THESES OF THE PhD DISSERTATION

INVESTIGATIONS ON COMPETITION IN THE LONG TERM GROWTH AND YIELS EXPERIMENTAL PLOTS ON THE SOPRON HILLS

University of West-Hungary
Forestry and Game Management Doctoral Program Róth Gyula
Subprogram E3 Forest Assets Management

Supervisor: DR. GÁBOR VEPERDI

Written by
TAMÁS HORVÁTH
Forest engineer

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Doctoral Program: Roth Gyula Forestry and Game Management

Leader: Prof. Dr. Sándor Faragó

Program: Forest Assets Management (E3)

Program leader: Prof. Em. Dr. Béla Lett

Supervisor: Dr. Gábor Veperdi

1. Definition of the topic

Growth and yield research has always played an important role in broadening the knowledge of forest science. The reason for this is not the curiousness of scientific workers but the need from the side of the forestry practice. The aim of the research is to estimate the future yield. Yield tables are one of the most important foundations of forestry planning.

Researchers considered model building, describing natural processes with equations as important. Model building, processing the data measured in the field and recognizing relations between data was earlier a labor-intensive task. Despite the above mentioned early research resulted in achievements which can be used even today.

The environmental factors have a long time effect on the forest ecosystems and to monitor these effect long term experiments are needed which require attention from the researchers throughout several human generations. These are the so called long term growth and yield experiments which play an important role in forest research not only in Hungary, but also in other countries. Data gained from these experiments provide important information for researcher and for the practical foresters as well.

In the German speaking area these experiments deliver data about the changes of the forest ecosystems for already more, than 130 years under continuous observation. This way several generations of foresters participated in the collection of the data and as a result of this work a database is available on the basis of which research workers of today can elaborate more precise and usable models using modern analysis methods.

To be able to use the data gathered 130 years ago not only the work of the specialist of the past is necessary but the same data have to be measured on the trees or on the experimental plots. Standardization of the measurement procedures is as important as the marking of the measurement spot for DBH or the permanent numbering of the trees in a experimental plot. In Hungary a Nelder circle was established in the year of 2009, and the first measurements were taken in 2011 according to the same methodology as in the case of similar plots in other countries. This experiment is planned for at least 100 years, during which it is necessary to measure the stand from time to time according to given methodology.

The long term growth and yield experiments have a long tradition also in Hungary. A boom was given to this research at the beginning of the 1960s, when the Sylviculture and Growth and Yield Department of the Hungarian Forest Research Institute designed the long term growth and yield, sylvicultural and spacing experiment network for the main species of Hungary under the leadership of Dr. Rezső Solymos. In the „golden age" of the growth and yield research (1961-1995) several remeasurements of several thousand plots were

accomplished as a result of which new yield tables and stand treatment tables were published.

The data of these and similar plots are available for the analysis of the actual problems. In Hungary besides the traditional cut system the different selection systems are being introduced, which means a challenge to the forest management based mainly on the cut system. The lack of long term experience and the new and different management methods make the data of the long term experiments even more important. They are more important because using these data we can make estimations on the behavior of the individual trees under different circumstances (biotic and abiotic). A certain consequence of the living together of trees is that they have an effect on each other. This effect can be neglected in certain cases (plantation management) but in the case of a selection forest we have to be aware of this effect in order to be able to monitor the processes. We can create a model from these experiences if we can express these effects in the form of numbers. Competition indices are a good tool for this task though these indices are not much mentioned in the Hungarian forestry literature.

In 1990 5 3 ha experimental plots were established in the Sopron Hills region covering the range of the typical stands in this region. The designation was based on the methodology of the long term growth and yield experiments, thus all stems were numbered and the coordinates of the trees were measured within a local system of coordinates. To promote further and more detailed analysis the specialists of the Faculty of Forestry did a detailed site survey on the area of the plots. In the time period since the establishment there were periodic remeasurements of the plots and the data were not analyzed in depth until now. The aim of the present work is to analyze the role of the single tree in the competition and different parameters of the competition in relation to the different growth parameters.

In the literature analysis part of the work it was necessary to deal with a topic which only indirectly uses the results of the research on competition, namely the single stem growth models. Computer simulation is going to be an effective and universal tool for management planning as it is already in several countries.

2. Aims of the research

A new challenge for forest managers is the introduction of non-cut forest systems where the site and stand conditions make the introduction of such systems possible based on the demands from the society. The theoretical background of the cut system is already elaborated, especially in the case of even-aged and pure stands.

The investigation of the mixed and uneven stands becomes more and more important. A key question in mixed stands is the interaction of different species having similar requirements towards the site, how do they interact, what are their competition circumstances.

The aim of the thesis is to investigate the development of the mixed stands based on the data of experimental plots typical for the Sopron hills and to express the role of the different species and social positions in the competition in the form of calculated values.

To achieve this goal a single individual parameter had to be calculated to express the role of the single trees in the stand.

There are several simple competition indices in the forestry literature. The aim was to select those which are the best at expressing the competition situation in the forest stands.

The data of the long term experimental plots have not been analyzed yet in this respect although the designation of these started before 1990. There is a risk that the effort put the in measurements on these plots is going to be lost without the work of the present research, because on the plots there were forestry operations not compliant with the original goals set at the designation of the plots. This way – though it cannot be considered as an aim – the research can be considered as a final result of the work with the experimental plots and the plots do not serve their original purpose any more.

3. Hypotheses

- It can be assumed, that in mixed stands with broadleaved and conifers the competition influencing growth has not the same effect for the different species. Two trees belonging to different taxons but having the same sizes (height and diameter) do not have the same effect on a third tree.
- It can also be assumed that the species specific properties have their effect in regard to competition not by themselves as a social position in the stand due to tending operations. The sizes of a given tree are a result of the complex effect of the species properties and tending operations, so the role in the competition is a combination of the above factors.
- According to the above competition indices containing merely tree sizes as independent variables do not estimate the actual competition situation properly, because they omit the species specific properties completely and only partly include the effect of forest tendings. It can be assumed, that an independent variable can be created summarizing the effect mentioned before and modifying the competition indices in a way that they show a stronger correlation with the growth parameters.

4. Material and methods

Before the 1990s there was a possibility to establish 5 experimental plots with 3 ha each to investigate the growth conditions for the typical forest stand types on the Sopron Hills. The designation of the plots and the first measurement of the individual trees were finished by the year of 1990. Besides measuring the trees 3-5 soil profiles were also opened to determine the site characteristics of the experimental plots.

After the first measurements one of the plots (near the Ojtozi promenade) was not remeasured because of the heterogeneous site conditions so this plot is not considered as a part of the analysis.

In the case of the other plots (named Bükkös, Házoldal, Kemping and Károly) there are 1, 1, 2 and 2 remeasurements respectively. So in the case of 2 experimental plots one growth cycle and in the case of another 2 plots 2 growth cycles could be investigated.

At the establishment in 1990 the local X, Y coordinates were determined for each tree, the trees were numbered and the spot for measuring DBH was also marked.

At every measurement the following data were recorded:
- breast height diameter from two directions
- Tree height

The following growth and increment parameters could be expressed for the individual growth periods:
- annual increment of the breast height diameter
- Annual increment of the tree volume

During the competition investigation the competition environment was determined for each stem (with the point sampling method or using a distance rank for the individuals). The calculations were performed using Microsoft Excel macros for determining competitor groups.

Exact and measured data are available for the trees on the 3 ha plots for every experimental plot. There is no data about the social rank and competition situation of the trees on the border of the plots therefore the situation of these trees has been considered during the analysis. Instead of artificially generating some kind of structure extending the edges the decision was made to omit a 20 m strip from the plots, thus generating a core area. This way we have exact information about the competition even on the edge of the core area.

According to the hypotheses the simplest distance dependent and distance independent competition formulae in the literature were applied and the following competition parameters were calculated:
- Growing space
- Growing space index
- Hegyi index

- Lorimer index
- ME (Martin and Ek) index

To support the result of the correlation analyses additional methods were used to investigate the factors influencing the single stem theoretical growth models to exclude the unknown factors.

The x and y coordinates available for each tree gave the possibility to use a two parameter spatial autocorrelation analysis for the experimental plots. Different global and local parameters were calculated, and besides the general statistical characteristics the nearest neighbor statistics were also calculated. The statistics calculated are as follows:
- descriptive statistics
- nearest neighbor statistics
- Moran's I (local and global)
- Geary's c (global)
- Getis-Ords's G (general)
- Gi (local)

Using the individual statistics the spatial distribution of the stems, the diameter classes, the diameter increment, the cuttings and the mortality was investigated.

Besides the statistical parameters of the competition and the increment the variability of the site was also presented based on the soil profiles and the site survey.

5. Results

Single tree volumes were calculated from the DBH and height data of the trees using the volume function of Király, and then the growth and increment data were calculated for the different time periods.

For each stem the listed competition indices were calculated and these were related to the increment data. This correlation shows the correctness of the given index. The correlations were calculated for all experimental plots and for all growth periods. A nonlinear model was the fitted to the results.
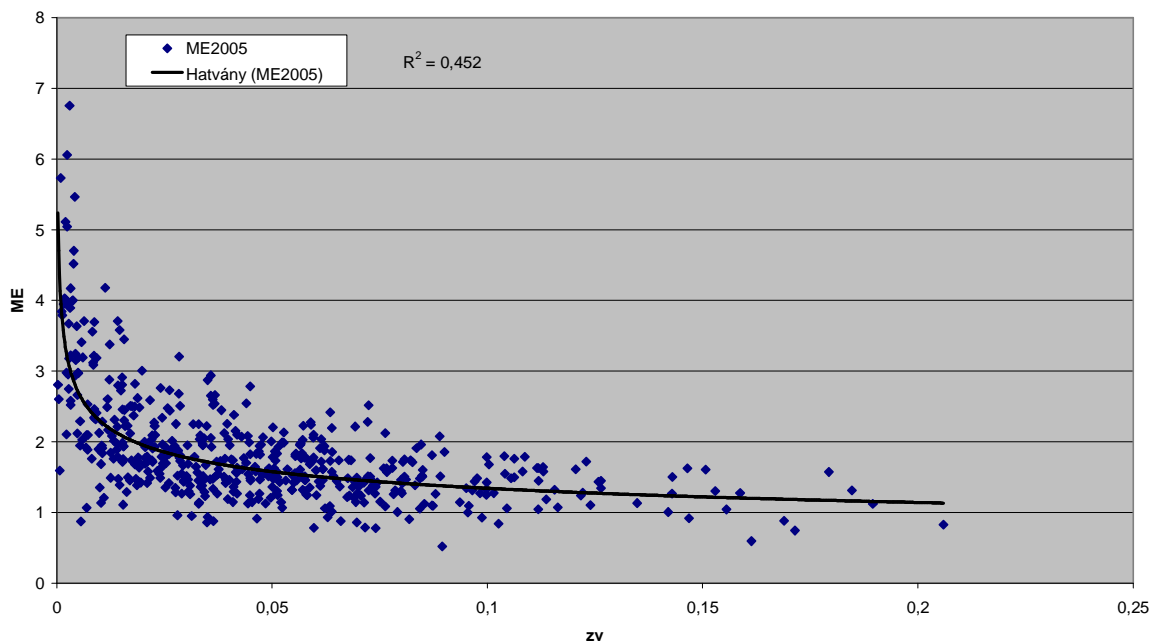

Figure 1: Correlation between the ME index in the second growth period and the annual volume increment for the experimental plot Házoldal

Besides these correlation analyses an attempt was made to create an independent variable which would expressed the accumulated effect of forest operations and species characteristics in the simple competition formulae.

In the calculations the height/diameter relationship was introduced as an independent variable into the competition formulae:

$$\text{Correction factor} = \frac{h}{d}$$

The modified indices are denoted with Modified Lorimer and Modifies ME respectively.
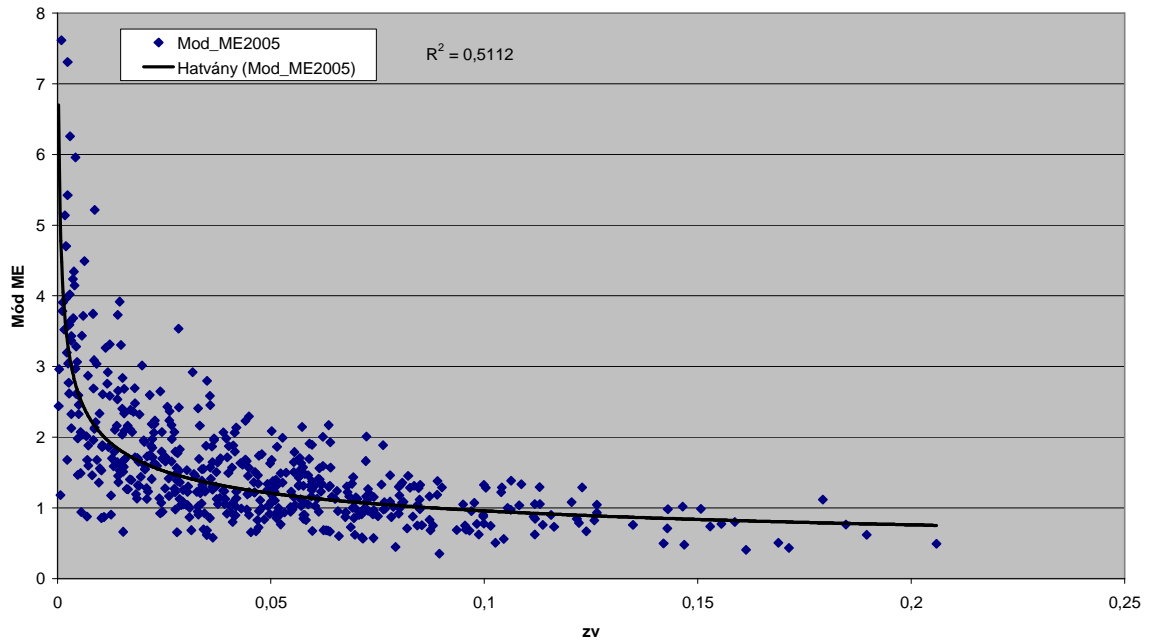
Figure 2: Correlation between the modified ME index in the second growth period and the annual volume increment for the experimental plot Házoldal

The different competition indices – including the modified ones – show different correlations between the annual increment of the volume and the diameter.

According to the summary tables the correlation with the volume increment is always higher, than the correlation with the diameter increment, the difference can be a magnitude in some cases. The modified competition indices showed except for one case always higher correlation with the annual increment of the diameter than the original ones.

In the case of the ME index the modified index showed also always stronger correlation than the original. The Hegyi index, the most wide-spread and used index gave in nearly all cases worse correlation than any of the Modified indices.

In stands with a considerable proportion of oak where the proportion of other species – and especially those of the conifers – is lower the correlation of the indices weak or very weak especially regarding the annual increment of the diameter. This weak relation is rather typical in older ages.

The modification factor brings significantly better results in the case of the ME index. This can be explained by examining the properties of the height/diameter relationship.

The height/diameter relationship has to express the individual properties (coming from their role within the stand) of the tree in the competition. This consists of the following elements:

- the height/diameter relation coming from the species properties

- the effect of the growing space changes due to the tendings and mortality
- effects from the site quality
- effect of a given stand structure
- effect of the stand age.

From the above one can see that the height/diameter ratio which is to express the effect of several factors is an effective tool in a more precise determination of the competition index.

In the different experimental plots the competition situation of the weaker trees – those of legging behind the average for the species – was also investigated.
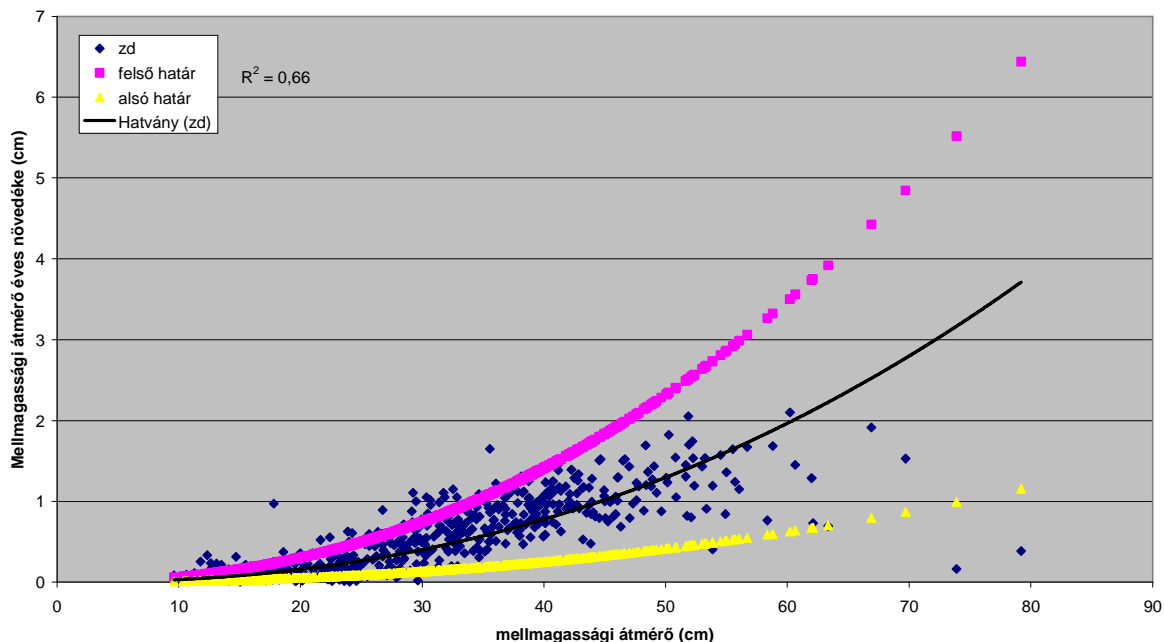

Figure 3.: The relation of the annual increment of the breast height diameter and the breast height diameter for beech on the experimental plot Bükkös

During the analyses the causes of the weaker growth was investigated with local statistical analyses and those individuals were identified where the typical competition situation and the site quality do not give sufficient explanation for the weaker growth. The amount of these individuals was expressed as a percentage.
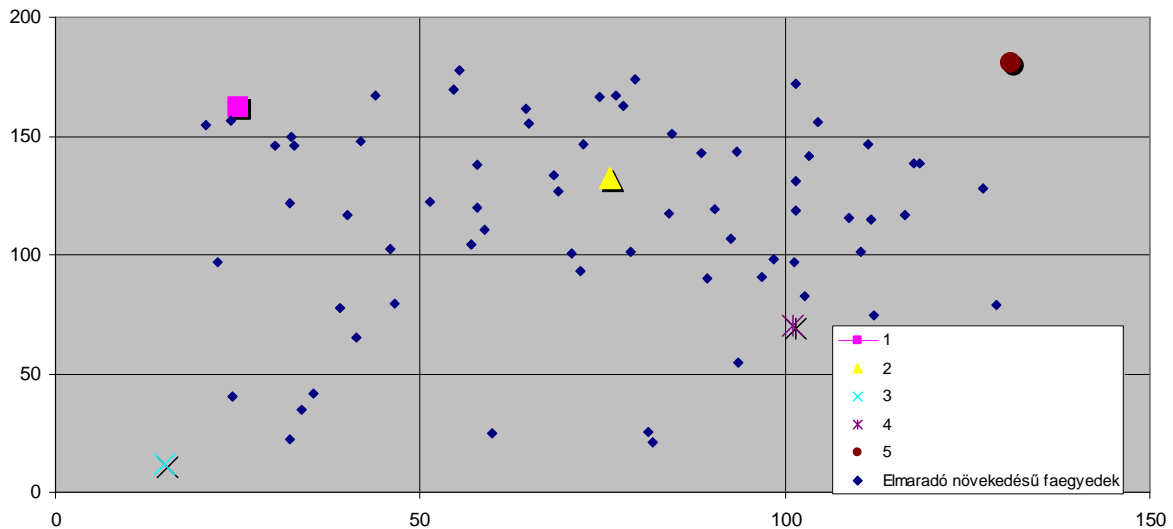
Figure 4.: Position of the five soil profiles and the individuals with weak growth within the experimental plot Bükkös

Summarizing it can be stated that the results support the initial hypotheses, so the conclusions are sufficiently supported.

The continuation of the observations is reasonable where the main crop remaining after the logging operation allows it. On areas heavily affected by logging (where there was no clearcut) additional data can be gathered concerning crown development which can contribute to the model development. An appropriate tool for such measurements is the cylindric mirror crown projection measurement tool designed by the author. The crown projection data are important in modeling the development of the crown.

Statistical methods with spatial parameters provide a new tool in describing the relation of the site factors and the growth.

6. Summary

To investigate the growth conditions of the typical stand types on the Sopron hills 5 experimental plots were designed in 1990. The data of 4 plots out of these 5 were periodically remeasured.

The plots were designed according to the guidelines for establishing long term growth and yield experimental plots, every stem received an identification number and the spot for measuring DBH was also marked. The data sheets about the measurements contain the species, the DBH (measured from two directions) the tree height and the relative coordinates of the tree within the experimental plots.

Based on the data of the measurements the growth and increment parameters were determined (annual increment of the DBH and the tree volume). Using these data different competition indices were calculated and in the selection of the indices the available data and the usability in stands with different structures were considered.

Additionally for every stem the growing space and the growing space index was calculated for the end of the growth period.

The growth data were then related to the following: growing space, growing space index, Hegyi index, ME index, Lorimer index.

In the case of the latter two indices the possibility of the inclusion of a correction factor was also investigated. In this case the correction factor is the height/diameter relationship. The modified competition indices are as follows: modified ME index and modified Lorimer index. These indices were also related to the growth data. The results of this investigation are in the theses.

Additional analyses were done regarding the spatial autocorrelation of the stems and the stem diameters. The statistical parameters of the autocorrelation gave additional information to the conventional stand structure parameters. The interpretation of the result also considered the data of the site survey.

The results of the investigation help to improve the stand and single stem growth models.

7. Theses

The analysis of the 4 experimental lots (Bükkös, Házoldal, Kemping and Károly) showed according to the initial hypothesis – thus it is possible to introduce species-specific parameters into the analysis of the competition of mixed broadleaved-conifer stands – the following results:

1. It is proven, that the role in competition of the mixed stands (broadleaved-conifers) is not uniformly distributed among trees but depends strongly on species and therefore it is necessary to introduce parameters specific to species into competition modeling.

2. After processing the data of the experimental plots it is proven, that the distance dependent competition indices provide a better correlation with the growth and increment parameters than the distance independent ones.

3. In stands represented by the experimental plots the simple competition indices are more sensitive to the change of the growth parameters, because the data showed a stronger correlation in this case.

4. In order to improve the modeling of the competition an additional independent variable was included which is the height/diameter relationship. It has been proven by calculations that in the case of the stands investigated – which are mainly mixed broadleaved-conifer stands – the height/diameter relationship sufficiently represents the species specific properties and the social situation of the trees within the stand.

5. In stands represented by the experimental plots the suggested modification of the ME (MARTIN AND EK 1984) competition index gave always better correlation between the competition index and the growth and increment parameters, especially in the case of the annual DBH increment.

6. The modification of the Lorimer index with the correction factor including species and social situation characteristics did not always result in an improved correlation, thus it can be stated that the distance independent competition indices represent the competition situation less precisely.

7. A typical characteristics of the modern growth and yield models is the use of single tree models in supporting forestry decisions. Based on the results outlined in the thesis it is recommended to use the modified ME (MARTIN ÉS EK 1984) distance dependent competition index in predicting forest growth.

8. Publications in the topic of the dissertation

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