Interrelations among Grey Alder Stand Characteristics

MARIS DAUGAVIETIS*, JĀNIS BISENIEKS AND MUDRĪTE DAUGAVIETE

Latvian Forestry Research Institute "Silava", Rigas Street 111, Salaspils, LV-2169

*Corresponding author: Maris Daugavietis,

e-mail: maris.daugavietis@silava.lv; phone: +371 29487621; fax: +371 67901359

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Abstract

The purpose of the study is to determine the interrelations of the assessment characteristics necessary for modelling the yield of grey alder stands. The models serve as a theoretical base that allows developing recommendations for forest cultivation technologies in line with the forest cultivation goals. The growth and yield tables for three site indexes, which have been used in forest management until now, do not encompass the whole variety of grey alder stands, so possibilities of expanding the tables are being looked for by introducing additional site indexes by means of extrapolation.

A new mathematical model for determination of grey alder site index has been developed on the basis of data obtained from stem analysis of sample tree trunks, which can be used to calculate curves of growth of the average height up to age 40, and a new scale for determination of the site index has been recommended, where site index is denoted as the average height of the stand in metres at age 20. The method of multiple regression has been used for interpretation of interrelations of stand assessment characteristics. The regression models incorporate three independent variables selected by way of logical analysis. The calculation of the regression coefficients uses data obtained from a one-time survey of 150 sample plots. A description of the sample plots is provided. Formulas of I. Liepa have been used for calculation of stem volume and current increment of the reduced volume of the stand. Mathematical models of the interrelations of stand assessment characteristics have been developed, which can be used to determine the following stand yield characteristics: average diameter, basal area, volume, the reduced actual volume increment and the current annual height increment.

It has been demonstrated that grey alder stands up to age 40 maintain a high yield and large annual current volume increment, which is higher than the average volume increment.

In the models, one of the main independent variables that can be regulated with forest management is the number of trees, and the models allow predicting the effect of thinning on the wood yield.

Key words: grey alder, site index, volume, the reduced current volume increment, current increment of average height, current increment of average diameter at breast height

Introduction

Forest management for a specific purpose requires growth models, which are its theoretical basis and which allow simulating the forest growth in accordance with the particular goals. These models allow developing a technology for the whole forest growth cycle – from regeneration to logging. Since no such models exist, developing them is an important task in forestry.

Development of forest growth models requires data on assessment characteristics obtained from periodically measured permanent sample plots over an extended period, which are currently not available in Latvia. In research practice, many permanent sample plots are lost due to various reasons: logging, natural damages, change of forest owners, lack of funds for maintenance, etc. Permanent sample plots in grey alder stands have not been established in Latvia so far. Thus, at the current stage of research, data obtained from single measurements in the established sample plots must suffice. It would be incorrect to call the models developed on the basis of this information "growth models"; rather, they are interrelations between stand characteristics, as instead of describing the dynamics of stand characteristics, they describe static. This applies also to previously developed growth and yield tables, whose name does not correspond to their content.

In Latvia, significant studies on the productivity of grey alder stands have been done by two scientists. In the middle of the last century, P. Mūrnieks graphically developed grey alder growth and yield tables with the traditional methodology, by using data obtained from 80 sample plots measured once (Mūrnieks 1950). Recently, a doctoral dissertation on the productivity and structure of grey alder stands was defended by Miezīte (2008), whose research is based on pair regression analysis of stand characteristics. The results of this work cannot be used in stand modelling.

In the last decades, there have been developments in mathematical modelling of growth and yield. Mathematical models for the growth of Latvian birch stands have been developed by J. Tauriņš, for coniferous tree stands – by J. Matuzānis, for young coniferous tree stands – by G. Ģērķis and J. Bisenieks, for wood yield and current volume increment – by I. Liepa (Matuzānis 1983).

The state index curves for H_{40} (dominant height at 40 –year-old) for alder and alder growing on different types of forest soils in Sweden was elaborated by Johhansson (1999). The growth and yield in stands of grey alder in Norway was evaluated by Borset and Langhammer (1966). The evaluation of biomass output for energy in grey alder stands is developed during last decades (Rytter et al. 2000, Uri et al. 2009, Daugaviete et al. 2009) and show the fast-growing of grey alder.

The aim of this study was to elaborate handy applied regression equations and tables for modelling the development of unmixed alder stands in Latvia.

With growing demand for timber, mainly in the power sector, more attention is paid to previously non-evaluated, mainly fast-growing tree species resources. Grey alder can be considered one of these non-evaluated tree species in Latvia, covering according to Central Statistic Bureau 10.2% of the total forest area. The management of more than 330,000 ha of grey alder stands without correct models of growth and yield is burdensome and problematic.

Material and methodology

Data to achieve the goal of the study have been obtained by establishing sample plots and measuring the required stand assessment characteristics. Data obtained from analysis of tree stem height growth have been used for development of a site index scale (Curtis 1964). For this purpose, 49 whole, undamaged, freely growing sample trees of average shape and size have been selected and felled in the 49 selected sample plots presented all site indexes. The distribution of the number of sample trees by site index is close to normal Laplas-Gauss distribution (Figure 1). Trunk analysis has been carried out with the typical method (Sarma 1949, Curtis 1964).Sample trees were felled and cut as near to the ground as possible. Cores from the sample trees were taken at the ground level, 0.5; 1.0; 1.5 and further by 1 m interval from ground level and at breast height (1.3 m). Tree age was determined in the laboratory by counting rings on the core of ground level. Ring width for increment calculation was measured at the 1.3 m core.

The multiple regression method has been used to explain the interrelations of stand assessment charac-

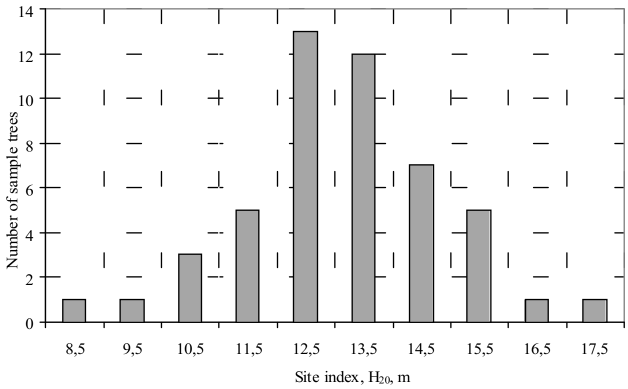

Figure 1. Distribution of sample trees

teristics (Liepa 1974). Development of multiple regression models requires sample plot data, evenly distributed among all three dimensions – age, site index and density (basal area or number of trees) – but at the same time having very different densities with the other characteristics unchanged. The growth and yield tables developed by Mūrnieks (1950) have been used in planning the creation of the sample plots. The sample plots have been established in large forest areas with homogenous growing conditions, even distribution of trees and the admixture of grey alder in the stand being at least 8/10 of stand volume. The sample plots have been established in such a way as to ensure that, with constant age and site index, they represent stands of a wide range of densities – from thin to full-density stands.

Trials have been established and measured partially by using the methodology of forest statistical inventory sample plot establishment. Depending on the number of trees in the stand, three types of circular sample plots have been used: 100 m^2 with all trees measured; 500 m^2 with all trees measured; and 500 m^2 with trees measured in three sectors depending on the tree diameter. In the sample plots, the diameter of all trees has been measured; the height of 15–20 trees has been measured for calculation of the height curve; and the width of the last 5 growth rings has been measured in cores drilled from 20 sample trees. In each sample plot, cores have also been drilled from 10–12 sample trees for determination of the tree age.

In accordance with the work methodology, a total of 167 sample plots were established and measured. The sample plots have been established throughout the territory of Latvia between lat. 56º 36.860 N and 56º 21.057 N and between long. 028º 09.669 E and 021ŗ 46.022 E by using the methods of establishment of sample plots for statistical forest inventory, in such a way as to ensure that each age group and site index includes stands of various densities, from light stands to stands of full density. From the research material gathered, 150 sample plots have been selected, considered to be pure stands, and have been used in the subsequent work. A summary and general characterization of these sample plots has been provided in table 1, which shows the range of variation of stand characteristics in individual sample plots – i.e. the minimum and maximum values of the assessment characteristics. It can be seen that the stand characteristics vary widely, so the research material is to be used for explanation of the interrelations of these characteristics.

For processing of the data gathered from the sample plots and calculation of the stand assessment characteristics, three computer programs have been developed in Excel format – one for each type of sample plot. The formulas of Liepa (1996) have been used for calculation of the grey alder stem volume and the reduced current stand volume increment.

$$v = 0.7450 \cdot 10^{-4} L^{0.81295} d^{0.069351\lg L + 1.85346}, \quad (1)$$

where v – grey alder trunk volume (m^3) with bark; L – Stem length, m; d – diameter at breast height, cm.

$$Z'_M = 12732.4 \Psi H^{\alpha} D^{\beta \lg H + \varphi - 2} \left[\frac{Z_H(\alpha + \beta \lg D)}{H} + \frac{Z_D(\varphi + \beta \lg H)}{10D} \right], \quad (2)$$

where Z'_M – reduced current actual stand volume increment, $m^3 (m^2)^{-1}$; H – average height, m; D – average diameter, cm; Z_H – current increment of average height, m; Z_D – current increment of diameter at breast height, mm; $\Psi = 0.7450 \cdot 10^{4}$, $\alpha = 0.81295$, $\beta = 0.06935$, $\varphi = 1.85346$.

The equilateral hyperbola suggested by Ozoliņš (1997) has been used for analytical smoothing of height curves:

$$H = 1.3 + \frac{d}{k \cdot d + c}, \quad (3)$$

where $c = \dfrac{N \cdot \Sigma \dfrac{1}{d_i \cdot (h_i - 1,3)} - \Sigma \dfrac{1}{d_i} \cdot \Sigma \dfrac{1}{h_i - 1,3}}{N \cdot \Sigma \dfrac{1}{d_i^2} - \Sigma \dfrac{1}{d_i} \cdot \Sigma \dfrac{1}{d_i}}$, $k = \dfrac{\Sigma \dfrac{1}{h_i - 1,3} - c \cdot \Sigma \dfrac{1}{d_i}}{N}$,

H – smoothed tree heights, d – freely selected tree diameters, a_1 – measured breast height diameters of sample trees, h_1 – measured heights of sample trees, N – number of sample trees measured.

For each sample plot, the following has been calculated: basal area and volume in each level, average diameter and height of the first level, and site index (H_{20}) using the new site indexing formula.

Results and discussion

In mathematical modelling, it is very important to select the right amount of variable characteristics to be included in the model, which must be done by way of logical analysis. Since no model can fully describe the dynamics of the biological processes of the studied characteristic depending on external factors, one of the main problems in modelling is reasonable selection of the factors affecting the characteristic. On the one hand, including too few factors in the model will produce an incomplete description of the characteristic; on the other hand – too many factors complicate the development and practical application of the model. Therefore, only the significant factors affecting the characteristic should be included in the model. Forest growth progression models usually use multiple regression equations with two or three independent variable factors or repressors. Such growth models have already been developed for pure pine, spruce and birch stands growing in Latvia (Matuzānis 1983).

The development of trees and forest stands occurs through interaction of many factors, so this process does not show such strong regularities as physical and chemical processes. Natural objects – trees and forest stands – are not bound by such definitive interrelations and mathematical formulas as minerals and mechanical objects. In forest assessment, we always come across many unavoidable sources of errors. Therefore it is impossible to perfectly determine the wood yield, increment and other assessment characteristics. Our goal is to avoid errors as much as possible in order to develop sufficiently simple and flexible methods suitable for scientific and practical applications. From this it follows that results obtained in forest assessment entail a certain level of approximation and probability.

Site indexes of grey alder stands

Data obtained from analysis of the trunk height of sample trees have been used for development of the site index curves. The interrelations of the age and height of trees are usually expressed with an S-shaped curve – a sigmoid. Grey alder is a fast-growing species from the very earliest age, so its growth progression curve does not include two inflection points. The growth of grey alder's height is characterized with simpler, steadily rising curves. The smoothing of data from each sample tree's height analysis has been carried out by analytically using a second level parabola passing through the point of intersection of coordinates. The obtained curve expresses the sample tree's growth during its entire lifetime. The smoothed data of the sample tree growth have been used to calculate the average characteristics of all sample trees, thus obtaining an average curve of height growth, which provides an overview of the shape and character of grey alder height curves, and can be used for selection of the general type of the mathematical equation for the site index system. The average height progression curve of all sample trees has been provided in

Figure 2.

Since a theoretically accurate general type of

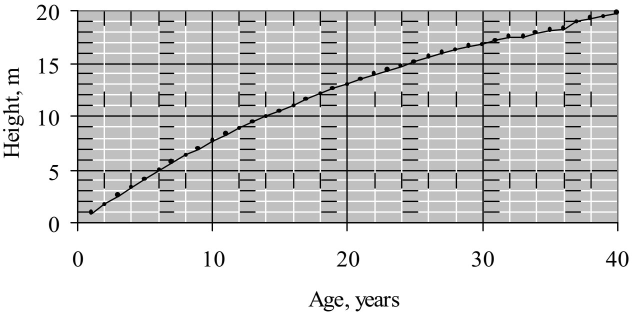

Figure 2. Average height curve of sample trees

mathematical equation expressing the interconnections of tree height has not yet been found, a simple equation must be developed empirically – one that would more fully describe the interrelations throughout the whole age range, as well. The most elementary mathematical solution, of course, is a linear equation. By finding a suitable age transformation (X-axis transformation), the height curve can be expressed in linear form. Moreover, the height growth of all sample trees is very well described by one section of the natural logarithmic curve. We found, empirically, that by transforming X-axis Ln (age+15), the height curve transforms into a straight line (Figure 3). It must be noted that this interconnection is very close – almost functional – which is evidenced by the high determination coefficient R^2=0.999.

The equation of the straight line in Figure 3 can

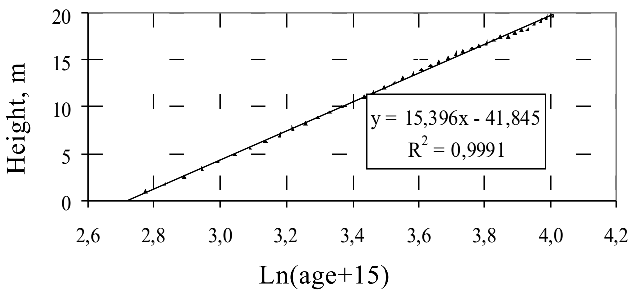

Figure 3. Interconnection of average tree height growth line and transform tree age

be expressed in a general form as follows:

$$H = -a + b\ \mathrm{Ln}(age+15), \quad (4)$$

where H – height; a and b – regression coefficients.

The site indexes of grey alder have been denoted as the stand's average height at age 20. Regression coefficient "b" is the tangent of the regression line against the abscissa axis, while the tangent of the angle is expressed by the opposite cathetus against the adjacent cathetus. In our case, the opposite cathetus is the height of the sample tree at the base age (20 years), which is denoted with site index H_{20}. The adjacent cathetus is a function of the base age, i.e. Ln(20+15)-Ln(15)=0.847, with a condition that the height curves pass through the point of intersection of coordinates (Y=0, X=0), as in that case, the straight line in Figure 3 intersect the abscissa axis and at Ln(0+15)=2.708**:**

$$b = \mathrm{tg}\ \alpha = \frac{H_{20}}{f(A_{20})} = \frac{H_{20}}{\mathrm{Ln}(20+15) - \mathrm{Ln}(15)} = \frac{H_{20}}{0.847}$$

Regression coefficient "a" of the linear equation is the point where the line crosses the ordinate axis if the abscissa value is 0.

Thereby we obtain a mathematical model of the grey alder site index curve system:

$$H = \mathrm{tg}\ \alpha\ (\mathrm{Ln}(age+15) - \mathrm{Ln}(0+15))$$

$$H = \frac{H_{20}}{0.847} \cdot (\mathrm{Ln}(age+15) - 2.708), \quad (5)$$

where H – stand height, m; H_{20} – height at base age (20 years) or site index, m.

If the age and height of the stand is known, the following formula is used to calculate the site index:

$$H_{20} = \frac{H \cdot 0.847}{\mathrm{Ln}(age+15) - 2.708} \quad (6)$$

Figure 4 demonstrates the growth of grey alder stand height by site index, calculated using the mathematical model (equation 5), and compared to the site index curves of Mūrnieks (1950). We see that the character of site index curves is slightly different. The site indexes of Mūrnieks (1950) also do not encompass the whole variety of growing conditions. In nature, there are stands whose site index reaches even H_{20}=20 m.

Site index curves H_{40}, given by Johansson (1999) show the height 20 m can be reached only at age of 40-70 years in the Scandinavian countries.

Interrelations of assessment characteristics

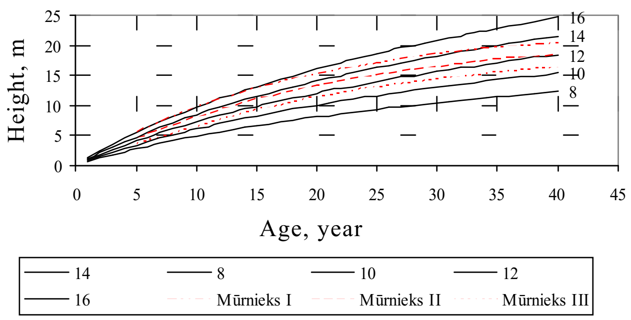

Figure 4. Development of tree height, stand age and site index (H_{20} and site index of P.Mūrnieks 1950)

In research of the interrelations of assessment characteristics, it is incorrect to use the traditional pair regression analysis, because the corresponding characteristic is being affected by several factors, and thus it is impossible to eliminate the effect of the strong background influence. Our study uses the multiple (multi-factor) regression analysis, which interprets studied characteristic *y* as the result of simultaneous and complex influence of several variables x_i, i.e. $y=f(x_1,x_2,...,x_k)$. For description of each studied characteristic, three independent variables have been selected, and the multiple stage or Cobb-Douglas function has been used for description of interrelation (Liepa 1974):

$$y = b_0 x_1^{b_1} x_2^{b_2} x_3^{b_3}.$$

To calculate the regression coefficients of the multiple nonlinear regression equation, its nonlinear parts have been linearized with logarithms**:**

$$\lg = \lg b_0 + b_1 \lg x_1 + b_2 \lg x_2 + b_3 \lg x_3 .$$

The regression coefficients have been calculated with the use of data obtained from sample plots by preparing and solving the normal equation system.

One of the most important assessment characteristics of a forest stand is the average diameter of the stand. In theory, there are several ways of calculating it, but basal area weighted diameter mainly is used in practice and in scientific studies. The average diameter is usually calculated for the primary stand. For grey alder, as a species that needs a lot of light, the secondary stand is weak and practically insignificant. As a result of logical analysis, we selected age, number of trees and site index as the factors affecting the average diameter of the stand. The calculated regression coefficients are as follows:

$$D = 0.9898 A^{0.6586} N^{-0.1883} H_{20}^{0.742} . \quad (7)$$

Inserting the stand total age (A) in years, the number of trees per 1 ha (N) and the site index (H_{20}), m, in the equation (7) allows calculating the stand's average diameter (D), cm. The signs of the regression coefficients show the direction of influence of the individual regressors. In our case, with increasing age and site index, the stand's diameter grows, while the number of trees has the opposite effect – the smaller it is, the larger the diameter with the remaining arguments of the function remaining constant. The biometrical values of the regression equation (7) are as follows: sum of squares Q = 3515.59; remainder sum of squares Q_z = 154.308; regression standard error s_D = 1.0 cm; multiple correlation coefficients R_D = 0.978; multiple determination coefficient R_D^2 = 0.96.

The main assessment characteristics affecting the volume of a stand are age, basal area and site index. The calculated multiple nonlinear correlation regression equation characterizing the stand volume is as follows:

$$V = 0.1625 A^{0.548} G^{1.011} H_{20}^{0.7855} , \quad (8)$$

where V – volume m^3 ha^{-1}; A – total age, years; G – basal area, m^2 ha^{-1}; H_{20} – site index, m.

The values characterizing the regression equation (8) are as follows:

Q = 1371228, Qz = 1307, s_v = 3.2 m^3 ha^{-1}, R_v = 1.000, R_v^2 = 0.999.

Statistical indicators point to a very close correlation between the stand volume and the three selected independent variables.

The stand volume is essentially bigger in Latvian grey alder stands in comparison with volumes of Sweden forests, given by Johansson (2005)

An equation has been developed for calculation of the basal area of a stand (9):

$$G = 0.0000451 A^{1.3278} N^{0.6582} H_{20}^{1.546} . \quad (9)$$

The values characterizing the regression equation (9) are as follows:

Q =15105, Q_z =1597, s_G = 3.5 m^2 ha^{-1}, R_G = 0.946, R_G^2 = 0.894.

The stand volume increment is one of the more informative characteristics, but also one of the most difficult to determine, as the increment is affected by many factors. The most significant ones are the tree species, age, origin, growth conditions, stand density and health. With an optimal combination of factors, it is possible to favourably influence the increment. The current volume increment is a value that cannot be measured, but can be calculated. It is the main indicator in assessment of the effect of various forest management activities on the growth of the stand. It is necessary to know the current volume increment of the stand or group of stands in order to correctly determine the volume to be logged in selection cutting. The current volume increment is the most significant factor for assessment of the intensity of the thinning, efficiency of stand fertilization, as well as other forest management activities.

There are several types of volume increment. This work examines the actual volume increment, i.e. the type of increment that is expressed by the summary increment of tree trunks growing in the stand or group of stands over the past 5 years. By dividing it with the number of years in the period (5), the average periodical actual current increment can be obtained. If the actual increment of one year has been determined, it is called the annual increment. Considering the difficulty of the methods for determining the annual increment, sometimes the average periodical current increment and the annual increment are considered to be identical, which theoretically is incorrect, as the value of the former is determined by the length of the period. The current actual volume increment is always a positive value. In any stand, along with the process of synthesis of organic substances (current volume increment), there is also an ongoing process of wood dying off. By subtracting the dead part from the current actual volume increment, the natural volume increment can be calculated. Its numerical value can be positive, negative or zero. Significant changes of volume dynamics are caused by the amount of logging. The natural increment of a forest is reduced by the amount of wood logged during the year. The difference between the natural increment and the logged volume is the actual forest volume increment, which is also called the volume change or difference. Therefore, the current volume increment should not be in any way correlated with the allowable cuttings.

The current stand volume increment has been calculated for each sample plot by multiplying the reduced current actual increment Z'_M by the stand's basal area. The reduced current volume increment has been calculated with the formula (2), by using drilled cores which have been used for determination of the width of growth rings. The current increment of the average height has been calculated by using the developed site index curve equation (5), whose first derivation after the stand age expresses the rate of growth of the stand, or, to be more exact, the current annual increment of height:

$$H'_{age} = Z_H = \frac{H_{20}}{0.847} \times (\text{age}+15), \qquad (10)$$

where Z_H – current annual height increment of the stand, m; H_{20} – site index, m; Age – total stand age, years.

For calculation of the current volume increment without gathering additional information, by using only the traditional forest inventory information, the reduced current volume increment has been smoothed depending on the stand age and site index. Multiple nonlinear regressions have been used for approximation of the data obtained from the sample plots. By using data obtained from 69 sample plots, the regression coefficients of the equation (11) have been calculated. The same equation can be used to calculate the reduced current volume increment, as well:

$$Z'_M = 0.8010 A^{-0.2588} H_{20}^{0.3095}, \qquad (11)$$

where Z'_M – reduced current actual volume increment, $m^3 (m^2)^{-1}$; A – stand age, years; H_{20} – site index, m.

The statistical values of the equation (11) are as follows:

Q_Z = 1.080, Q = 1.674, = 0.13, = 0.596.

The statistical values of the equation (11) are very modest, since, as expected, there is significant dispersion of data. The regression equation explains only a third (R^2=0.35) of the total data dispersion, while the rest is due to background influence. Literature also contains references (Liepa 1996) to the variation coefficient of the volume increment being very large: 45–90%. The most surprising finding in our study is the fact that, in grey alder stands even at an advanced age (40 years), with the right basal area, the current volume increment is significant (20–30 $m^3 ha^{-1}$ per year). It is also confirmed by the width of the growth rings measured in the sample plots: 2–3 mm.

The discovered interrelations of grey alder stand assessment characteristics can be used for modelling of stand productivity and for development of temporary programs of grey alder management. In time, by gathering research materials and periodically re-measuring the permanent sample plots, the models can be improved. Data cannot be extrapolated in the modelling process; i.e. the values of the independent variables placed in the formulas must not exceed the values obtained in the sample plots (Table 1).

In the forest cultivation process, the main reasonably manageable and easily determinable characteristic, which has been included in the developed models, is the number of trees per hectare. In natural stand growth, the process of a decrease in trees, according to the literature, has a hyperbolic nature (Антанайтис и др. 1986). By assuming that the number of trees in 5-year-old stands depending on the site index is 10000, 8000, 6000 and 4000 per ha^{-1}, as well as by analyzing the sample plot data, the following regression equations have been obtained for prediction of the changes of the number of trees with the increase in age:

$N = 45801A^{-0.9455}$, if $H_{20}=8$ (12)
$N = 34736A^{-0.9123}$, if $H_{20}=12$ (13)
$N = 24012A^{-0.8617}$, if $H_{20}=16$ (14)
$N = 13901A^{-0.7740}$, if $H_{20}=20$ (15)

Table 1. Summary of sample plots

Age	Number of plots	Site index, H_{20}	Basal area	Number of trees
5	7	6.6–14.0	0.8-6.0	2920 –11900
6–10	25	8.1–19.7	2.3-22.5	2640 –12000
11–15	32	4.9–7.1	2.1-27.9	1220 –15700
16–20	30	8.8–21.8	9.9-39.8	720–16300
21–25	17	10.7–18.5	12.4-38.4	920–5140
26–30	18	10.7–18.1	19.5-50.0	1100–4660
31–35	9	10.9–16.2	20.2 -43.2	1220 –3640
36–40	9	10.4–17.2	19.4-42.1	840–1860
>40	3	10.9–13.2	18.6-42.6	880–2200

Considering the dynamics of the number of trees in accordance with the equations (12–15), modelling of stand productivity characteristics has been carried out (Table 2). The average stand volume increment has been calculated by dividing the volume by age, while the total productivity has been calculated as an integral of the actual current volume increment. Although the table does not describe the growth of grey alder stands, it shows that, until the age of 40, the current volume increment is larger than the average increment.

Table 2. Productivity of Grey Alder per ha

Age, year	Height, m	DBH, cm	Number of trees	Basal area, m^2	Volume, m^3	Volume increment			Total production, m^3
						current, $m^3 (m^2)^{-1}$ *	current, m^3	middle, m^3	
				Site index = 8 m					
5	2,7	2.3	10000	4.2	9	1.01	-	1.7	
10	4,8	4.1	5200	6.9	21	0.84	5.1	2.1	34
15	6,5	5.7	3500	9.1	34	0.76	6.4	2.3	66
20	8,0	7.3	2700	11.3	50	0.70	7.4	2.5	104
				Site index = 12 m					
5	4.1	3.4	8000	7.1	20	1.14	-	4.0	
10	7.2	5.9	4300	11.8	49	0.95	9.8	4.9	69
15	9.8	8.2	2900	15.5	81	0.86	12.4	5.4	131
20	12.0	10.4	2300	19.5	119	0.80	14.5	6.0	203
25	13.9	12.5	1800	22.3	155	0.75	16.2	6.2	284
30	15.6	14.5	1600	26.2	201	0.72	17.8	6.7	373
35	17.1	16.5	1400	29.4	246	0.69	19.6	7.0	471
40	18.4	18.4	1200	31.8	286	0.67	20.7	7.2	575
				Site index = 16 m					
5	5.4	4.5	6000	9.4	34	1.25	-	6.7	
10	9.7	7.8	3300	15.8	83	1.04	14.4	8.3	106
15	13.1	10.8	2300	21.4	140	0.94	18.4	9.4	198
20	16.0	13.7	1800	26.6	205	0.87	21.7	10.2	306
25	18.5	16.4	1500	31.6	276	0.82	24.6	11.0	429
30	20.8	19.0	1300	36.6	353	0.78	27.4	11.8	566
35	22.7	21.5	1100	40.3	423	0.75	29.5	12.1	714
40	24.5	24.0	1000	45.0	510	0.73	31.6	12.8	871
				Site index = 20 m					
5	6.8	5.8	4000	10.5	45	1.33	-	9.0	
10	12.1	10.0	2300	18.2	114	1.12	17.6	11.4	133
15	16.4	13.8	1700	25.4	200	1.00	23.1	13.3	248
20	20.0	17.3	1400	32.6	300	0.93	28.1	15.0	389
25	23.2	20.6	1200	39.4	411	0.88	32.6	16.5	552

The developed regression equations can be used with a high degree of certainty, with some limitations – i.e. within the scope of the gathered empirical material up to a certain stand age:

if $H_{20} < 10$ to 20 years,
if $10 \leq H_{20} \leq 18$ to 40 years,
if $H_{20} > 18$ to 25 years.

Conclusions

1. Based on data obtained from analysis of sample trees trunks, a mathematical model of grey alder site index system has been developed that can be used to calculate the average height growth curves up to age 40 for any site index. Site indexes have been denoted as the average stand height, in metres, at age 20. The developed model has also been used for calculation of the current increment of height.

2. Mathematical models of the interrelations of stand assessment characteristics have been developed that can be used to determine stand productivity characteristics: average diameter, basal area, volume and current actual volume increment.

3. The discovered interrelations of assessment characteristics can be used for modelling of stand productivity and development of grey alder cultivation programs.

4. Grey alder stands up to age 40 still remain highly productive, and the current volume increment during this period has always been larger than the average increment.

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ЗАКОНОМЕРНОСТИ ТАКСАЦИОННЫХ ПОКАЗАТЕЛЕЙ В ДРЕВОСТОЯХ СЕРОЙ ОЛЬХИ (*ALNUS INCANA* (L.) MOENCH.)

М. Даугавиетис, Я. Бисениекс и М. Даугавиете

Резюме

В статье приведены результаты исследований зависимостей между таксационными показателями древостоев серой ольхи. Опыты проводились с целью разработки моделей продуктивности насаждений.

На основе анализа изменений высоты 49 модельных деревьев и данных обмера деревьев на 150 временных пробных площадях, заложенных по всей территории Латвии в насаждениях возрастом до 40 лет с разным бонитетом и полнотой, разработаны:

- новая шкала бонитетов насаждений серой ольхи, где бонитеты обозначены средней высотой насаждения в возрасте 20 лет – H_{20};

- множественные регрессионные уравнения для расчета суммы площади сечения древостоя (G), среднего диаметра на высоте груди (D), запаса стволовой древесины (V), текущего прироста высоты (Z_H) и текущего редуцированного прироста запаса ($Z_M^{'}$).

Выявленные закономерности взаимосвязей между таксационными показателями древостоя могут быть использованы для разработки программ выращивания серой ольхи, например, для определения интенсивности рубок ухода.

Один вариант моделирования показателей продуктивности насаждений серой ольхи, рассчитанный на основе разработанных математических моделей, приведен в таблице 2. Показано, что в насаждениях серой ольхи возрастом до 40 лет сохраняется высокая продуктивность и текущий прирост запаса превышает средний прирост запаса древостоя.

Ключевые слова: серая ольха, запас древостоя, бонитет, редуцированный текущий прирост запаса, текущий прирост средней высоты, текущий прирост среднего диаметра на высоте груди.