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CALCULATION ACCURACY OF GROWING STOCK BY DIFFERENT METHODS WHEN FULFILLING VISUAL-MEASURING FOREST INVENTORY

The article analyzes calculation accuracy of growing stock by different methods when fulfilling visual taxation of forest. It is shown that the methods currently used in practice have significant systematic error leading to underestimation of growing stock. Distribution modeling of stem diameter on the basis of the average diameter of the stand and series of the distribution of natural diameter classes makes it possible to increase significantly the accuracy of calculation of growing stock and reduce the systematic error. More accurate methods of growing stock calculation are also more labor-intensive in terms of calculations. However, the widespread introduction of computing machinery into practice of forestry makes this disadvantage insignificant. Thus, the higher labour intensity in growing stock calculation the higher its accuracy.

Introduction. Metrical taxation is widely used in forest management in forest inventory of mature and maturing stands. In addition, this method is used for the taxation of large cutting areas and forest inventory by sampling method. When using this method the basic inventory indexes of growing stock are been determined by means of measurements. These include such indexes of forest stand as composition, height, diameter and absolute density, and growing stock is calculated by means of variety of standard manuals. When fulfilling production inventory standard table is used to calculate the growing stock. On its basis there have been developed two special tables, according to the first one appraiser at first determines relative density, depending on species, average height and total basal area, and then another table defines growing stock depending on species, height and relative density. This technique makes possible calculations to obtain the same result without performing calculations using the formula:

$$M_e = M_n D, \quad (1)$$

where M_e – amount of the stand evaluated, m^3 / ha; M_n – normal growing stock, m^3 / ha, which is taken from the standard table depending on species and average height of the stand; D - relative density.

However, the growing stock can be calculated not only by means of standard tables. When taxation of cutting areas is being fulfilled by means of forming of relascope circular plots, it is proposed to calculate growing stock on the basis of the measured total basal area and height of the stand with the use of form-height table [1] by formula:

$$M_e = G_e HF, \quad (2)$$

where G_e – total basal area of the stand evaluated, m^2/ha; HF – form height, m.

The choice of method being used by forest managers for determining growing stock when fulfilling visual taxation is determined by simplicity and speed of stand volume inventory, as well as the possibility to avoid doing any calculations in the forest. Many performers keep in mind the main and the most commonly used part of the standard, and in most cases they are able to estimate growing stock without consulting the table. However, the widespread introduction of computer technology makes it possible to change the approach to the choice of method for growing stock calculation. At the moment, and forest inventory data, and materials of cutting areas taxation are processed using computer technology. Consequently, the complexity of performing calculations fades into insignificance. In this regard, when choosing the method of calculating the growing stock it is reasonable to use other appropriate criteria, for example, its calculation accuracy, that is being more meaningful characteristic of the method. This paper is devoted to a comparative evaluation of the accuracy of growing stock calculation by various methods of taxation of forest stands.

Objects and methods of research. To perform the analysis of the accuracy of forest stand estimation there have been used the used data of stands inventory on sampling areas. The calculations were performed for pine. There have been chosen pure even-aged stand, the density of which is not less than 20 stems per hectare, and the average height determined by a certain schedule, was not less than 4.5 m. The test elements of the forest were presented from the first to sixth age classes (Table 1).

Table 1

Distribution of forest elements (pine) according to age classes

Age class	Number of sampling areas, pcs.
1d	48
2nd	61
3d	209
4th	293
5th	235
6th	27
7th or more	6
Total	879

Enumeration of trees for selected pure even-aged stand was processed by standard methods with forest stand estimation per hectare using category tables. Growing stocks thus obtained were used as controls. In addition, based on recalculation of inventory indexes growing stock was being determined by several methods described below.

According to standard tables. In this method of determining the average height of growing stock and total of basal area per hectare have been used calculated according to enumeration of trees. Calculations were carried out in two stages. Firstly relative density has been determined according to well-known formula:

$$\Pi = \frac{G_e}{G_n}, \quad (3)$$

where G_e - total basal area of estimated stand, m^2 / ha; G_n - total basal area of normal stand m^3 / ha, which was taken from a standard table, depending on species (pine) and average height of the stand.

Next, using the determined relative density, growing stock was calculated by the formula (1).

Table of form heights. Depending on species and average height obtained after enumeration, form height has been defined according to form height tables [1]. Then, using the obtained total basal areas according to estimation data growing stock was calculated by the formula (2).

By an average tree. Tables that are used to determine the growing stock in the processing of enumeration, there have been calculated the volume of stem having diameter and height being equal to average diameter and height of stand. Further growing stock per hectare have been determined by the formula

$$M_e = V_{av} \frac{G_e}{G_{av}}, \quad (4)$$

where V_{av} - average volume of stem of estimated forest stand, m^3; G_{av} – basal area of average tree, m^2, calculated by the formula

$$G_{av} = \frac{\pi D_{av}}{40\ 000}, \quad (5)$$

where D_{av} - average diameter of forest stand, cm.

Despite of the fact that when considering estimating for each pure even-aged stand there have been calculated a number of stems per hectare by the formula (4), ratio G_e/G_{av} is used instead of this quantity. In the future, instead of the number of stems per hectare there will be used this expression. This is due to the fact that during metrical taxation the number of stems per hectare is usually not determined, and average diameter and total basal area are always estimated.

By means of distribution of tree line by natural diameter classes (according to A. V. Tyurin, D ≤ 25 cm). On the basis of average diameter distribution of trees by natural diameter classes for forest stands with average diameter of 25 cm [2] for each pure even-aged stand, enumeration of trees by natural diameter classes took place (per 1 ha). The number of trees for each natural diameter class has been calculated as follows:

$$N_i = \frac{P_i G_e}{100 G_{av}}, \quad (6)$$

and the absolute value of t natural diameter class has been determined by the formula

$$D_i = E_i \cdot D_{av}, \quad (7)$$

where N_i - number of stems in the i-th natural diameter class, pcs.; D_i - absolute quantity of the i-th natural diameter class, cm; E_i - quantity of the i-th natural diameter class.

Further, according to the same tables being used for tree enumeration there have been determined stem volumes corresponded to natural diameter classes, and then there have been calculated the growing stock per hectare as follows:

$$M_e = \sum_{i=1}^{k} V_i \cdot N_i, \quad (8)$$

where V_i - stem volume in the i-th natural diameter class, m^3; k – the number of natural diameter classes.

By means of distribution of tree line by natural diameter classes (according to A. V. Tyurin, D > 25 cm). When using this method growing stock per hectare was calculated as in the previous case, using the formulas (6) - (8) only on the basis of the average diameter distribution trees by natural diameter classes for forest stands with average diameter of 25 cm [2].

By means of distribution of tree line by natural diameter classes (according to A. V. Tyurin, all forest stands). As in previous cases, in this method growing stock per hectare is determined by formula (6)–(8), on the basis of average diameter distribution of trees by natural diameter classes for all plants together obtained by Tyurin [2].

By means of distribution of tree line by natural diameter classes (according to V.F. Baginski). In this case, when determining the growing stock there have been used a number of diameter distribution of trees by relative diameter classes, resulted from the development of commodity tables under V.F. Baginski [3]. The calculation of growing stock have been done using formulas (6) - (8) as in the previous three methods.

By means of distribution of two tree line by natural diameter classes for 1-2 and 3-6-th-th age *classes*. With this method, estimation of growing stock volume per hectare has been fulfilled as follows: firstly there have been chosen one of two lines of stem diameter distribution according to natural diameter classes depending on age of estimated forest stand, one of them being obtained for pineries of 1-2nd age class, and the other - for 3-4 age class of [4].

Further, for selected line of tree diameter distribution there have been determined absolute quantities of natural diameter classes by the formula (7) and the frequency by the formula (6). Then, for each natural diameter class there have been determined volume of one tree according to volume tables and growing stock per hectare being determined by the formula (8).

By means of distribution of tree line by natural diameter classes for pine stands. To implement this method, we constructed a line distribution of the number of stems in percentage by natural diameter classes for pine stands.

This line was being constructed in the same manner and to the same data as distribution tree lines by natural diameter classes for pine stands 1-2 and 3-6 age classes [4].

Obtained number of distribution has been smoothed by beta function. Null hypothesis (the empirical distribution obeys the beta distribution) was tested by using Pearson criterion χ^2. The calculation results are allowed to take null hypothesis.

Thus, the number of tree diameter distribution is well described by this function. The obtained empirical and theoretical frequency shifts (in percent) of diameter distribution by natural diameter classes in pine forest stands are given in Table. 2.

Thus distribution line obtained was being used in the method described when estimating growing stock.

Using formula (6) the relative frequencies of the smoothed function of beta-distribution line (Table 2) have been transferred to the absolute quantities, absolute quantities of natural diameter classes for each estimation have been calculated by the formula (7).

After determining the volume of one stem for each diameter class the stock has been calculated by the formula (8).

For each of 879 pure even-aged stands growing stock being determined by all nine methods described above and compared with the stock obtained by means of standard estimation (control). There have been calculated the deviation of growing stocks obtained by all nine methods to growing stock data resulted from enumeration survey.

Further processing of the materials is as follows. For each of the analyzed method of calculating the maximum value of inventory is determined maximum quantities of deviation to the higher or lower degree. There have been also calculated as the arithmetic average deviation (bias) and RMS deviation (standard error).

Table 2

Distribution lines of stems diameters by natural diameter classes (pine)

Diameter class	Frequencies, %	
	experimental	theoretical
0.2	0.1	0.1
0.3	0.4	0.5
0.4	1.4	1.4
0.5	3.7	3.4
0.6	6.7	6.5
0.7	9.7	10.0
0.8	12.4	13.1
0.9	14.6	14.7
1.0	14.9	14.3
1.1	12.8	12.3
1.2	9.6	9.3
1.3	6.3	6.4
1.4	3.6	3.9
1.5	1.9	2.2
1.6	1.0	1.1
1.7	0.5	0.5
1.8	0.2	0.2
1.9	0.1	0.1
2.0	0.1	0.0

Thus, obtained quantities in cubic meters, and expressed in percent to arithmetical average of growing stock per hectare all estimated growing stands listed in Table 3.

In addition to the absolute deviations there have been calculated deviations expressed in percent to growing stock resulted estimation data, which was being accepted as true value. The maximum values for relative deviations to higher and lower degrees are given in Table. 4.

Results and discussion. As the results of calculations shown in Table 3, standard method for value estimation of growing stock leads to an underestimation of the obtained values.

It gives a considerable negative system-themed error being about four and a half cubic meters, accounting for 1.9% of the average growing stocks per hectare for all analyzed estimations.

Maximum deviations occurring in this method of growing stock calculation reaches 51 m^3 to the lower degree and 35 m^3 to the higher one.

It would be interesting to compare these deviations with random errors in volume estimation of growing stock, which are regulated by the rules of the forest management [5]. In this document, the error values are given in relative terms (as a percentage).

When taxation mature and overmature stands included in calculation of final felling and sites selected for thinning as well as for logging updates and reformation, the set value of permissible error comprises 15%. When estimation all other plantations we consider acceptable error being not higher than 20% of the growing stock.

Table 4 shows the maximum values of deviations to higher and lower degrees, which are expressed as a percentage of growing stock, according to a specific enumeration of trees.

With regard to deviations to lower degree of growing stocks, they fit into the maximum value of the allowable error frame, whereas the lower deviations (up to 28%) can lead to the fact that growing stock will be determined according to the invalid instruction forest inventory accuracy, and it is not due to quality of taxator work, but the method used in calculations.

Analysis of deviations occurring in growing stock calculation by the formula (2) with the use of form height table [1] shows that this method provides greater accuracy than a method of growing stock estimation by standard table (Table. 3). More accurate results can be obtained by the method considering average tree volume, but its systematic error is still larger.

The following methods for volume estiomation involve modeling of trees distribution by natural diameter classes and average frequencies according to natural diameter classes obtained for different sets of plants by various authors. Movement in this direction results in a significant complication of the process of performing calculations. However, as the results of the analysis, this method for most of the tested lines of stem diameter distribution (in percent) by natural diameter classes leads to a significant increase in the accuracy of calculation of the growing stock.

Three of the analyzed variants, involving the use of M.V. Turin's line for stands with stem diameter higher than 25 cm [2], for a line of pine stands in Belarus obtained in this work (Table. 2), and for earlier obtained pinery lines of 1-2 and 3-6 age class [4] are characterized by a systematic error not exceeding one cubic meter of wood per hectare. This is less than 0.2% from the average growing stock for all pure even-aged stands being estimated.

The most accurate method of calculation from being considered should be recognized that of based on the use of two lines of trees in the natural distribution of diameter classes for pine 1-2 and 3-6- age classes, as it is characterized by the lowest RMS deviation value. Its systematic error is also low - 0.4 m^3, or 0.2% of the average growing stock for all pure even-aged stands being analyzed.

Conclusion. Currently used practice of forestry methods of growing stock calculation when fulfilling visual taxation has rather bad systematic error underestimating growing stocks. When fulfilling visual taxation, it comprises - 4.6 m^3 (-1.9%), while taxation of cutting areas by sampling methods it comprises -3.7 m^3 (-1.5%).

Table 3

Analysis of growing stock deviations per ha calculated by different methods to the growing stock obtained by tree estimation

Methods of growing stock estimation	Deviations							
	absolute, m^3				relative, %			
	maximum		average		maximum		average	
	to the lower degree	to the higher degree	arithmetic	quadratic	to the lower degree	to the higher degree	a arithmetic	quadratic
By standard tables	–51.3	35.2	–4.6	12.1	–21.3	14.6	–1.9	5.0
By form heights tables	–46.9	22.2	–3.7	10.8	–19.5	9.2	–1.5	4.5
By average tree	–29.9	3.1	–3.7	5.6	–12.4	1.3	–1.5	2.3
By natural diameter classes: – according to M. V. Tyurin: $D \leq 25$ cm	–17.5	9.1	2.2	3.5	–7.3	3.8	0.9	1.5
$D > 25$ cm	–22.2	5.3	0.1	2.9	–9.2	2.2	0.0	1.2
All plantings	–22.6	2.8	–1.1	2.8	–9.4	1.2	–0.5	1.2
– according to V. F. Baginski	–14.7	13.9	4.6	5.6	–6.1	5.8	1.9	2.3
– by two tree line distribution according to natural diameter classes for 1-2 and 3-6 age classes	–13.7	9.5	–0.4	2.0	–5.7	4.0	–0.2	0.8
– by tree line distribution according to natural diameter classes for all age classes	–19.1	5.6	–0.2	2.2	–7.9	2.3	–0.1	0.9

Table 4

Maximum relative deviations of growing stock

Methods of growing stock estimation	Maximum relative deviations, %	
	to the lower degree	to the higher degree
By standard tables	–28.1	11.2
By form heights tables	–27.4	5.4
By average tree	–16.5	0.7
By natural diameter classes: – according to M. V. Tyurin: $D \leq 25$ см	–11.0	3.9
$D > 25$ см	–12.9	1.9
All plantings	–13.0	1.6
– according to V. F. Baginski	–10.3	5.4
– by two tree line distribution according to natural diameter classes for 1-2 and 3-6 age classes.	–12.2	5.4
– by tree line distribution according to natural diameter classes for all age classes.	–12.0	3.2

This leads to an underestimation of growing stock. To reduce the error in growing stock estimation when fulfilling visual taxation it is reasonable to use more accurate methods.

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