (coefficient of negative correlation usually does not exceed 0,3-0,5, but mostly statistically significant (P=0,95)).

When relations between crown defoliation and tree growth are investigated, linear (radial) increment usually is considered as a response indicator. However, the same radial increment can represent very different biomass increment in the case, when diameter of trees is different. Annual increment of basal area, represents increment of biomass and crown productivity, much better. During our investigations, impact of crown defoliation was investigated to both - radial and basal area increment.

Taking into account, that coniferous have needles of several years, there is useful to know duration of growth, which relates most closely to the present state of crown. Correlation of crown defoliation with the radial and basal increment for the period from 1 to 10 years was investigated.

Results were obtained, that with increase of the length of period, increment is measured, correlation with crown defoliation usually increase up to 5-6 years period and then is coming down. Consequently, increment of five last years is best of all to take into account when its correlation with current crown state is investigated. In all cases, correlation of crown defoliation with basal area increment was closer of that for radial increment. For five years period correlation of crown defoliation with radial increment was 0,35÷0,40 and with basal area increment - 0,5÷0,55 for investigated Scots pine stands.

As it was showed by H.Cramer, during investigation of tree crown defoliation impact to the tree increment, it is very important to take into account quantitative parameters of crown as well. In an opposite case, interpretation of tree crown defoliation - tree increment relations becomes problematic (Kramer, 1986). Crown surface area or crown volume usually are considered as a main crown quantitative parameters in such kind of investigations.

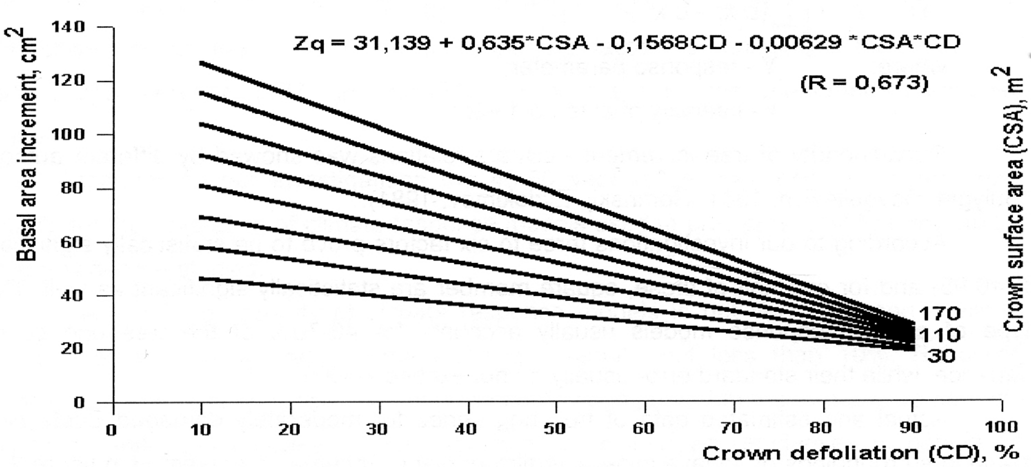

Figure 1. Impact of crown defoliation to the Scots pine basal area increment

Results of multiple regression analysis (Fig. 1) showed, that for suppressed trees with small crowns influence of crown defoliation to the tree growth is much weaker than for dominant trees with well developed crown. As it can be seen from figure 1, in the case of increase of crown defoliation from 10% up 90% increment of basal area for suppressed trees (crown surface area $30m^2$) was reduced about 2 times, and increment of dominant trees (crown surface area $170m^2$) - more than five times.

Multiple regression coefficient in this case equals to 0,673, consequently almost one half of tree increment variations can be explained by tree defoliation, when quantity of crown (crown surface area) is taken into account.

Methods of control periods, based on the multiple climate response models, usually are considered as a main tool for the assessment of anthropogenical changes of tree growth. The main priority of those methods - long term data are used. On the basis of short term data, erroneous conclusions can be made rather often, if temporal fluctuations of investigated indicators will not be taken into consideration.

Climate response models are usually considered as the linear response models. For climatic conditions, far from optimal, such simplification seems acceptable. But V.E.Shelford already in the beginning of our century has showed that surplus of moisture, temperature, as well as their deficiency limit activity (growth) of live organisms (Shelford, 1913). Numerous experiments showed that so called curves of tolerance are the best approximated by bell shaped curves of the type:

$$Y = e^{a+bx-cx^2} \qquad (1)$$

or after logarithmic transformation:

$$\ln Y = a + bx - cx^2 \qquad (2)$$

and in a multivariate case it will be:

$$\ln Y_j = a_0 + \left[\sum\left(b_i x_i - c_i x_i^2\right)\right] \qquad (3)$$

where: Y - response parameter;

x - intensity of external factor.

Curvelinearity of tree increment - climate relations was showed by different authors (Bulygin, Dovgullevich, 1981; Gortinskij, Evdokimov, 1981).

According to our investigations three to six factors prove to be statistically significant (P=0,95) and for one half of these, square member are statistically significant as well. This type of climate response models usually accounts for 40-70% of the tree ring series variance, while their standard error usually do not exceed 7-10%.

Actual and estimated data of tree ring series for moderately damaged Scots pine stand in surroundings of Jonava mineral fertilizers plant "Achema" is presented in figure 2. It can be seen, that three different periods of trees reaction could be singled out after constructions of "Achema" in 1965. The first one (1966-1978) could be called as fertilization period, with improved growth of Scots pine trees. Second - depression period was started in 1979, and exclusively cold winter of 1978/79 was an additional unfavorable external factor in this case. And third period - recovering of damaged stands was started from 1989, when production and pollution of factory was greatly reduced. A rather significant recovery of damaged forests was noticed in the surroundings of other local pollution sources, as a consequence of reduced production and reconstruction.

These local recovery processes are very interesting, and valuable from the scientific point of view and create possibilities for deeper investigations of recovering capacities of damaged forest ecosystems.

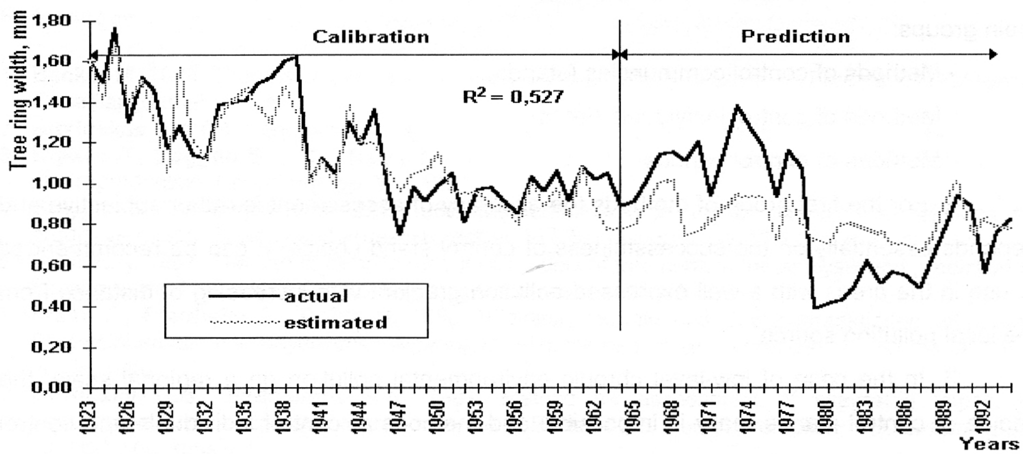

Figure 2. Actual and estimated, by climate response model, Scots pine tree rings

Our investigations showed (Juknys, 1993), that closeness of climate - tree ring width relations also depends on the length of time series. If the length of time series exceeds 50 years, the closeness of climate - tree ring relations usually decreases. As mentioned by F.H.Schweingruber, the reaction of trees to external factors is changing in the process of aging (Schweingruber, 1987) and possibly it is a reason for the phenomena mentioned above.

According to our investigations the 40-60 year length tree ring series are most suitable for the calibration of climate response models used to predict normal tree growth for the forest decline studies.

The resolving capacity of climate response models is not very high and it allows detection of anthropogenical increment changes usually not less than 10%. Resolving capacity of these pure statistical methodology could be improved in the future if we can find way to estimate quantitatively the consequences of well-known regularities of population dynamics, in which all live organisms are striving for the equilibrium state in their interaction with external factors. Under those homeostatic mechanisms, tree response after extreme unfavorable climatic conditions is not adequate to their influence and limits the possibilities of pure statistical methods.

Considering such characteristics of the system as resiliency, elasticity, etc., more complex investigations of endogenous regularities of tree growth process and its relations with exogenous factors are necessary.

CONCLUSIONS

1. A lot of different methods for the assessment of anthropogenical changes of tree increment were elaborated. According to the method of evaluation of normal tree increment, as a basis for assessment of anthropogenical changes, they can be classified into three main groups:

- Methods of control communities (stands);
- Methods of control individuals (trees);
- Methods of control periods.

2. For the first group of methods the accuracy of assessment is rather subjective and depends essentially on the successfulness of control stand choice. It can be recommended to use in the areas with a well expressed pollution gradient with increasing of distance from the local pollution source.

3. In the case of low-level chronic environmental pollution on a regional scale, the choice of control stands really is impossible and methods of control individuals and control periods are recommended.

4. Investigations of methods of control individuals showed, that with increase of the length of period, increment is measured, correlation with crown defoliation usually increase up to 5-6 years period and then is coming down. Correlation of basal area increment with crown defoliation is closer of that for radial (linear) increment. Five years basal area increment is recommended as a most suitable response indicator for the investigations of crown defoliation - tree increment relations.

5. Results of multiple regression analysis showed, that for suppressed trees with small crowns influence of crown defoliation to the tree growth is much weaker than for dominant trees with well developed crowns. In the case of increase of crown defoliation from 10% up to 90% increment of basal area for suppressed trees was reduced about two times, and increment of dominant trees - more than five times.

6. Climate response models, as a basis for retrospective prediction of normal increment for the period of injury, usually are considered as a linear models. For the climatic conditions close to the optimal, such simplification not always is acceptable. Our investigations showed, that during the construction of climate response model usually three

to six climatic factors prove to be statistically significant (P=0,95) and for half of these, square members are statistically significant as well. This type of climate response models usually accounts for 40-70% of the tree ring series variance, while their standard error usually do not exceed 7-10%.

7. Closeness of climate-tree ring relations depend on the length of time series. When the length of time series exceeds 50 years, the closeness of relations usually decreases. Changing of the reaction of trees to the impact of external factors during ontogenezis possibly is a reason for this phenomena. The 40-60 years length tree ring-series are most suitable for the calibration of the climate response models used to predict normal tree growth for the forest decline studies.

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