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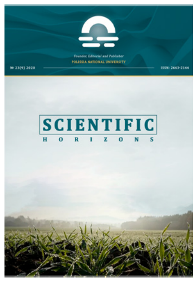

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Influence of the Value of Relascopic Coefficients on the Accuracy of Determining the Stand Basal Area

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Abstract. When conducting angle-count sampling in the forests of Ukraine, the most common is the use of factor gauge with a relascopic coefficient of 1. According to the standards, the recommended value of this coefficient depends on the approximate stocking and mean diameter of the stand and can be 0.5, 1, 2, 3, and 4. Proceeding from the fact that in Ukraine there are no tools for relascopic measurations that would allow making measurements using the 5 values of the relascopic coefficient provided for in the standards, the authors of this paper developed and tested an original model of the factor gauge "Crab". The purpose of this paper is to investigate the accuracy of determining the stand basal area of stands using relascopic coefficients of various values depending on the mean diameter and stand density. By comparing the data on fixed-area plots with a radius of 17.85 m with the data of angle-count sampling, it was discovered that no systematic errors were found that underestimated or overestimated the results of angle-count sampling. It is determined that deviations of the stand basal area from the true values slightly depend on the value of the relascopic coefficient, as well as on the stocking and mean diameter of the stand. According to the authors, the accuracy of the results of determining the stand basal area during angle-count sampling directly depends on the representation of the tree selection zone within the circular sample. This is completely random when using any relascopic coefficient. It is established that in mixed forest plantations, the greatest accuracy in determining the sum of cross-sectional areas of individual forest elements is provided by small coefficients (1, 0.5, and 2). In pure stands, it is advisable to use larger relascopic coefficients (2-4). This implies a corresponding increase in the number of measurements that can better cover stands and increase the accuracy of the results obtained

Keywords: angle-count sampling, fixed-area plots, factor gauge, mean diameter, stocking

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INTRODUCTION

Angle-count sampling is crucial in the system of selective forest inventory. This method, according to many scientists, is one of the greatest achievements of forest measurations [1; 2]. The main task in conducting angle-count sampling was primarily to determine the stand basal area of trees per unit area using protractor tools [3]. However, later, at the beginning of the second half of the 20th century, the possibility of using the method of relascopic samples to determine other tax indicators of the tree stand was proved [4]. At the same time, the basic principles of forming a sample depending on the biometric indicators of trees were described. This eventually led to the establishment of so-called relascopic coefficients (BAF), which directly depended on the diameter of the accounting trees. Based on the results of these studies in Ukraine, as in many countries, the corresponding standards were formed. The standards indicate the values of relascopic coefficients depending not only on the mean diameter, but also on the stand density [5; 6].

Like any sampling method, angle-count sampling gives a certain error in the results of measuring the stand basal area (SBA). In the publication of Finnish scientists [7] on combined plots with a maximum radius of 9 m, the use of angle-count sampling with BAF 1 was evaluated as a promising method for evaluating tax indicators. Technological methods of angle-count sampling, when adapted to the selection of appropriate laser scanning signals, are considered acceptable according to the conclusions of German scientists [8]. Comparison of the results of determining the sum of cross-sectional areas and density by Spanish scientists [9] did not reveal considerable differences in accuracy between inventory systems (relascopic and with a fixed value of the circular sample radius) for most of the stands and forest types under study. Indonesian scientists reached similar conclusions [10]. However, Brazilian scientists concluded that upon determining the SBA and wood stock per 1 ha, it is more expedient to use the angle-count sampling methods [11]. B. Zeide and J.K. Troxell [12] noted that small BAFs lead to a systematic underestimation of SBA. This is usually conditioned upon the presence of dense undergrowth, poor lighting conditions, hidden trees, and incorrect counting at high density [13]. Some Ukrainian scientists have investigated that upon using BAF 1, which is most frequently applied in Ukraine, there is also a systematic underestimation of SBA [14; 15]. However, another study of these scientists notes that the relascopic method with the same value of the relascopic coefficient makes provision for the highest accuracy in predicting tax indicators of forest stands based on the k-NN method [16].

Another controversial issue is the use of the value of relascopic coefficients in inventory. It is quite common to use large BAF values in countries outside Ukraine [17]. In the Scandinavian countries, measurements are made with a relascopic coefficient from 1.5 to 4 [18]. This is explained by the fact that upon measuring in stands with high density, the use of a larger relascopic coefficient avoids cases of overlapping trees. These trees are located further to the centre of the angle-count sample plot. Therewith, it is also possible to reduce the probability of questionable trees getting into the sample [19; 20]. As early as 1955, it was determined that the mean SBA values increase with increasing BAF [21]. According to other scientists [22], large BAFs are effective in sampling, ensuring proper accuracy. Carlton Scott [23] noted that the use of lower BAF values implies lower standard error values and is appropriate in mixed plantations. But the advantage of using large relascopic coefficients is the speed of accounting, which is advisable in low-quality stands. Studies by other American scientists [24] also demonstrated an increase in coefficients of variation with an increase in BAF.

Regulatory reference books in Ukraine recommend using the BAF value depending on the mean diameter and stand density [4]. The forest Tax Reference Book [6], as well as the standards developed under the USSR [5] note that the use of large values of the relascopic coefficient to ensure the necessary accuracy causes a multiple increase (for BAF 0.5 decrease) in the number of measurements compared to BAF 1. However, the "All-Union standards" [3] indicate that due to the low dependence of the efficiency of angle-count sampling on the value of the relascopic coefficient, it is advisable to use optical squares with higher BAF values. To confirm or refute the recommended data on the feasibility of using the relascopic coefficient in stands of varying density and diameter, as well as data on the probable systematic underestimation of SBA in BAF 1, appropriate studies were conducted.

MATERIALS AND METHODS

This study was conducted in three stages. At the preparatory stage, a relascopic template "Crab" was developed and tested for the possibility of performing measurements using 5 BAF values: 0.5, 1, 2, 3, 4. At the stage of field work, SBA measurements were carried out on circular and angle-count sample plots using coefficients 0.5, 1, 2, 3, 4. During desk processing of the data, the accuracy of determining SBA in relascopic areas was analysed, depending on the mean diameter, density, composition, and uniformity of tree placement.

The primary task was to develop a relascopic template with the ability to perform measurements using BAF 0.5, 1, 2, 3, and 4. The main criteria for developing the relascopic template model were the versatility of measurements, ease of use, and the possibility of long-term operation. For the possibility of using the 5 BAF values provided for in the regulatory recommendations: 0.5, 1, 2, 3, 4 the width of the dioptres was calculated accordingly. For the convenience of using the relascopic template, options for fixing the tool using only one hand were provided. The estimated distance of the dioptre from the observer's eye was 50 cm. The accuracy of the scope width for each BAF was checked indoors using sheets of white paper on a dark background. For this, a sheet of paper was attached to a height of 1.3-1.6 m on a vertical dark surface at a distance of 10 m from eye level (the length was determined using a LDM-100 CEM laser tape measure) and sighting was performed through a sighting slot of the appropriate size. When calibrating BAF 0.5, a sheet with a width of 14.1 cm was used, BAF 1 – 20.0 cm, BAF 2 – 28.2 cm, BAF 3 – 34.6 cm, and BAF 4 – 40.0 cm. Upon applying the appropriate value of the relascopic coefficient, Sheets of the specified width had to fit exactly into the dioptre.

Field studies were conducted during the autumn-winter period of 2020-2021 on specially laid fixed-area plots (FAP) with a radius of 17.85 m, which corresponds to an area of 1,000 m^2. The size of the FAP is conditioned upon the purpose of conducting angle-count sampling using BAF 0.5 at the same sites, which involves sampling trees that are more distant from the centre of the sample (the diameter of the boundary trees is 25 cm). In total, 14 FAP were laid in the plantations of Levkivskyi and Tryhirskyi forest districts of the State Enterprise "Zhytomyr Forestry". Plots were selected in such a way that there was no under storey and large young growth. The age of plantations ranges from 20 to 120 years. The density of land plots according to forest management materials ranges from 0.5 to 0.9. According to the composition of stands, the experimental plots differed as follows: 10 FAP in pure stands (8 pine stands, 2 birch stands) and 4 FAP in mixed stands (2 pine stands, 1 birch stand, 1 oak stand). Mixed stands were selected to investigate the correctness of determining the composition of plantations using a factor gauge. Before carrying out angle-count sampling using a template with the conditional name of the model "Crab", a centre was fixed at each FAP and the territory was divided into four sectors using measuring tapes. This was done for the convenience of conducting a list of tree diameters, as well as for further determining the uniformity of their placement. Each tree was measured using a measuring fork with millimetre accuracy. The belonging of the extreme trees to the FAP was determined using a LDM-100 CEM laser rangefinder. The sum of cross-sectional areas was determined using Excel tools under desk conditions. The results of measurements at the CTA served as a control. From the centre of the FAP, each element of the forest was measured using the "Crab" template in 5 variants with the corresponding accuracy for each BAF (from 0.25 m^2 at BAF 0.5, 0.5 m^2 at BAF 1, 1 m^2 at BAF 2, 1.5 m^2 at BAF 3, and 2 m^2 at BAF 4). At FAP No. 5, 9, and 12, where the mean tree diameter was relatively small (8-12 cm), angle-count sampling was performed at three equidistant points in circular samples to ensure the adequacy of samples with BAF values of 2-4.

RESULTS AND DISCUSSION

Proceeding from the results of a continuous list of trees at the FAP, accurate indicators of SBA, relative density and mean diameter were determined. The uniformity of tree placement in FAP can generally be considered uniform, as evidenced by the variability of SBA in sample sectors. Only FAP 7 contained an uneven arrangement of trees (Table 1).

***Table 1**. Results of SBA measurements at experimental sites*

No. sample plot	SBA on the FAP (control), m^2/ha	SBA on the angle-count sample plots, m^2/ha					Mean diameter, cm	Stand stocking	Variability of SBA in FAP sectors, %
		BAF 0.5	BAF 1	BAF 2	BAF 3	BAF 4			
1	33.4	39.5	32.0	34.0	39.0	36.0	23.8	1.14	14.3
2	53.7	50.5	57.0	58.0	60.0	60.0	30.1	1.10	16.5
3	14.7	18.0	19.0	16.0	15.0	16.0	17.2	0.52	17.1
4	27.8	31.5	30.0	22.0	25.5	28.0	30.0	0.86	13.4
5	17.3	20.3	20.8	21.6	19.5	18.8	7.9	0.55	17.8
6	50.6	41.5	52.0	58.0	66.0	64.0	33.8	1.00	8.5
7	29.0	24.5	34.0	31.0	37.5	36.0	30.0	0.67	33.7
8	35.5	35.5	39.5	43.0	45.0	36.0	30.5	0.75	14.7
9	19.3	20.8	18.8	19.0	20.3	22.0	12.3	0.63	13.6
10	38.8	39.0	35.0	40.0	39.0	34.0	35.9	0.79	18.9
11	35.1	30.0	29.5	26.0	25.5	26.0	28.9	0.96	7.7
12	14.8	19.0	18.0	18.0	19.5	22.0	8.9	0.63	11.6
13	23.6	27.5	22.0	24.0	24.0	20.0	17.8	0.88	16.4
14	39.0	41.0	47.0	39.0	39.0	30.0	24.2	0.82	13.4

In fact, in terms of density, 4 plots (sample plots 3, 5, 9, 12) were represented by low-density stands, as well as 4 plots (sample plots 7, 8, 10, 14) were medium-density and, respectively, 6 plots (sample plots 1, 2, 4, 6, 11, 13) were high-density stands. According to the recommendations [4], considering the density and mean diameter of stands in all experimental low-density stands, it would be necessary to perform measurements using BAF 0.5 and 1. BAF 2 and 3 are recommended in medium-density stands, while BAF 3 and 4 are recommended for high-density stands. However, as the calculations proved, the recommended relascopic coefficient in only one experimental site (No. 13) yielded the SBA value close to the control one.

Comparison of measurements of the sums of cross-sectional areas per 1 ha according to relascopic and list taxation data indicated corresponding discrepancies between the values both up and down (Table 2).

***Table 2**. Differences in the results of SBA measurements on the angle-count sample plot compared to the control (FAP)*

No. sample plot	Mean diameter, cm	Stand stocking	BAF, $SBA_{control} - SBA_{angle\text{-}count}$, m²/ha				
			0.5	1	2	3	4
1	23.8	1.14	6.1	-1.4	0.6	5.6	2.6
2	30.1	1.10	-3.2	3.3	4.3	6.3	6.3
3	17.2	0.52	3.3	4.3	1.3	0.3	1.3
4	30.0	0.86	3.7	2.2	-5.8	-2.3	0.2
5	7.9	0.55	3	3.5	4.3	2.2	1.5
6	33.8	1.00	-9.1	1.4	7.4	15.4	13.4
7	30.0	0.67	-4.5	5.0	2	8.5	7.0
8	30.5	0.75	0.0	4.0	7.5	9.5	0.5
9	12.3	0.63	1.5	-0.5	-0.3	1.0	2.7
10	35.9	0.79	0.2	-3.8	1.2	0.2	-4.8
11	28.9	0.96	-5.1	-5.6	-9.1	-9.6	-9.1
12	8.9	0.63	4.2	3.2	3.2	4.7	7.2
13	17.8	0.88	3.9	-1.6	0.4	0.4	-3.6
14	24.2	0.82	2.0	8.0	0.0	0.0	-9.0

Analysis of the difference in SBA indicators during angle-count sampling and control generally indicated that the results of angle-count sampling measurements mostly overestimate the true (control) values upon using all BAF values. Based on the sum of the differences, it was determined that in general, the maximum overestimation of SBA values occurred when using BAF 3, the minimum – when using BAF 2. Underestimating $SBA_{angle\text{-}coun}$ values is mainly observed in high-density plantations, mainly upon using individual BAF values. These results refute the claims of some scientists regarding the systematic underestimation of the SBA values obtained during angle-count sampling [12-14], as well as the hypothesis of the previous studies of the authors of this paper upon using BAF 1 [15]. To compare the accuracy of determining SBA at relascopic sites using different BAF values, the relative deviation for each variant compared to the control was identified (Table 3).

***Table 3**. Results of SBA measurements at experimental sites*

No. sample plot	Mean diameter, cm	Stand stocking	BAF				
			0.5	1	2	3	4
1	23.8	1.14	18.3	4.2	1.8	16.8	7.8
2	30.1	1.10	6.0	6.1	8.0	11.7	11.7
3	17.2	0.52	22.4	29.3	8.8	2.0	8.8
4	30.0	0.86	13.3	7.9	20.9	8.3	0.7
5	7.9	0.55	17.1	19.9	24.9	12.7	8.7
6	33.8	1.00	18.0	2.8	14.6	30.4	26.5
7	30.0	0.67	15.5	17.2	6.9	29.3	24.1
8	30.5	0.75	0.0	11.3	21.1	26.8	1.4
9	12.3	0.63	7.5	2.6	1.6	4.9	14.0
10	35.9	0.79	0.5	9.8	3.1	0.5	12.4
11	28.9	0.96	14.5	16.0	25.9	27.4	25.9
12	8.9	0.63	28.4	21.6	21.6	31.8	48.6
13	17.8	0.88	16.5	6.8	1.7	1.7	15.3
14	24.2	0.82	5.1	20.5	0.0	0.0	23.1
	Mean deviation		13.1	12.6	11.5	14.6	16.4

Notably, the average values of relative deviations in angle-count sampling using 5 BAF values are quite close and do not give grounds to draw any reasonable conclusions. However, the data in Table 3 demonstrates that even with similar values of density and mean diameter, deviations within each BAF value can vary greatly.

Analysis of the dependence of the relative deviation of the SBA on the mean diameter revealed a significant relationship only upon measuring with BAF 0.5 – r=0.53 (Fig. 1). When performing SBA measurements using the BAF 1 value, the dependence of the relative deviation from the mean diameter is moderate – r=0.38 (Fig. 2).

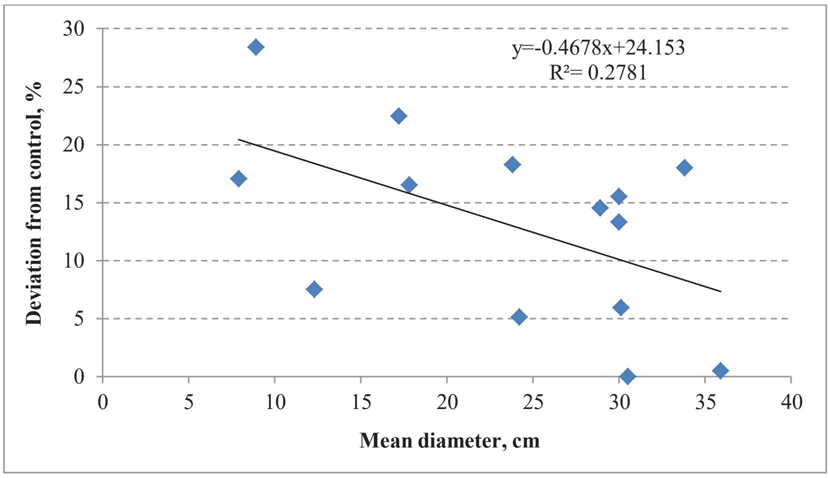

***Figure 1**. Dependence of the relative deviation of the SBA on the mean diameter for measurements with BAF 0.5*

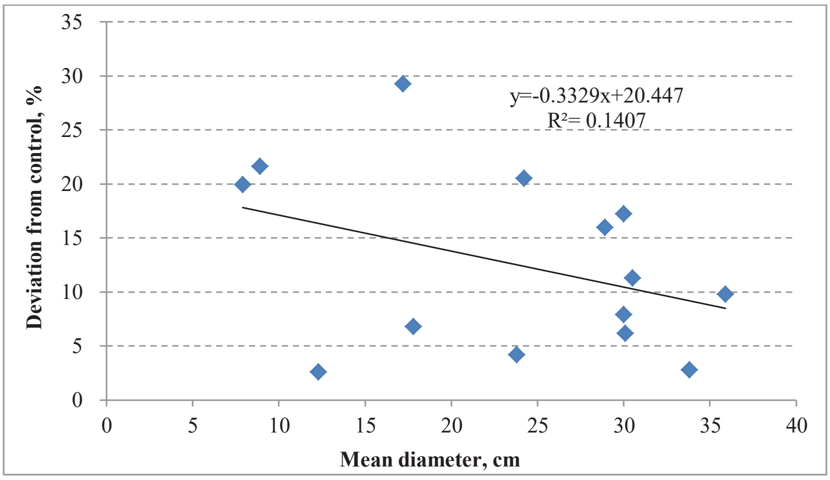

***Figure 2**. Dependence of the relative deviation of the SBA on the mean diameter for measurements with BAF 1*

At higher coefficients (BAF 2-4), no such relationship was detected. For a more thorough analysis, it was decided to group the data of experimental sites depending on their mean diameters and density, similar to the form of recommendations [5]. The first group included four test areas with the smallest mean tree diameter (Table 4). What is common for these sections is low density, which allows using the relascopic coefficient of 0.5 and 1 according to the recommendations. According to the data of relative deviations in these sections, it is noted that the BAF values of 3 and 2 yield slightly higher accuracy.

***Table 4**. Deviation of SBA from the angle-count sample plot control with the recommended BAFs 0.5-1, (%)*

No. sample plot	Mean diameter, cm	Stand stocking	BAF				
			0.5	1	2	3	4
3	17.2	0.52	22.4	29.3	8.8	2.0	8.8
5	7.9	0.55	17.1	19.9	24.9	12.7	8.7
9	12.3	0.63	7.5	2.6	1.6	4.9	14.0
12	8.9	0.63	28.4	21.6	21.6	31.8	48.6
Mean deviation			18.8	18.4	14.2	12.9	20.0

The second group included test areas with medium-density stands (Table 5). Notably, the accuracy of angle-count sampling at the experimental sites of this group turned out to be better for all BAFs universally. However, the smallest deviations in the determination of SBA were noted for measurements using BAFs 0.5 and 2.

***Table 5**. SBA deviation from angle-count sample plot control with recommended BAFs 2-3, (%)*

No. sample plot	Mean diameter, cm	Stand stocking	BAF				
			0.5	1	2	3	4
7	30.0	0.67	15.5	17.2	6.9	29.3	24.1
8	30.5	0.75	0.0	11.3	21.1	26.8	1.4
10	35.9	0.79	0.5	9.8	3.1	0.5	12.4
14	24.2	0.82	5.1	20.5	0.0	0.0	23.1
Mean deviation			5.3	14.7	7.8	14.1	15.2

The third group included test areas laid in high-density stands, wherein, depending on the mean diameter, it is recommended to measure relascopic areas using BAFs 3 and 4 (Table 6).

***Table 6**. SBA deviation from angle-count sample plot control with recommended BAFs 3-4, (%)*

No. sample plot	Mean diameter, cm	Stand stocking	BAF				
			0.5	1	2	3	4
1	23.8	1.14	18.3	4.2	1.8	16.8	7.8
2	30.1	1.10	6.0	6.1	8.0	11.7	11.7
4	30.0	0.86	13.3	7.9	20.9	8.3	0.7
6	33.8	1.00	18.0	2.8	14.6	30.4	26.5
11	28.9	0.96	14.5	16.0	25.9	27.4	25.9
13	17.8	0.88	16.5	6.8	1.7	1.7	15.3
Mean deviation			14.4	7.3	12.2	16.0	14.6

According to the results of the values of average deviations, the most accurate accounting was found in high-density stands using the BAF 1 coefficient. The remaining BAF values indicate generally similar deviation rates.

Before fieldwork, the working hypothesis was that the accuracy of angle-count sampling at FAP with a radius of 17.85 m using various BAFs would primarily depend on the mean diameter of the trees on the sample. The selection area at BAF 0.5 and 1 is the largest, and at diameters greater than 20 cm will approach the FAP. Therefore, higher accuracy seemed most probable upon using these values of relascopic coefficients. However, behavioural analysis indicated that there was no relationship between the accuracy of different BAF levels and the mean diameter. Only upon conducting studies in four mixed plantations was some connection found. The greatest accuracy in determining SBA in the context of forest elements is provided by small BAFs 1, 0.5, and 2 (Table 7).

***Table 7**. Results of SBA measurements at experimental sites in mixed stands, m^2/ha*

No. sample plot	Stand composition	SBA on the FAP (control) m^2/ha	BAF, SBA on the angle-count sample plots, m^2/ha				
			0.5	1	2	3	4
1	5Cb	15.4	22.5	15	12	12	16
	4Qr	15.1	17	14	20	24	20
	1Ap	3.5	1.5	3	2	3	0
5	8Ps	14.6	16	15.25	17	13.5	12
	2Bp	2.8	4.25	5.5	4.6	6	6.8
9	7Ps	12.9	12.75	11.25	12.5	13.5	14
	3Bp	6.4	8	7.5	6.5	6.75	8
12	7Bp	9.9	13.25	13.5	14	15	16
	2Ps	3.4	2.5	1.75	2	1.5	2
	1Pt	1.5	3.25	2.75	2	3	4

***Notes**: Cb is the Common hornbeam (Carpinus betulus L.), Qr is the Common oak (Quercus robur L.), Ap is the Norway maple (Acer platanoides L.), Ps is the Scots pine (Pinus sylvestris L.), Bp is the Silver birch (Betula pendula Roth.), Pt is the Common aspen (Populus tremula L.)*

However, it is very probable that a corresponding increase in measurements using relascopic coefficients BAF 3 and 4 can also yield sufficient accuracy. In general, the results of the conducted studies confirm the data of foreign scientists regarding the feasibility of using large values of relascopic coefficients [17-20]. The use of small relascopic coefficients is justified only in mixed plantations, which is consistent with the data of Carlton Scott [23]. Along with this, the authors of this paper can refute the statement regarding an increase in SBA values with an increase in the BAF value [21].

CONCLUSIONS

The specially developed model of the factor gauge "Crab" has proven itself quite well upon determining the SBA using 5 normatively prescribed BAF values. In comparison with the results of SBA measurements at the FAP, which served as a control, no systematic errors were detected during relascopic pattern measurements that would unilaterally distort the results of angle-count sampling. Data on possible systematic underestimation of SBA values in relascopic sites both at the value of BAF 1 and at other relascopic coefficients based on the results of the study can be refuted.

When conducting angle-count sampling in mixed stands, it turned out that the greatest accuracy in determining SBA in the context of forest elements is provided by the use of small BAFs 1, 0.5, and 2. Upon determining the total SBA in low-density young stands, the smallest deviations from the control were noted at BAF 2 and 3, in older medium-density middle-aged stands – at BAF 0.5 and 2, in high-density maturing and mature stands – at BAF 1.

There is reason to assert that deviations from the true values of the SBA slightly depend on the value of the relascopic coefficient, as well as on the density and mean diameter of the stand. Most essentially, according to the authors of this paper, the accuracy of the results of determining SBA in angle-count sampling depends on how well the trees in the selection zone of a certain BAF value represent the entire selection area of FAP, which is completely random in nature. Since larger BAF 2-4 values make provision for a corresponding increase in the number of measurements that can better cover plantings, there are prerequisites to recommend these relascopic coefficients, also considering the ease of accounting.

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Вплив величини реласкопічних коефіцієнтів на точність визначення суми площ поперечних перетинів

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Анотація. При проведенні реласкопічної таксації в лісах України найбільш поширеним є використанням кутових шаблонів із величиною реласкопічного коефіцієнта 1. Рекомендована величина даного коефіцієнта відповідно до нормативів залежить від орієнтовної повноти та середнього діаметру деревостану і може становити 0,5, 1, 2, 3 і 4. Виходячи з того, що в Україні відсутні засоби для реласкопічної таксації, які б давали змогу проводити заміри з використанням 5-х передбачених у нормативах значень реласкопічного коефіцієнта, було розроблено власну модель реласкопічного шаблону «Краб» та проведено його апробацію. Метою даної роботи є дослідження точності визначення сум площ поперечних перетинів насаджень при використанні реласкопічних коефіцієнтів різної величини залежно від середнього діаметру та повноти деревостанів. Шляхом порівняння даних на кругових пробних площах радіусом 17,85 м із даними реласкопічної таксації встановлено, що систематичних помилок, які б занижували чи завищували результати реласкопічної таксації виявлено не було. Визначено, що відхилення суми площ поперечних перетинів від істинних значень незначною мірою залежать від величини реласкопічного коефіцієнта, а також від повноти і середнього діаметру деревостану. На думку авторів, точність результатів визначення суми площ поперечних перетинів при реласкопічній таксації залежить напряму від репрезентації зони відбору дерев в межах кругової проби. Це має цілком випадковий характер при використанні будь-якого реласкопічного коефіцієнта. Встановлено, що у мішаних насадженнях найбільшу точність визначення суми площ поперечних перетинів окремих елементів лісу забезпечує саме використання невеликих коефіцієнтів (1, 0,5 і 2). У чистих насадженнях доцільним є застосування більш великих реласкопічних коефіцієнтів (2–4). Це передбачає відповідне збільшення кількості замірів, які можуть краще охопити насадження і збільшити точність отриманих результатів

Ключові слова: реласкопічна таксація, кругові пробні площі, реласкопічний шаблон, середній діаметр, повнота насадження