Optimization of Sampling Square Size in Assessment of Gap Area

JONAS SALADIS
Lithuanian Forest Research Institute,
Liepų 1, Girionys LT-53101, Kaunas reg. Lithuania

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In the article the parameters of gap area assessment in moderately and highly stocked pine (*Pinus sylvestris* L.) stands are studied. Using different sampling square sizes, the assessed area of gaps increases with decreasing size of a quadrant. To choose an optimal sampling square size, the method of gap area variability minimization regarding manual work expenditures and the spreading level of certain forest stands was used. It was estimated that minimal variability of gap area could be achieved using quadrants with the size equal to ¼ and 1/16 of an average tree growing area in moderately stocked stands. In highly stocked stands sampling squares equal in size to ¼ of an average tree growing area should be used. Optimal work expenditures are necessary for manual revision of data files, for the calculation of which quadrants equal in size to ¼ of an average tree growing area were used. Regarding the above mentioned facts in Lithuanian pine stands, the size of a equal to ¼ of an average tree growing area is recommended for assessment of gap area.

Key words: gap area, assessment, work expenditures, optimization of the parameters

Introduction

The inequality of plant distribution and their quality have been very interesting to nature researchers for a very long time. To study this phenomenon much attention has been paid until now. Attempts were made to obtain as exact as possible theoretical parameters for the description of the trees distribution in different stands. To make all this work more efficient, it is necessary to reduce labour expenditures for the assessment of desirable parameters and their precision. Thus, we need to know a lot of empirical parameters, which are more or less dependant on each other and use for this assessment as little as possible data from forest measurements. Usually, the most precise data are expected from larger forest plots. With increasing plot area the precision of estimated parameters increases as well, because owing to a greater number of trees forest parameters are better represented.

Juknys *et al.* (1981) have estimated that permanent sample plots must contain at least 200-250 trees. Such a number of trees in some stands can be expected in an area of up to 1 ha. Unfortunately, it is impossible to allocate so large sample plots in one stand when a statistically based sample design is applied. When these plots are established in the predefined places, most of them will contain trees from 2 or even more stands. This increases the variability and decreases the precision of results. Measuring such a big sample plot is time and labour consuming. Thus, a reasonable compromise of desired precision between -the results and necessary work expenditures is needed.

Quite often for tree distribution and competition assessment sophisticated statistical and mathematical methods are applied. As a result of these calculations, different indices showing tree distribution type or tree competition intensity are obtained. These methods could be divided into two groups. In the first group tree growth area (Тябера, 1982) and most competition indices are used (von Gadow, Hui 2002, Hopkins 1954, Penttinen *et al.* 1992, Pukkala, Kolström 1987, Morisita 1959). These indices could be used to characterize a single tree. Another group of spatial distribution indices can be calculated as sets of the data. They could not be used for the characterization of a single tree. Following some processing, it is possible to get results, i.e. parameters for the characterization of a group of trees in a sample plot or a stand. If the extent of parameter variability is not known, it is not clear, what amount of field measurement data is necessary. Of course, collection of numerous data sets for a reliable assessment takes more time. The size of these data sets could be estimated using specific methods and calculations.

Many authors point out, that the basic factor in the optimisation of assessment is the variability and time expenditures (Smith 1938, Juknys 1974). In our case it is the dependence of variability on the size of a sampling unit. In agricultural practice the achievement of a uniform density is easier than in a forest stand due to a more intensive handling and shorter rotation period. Owing to a long forest stand formation process, gaps without trees are very common. They have a negative influence decreasing the yield of stand. Sufficient space in young stands increases the vitality and productivity of trees (Kuliešis, Saladis 1996), while in older stands it causes productivity losses and leads to a greater tree distribution diversity.

Thus, there are many basic issues in the research of gap area. First of all, it is necessary to delimitate the gap area. This problem was successfully solved in our previous works (Saladis 1996, 1999, Kuliešis, Saladis 1998). The second problem is the reduction of gap area variability. This parameter has been poorly researched until now. These two issues are very closely related, because the delimitation method influences assessment precision, i.e. the result we expect to get. This article has an objective to clarify the relation of gap area variability to stand stocking level, and to choose optimal sampling square size for gap area assessment in the future.

Materials and methods

Materials

For the research the data collected from two forest stand groups were used. Each of them contains 3 permanent sample plots established in 1984 in pure Scots pine (*Pinus sylvestris* L.) stands. Stands of the first group are located in Veisiejai forest enterprise (Table 1). These stands are middle-aged and highly stocked. Stands of the second group are distributed in Druskininkai forest enterprise, located closely to Veisiejai forest enterprise. These stands are premature and moderately stocked. All the plots are designed for stand yield observation. The measurements were carried out in 1984, 1988, 1992-1993 and 1998-1999.

Table 1. Description of permanent sample plots

No	Forest enterprise, district, block, plot	Age at measurement time, years		Stocking level at measurement time		Forest site, forest type	Site index class
		first	fourth	first	fourth		
	Highly stocked mid-aged pine stands						
1	Veisiejai, Kapčiamiestis, bl. 33, pl. 17	48	62	1.06	1.05	Nal, v	III,3
2	Veisiejai, Paliepis, bl. 12, pl. 1	51	66	0.99	1.01	Nbl, v-m	II,7
3	Veisiejų, Kapčiamiestis, bl. 31, pl. 24	40	55	0.95	1.02	Nbl, v-m	II,0
	Moderately stocked premature pine stands						
4	Druskininkai, Latežerio, bl. 292, pl. 1	59	74	0.90	0.76	Nal, v	III,1
5	Druskininkai, Randamonys, bl. 211, pl. 11	60	81	0.86	0.83	Nal, v	II,9
6	Druskininkai, Senovės, bl. 261, pl. 8	68	82	0.85	0.79	Nal, cl	III,6

All stands are growing on poor and very poor forest sites on mineral soils of normal humidity. The site index class was estimated to be from Class I to Class IV. During the establishment of permanent sample plots, the area of each plot was divided into 6-9 smaller subplots for an easier estimation of tree coordinates. For all trees in a sample plot, *dbh* and the coordinates of growing place by measuring direction and distance from the centre of a subplot to tree stem axis were measured. For model trees, additionally stump diameter, height and crown base height were measured. During the remeasurements in 1988, 1992-1993 and 1998-1999, for all trees dbh and for model trees - stump diameter, height and crown base height were measured.

Methods of gap area estimation

For gap area estimation the original method was used (Saladis 1996, 1999). The scheme of the estimation of gaps is shown in Figure 1. In each sample plot mean growing area *F* was calculated as the ratio of a plot area the number of trees. Then the area of the sample plot was divided into small sampling squares, the size of which depends on mean growing area *F*. In the research four different sizes of sampling squares were used. The smallest sampling square was set to 1/16 *F*. The three remaining sampling square sizes were larger by 2.25, 4 and 9 times, respectively. Coordinates of the sampling square centre were calculated for each sampling square. Having calculated crown diameters by the models constructed by Juodvalkis (Юодвалькис

a)

b)

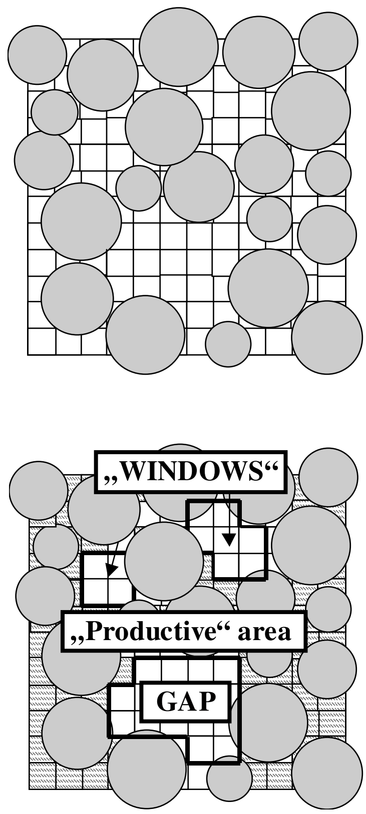

Figure 1. Scheme of gap area assessment when the size of sampling squares equals to ¼ *F* :
a) Plot area is divided into sampling squares;
b) Plot area is divided into gaps, ‘windows’ and productive plots.

1985), we found out, which sampling squares had been used by growing trees. These were the sampling squares, the centre of which was reached by one or more tree crown radii. A compact plot with gap area equal to *F* or larger was obtained as a result of joining the remaining "unused" sampling squares. These areas without trees, the so-called 'unproductive' stand areas, were divided into 2 categories - gaps and 'windows' (small gaps). "Unused" areas smaller than 1 *F* and located within productive areas were marked as productive areas. The area of 'windows' was larger than 1 *F* and less than 2 *F*. The area of gaps was equal to 2 *F* or larger. This distribution was based on the results of our previous investigations (Saladis 1996). The remaining sampling squares were called a 'productive' stand area.

The variability of gap area was investigated using the data of two stand groups consisting of 3 stands. Every stand was measured 4 times. Thus, in every group 12 sets of data were used for calculation. For every group average percentage of gap area, standard deviation and standard error were calculated.

Assessment of optimal calculation parameters

In the calculation of gap area, the most difficult task is the ascertainment of the border of unproductive area. Other parameters, such as unproductive area (gaps and 'windows') and productive area depend on the result of this task. The above mentioned parameters depend on the size of sampling squares used to divide a plot. This size is dependent on the average tree growing area and leads to the increase or decrease in gap ascertainment precision. E.g., the use of large size sampling squares diminishes the possibility to assess the influence of every tree. On the other hand, the use of small sampling squares increases the amount of work necessary for the ascertainment of gaps and data revision. In some cases non-essential information can be obtained. The above mentioned factors seriously affect the variability of gap area expressed in both absolute and relative values. This raises the necessity to study the influence of different sampling square sizes. For the assessment of optimal sampling square size standard deviation was used. It was assumed that optimal sampling square size must cause minimal gap area variability.

All the calculations of gap area assessment were done using original computer software created by the author of this article. At present there is the only stage that must be done manually, i.e. distinguishing between gaps and "windows". This can be done by manual reviewing and marking data array. In this process it is necessary to mark isolated sampling squares, the size of which is smaller than that of 'windows' (1*F*) as productive areas. Time necessary for the revision of these data arrays was assessed and used for the assessment of an optimal sampling square size.

Results

It was found out, that with the changing sampling square size different results in highly stocked as well in moderately stocked stands were obtained (Figure 2). The average of every group, using different sampling square sizes, is shown using different lines. With increasing sampling square size, gap area decreases. Using different sizes of gaps, differences in the highest and lowest values, comprised 12.6-16.3% in highly stocked stands and 17.1-21.5% in moderately stocked stands.

The greatest difference was ascertained comparing estimations based on the 1rst and the 2nd sampling square sizes or the 4th and 9th sampling square sizes. The differences between higher and lower values were about 10% in highly stocked stands and up to 12 % in moderately stocked stands. In both groups of stands these differences were about 3-4 times larger than the ones obtained using the 2nd and the 4th sam-

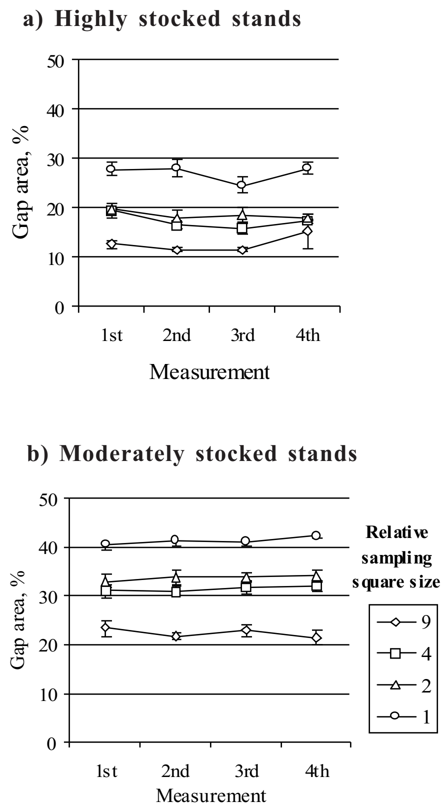

Figure 2. Differences of gap area values using different sampling square size

pling square sizes. The differences in highly stocked stands made up to 2.6 % and in moderately stocked stands – 4.4 %.

The results showed that gap area is highly dependent on sampling square size used in the calculation. Using different sizes, close values of gap area for very different stands or very different gap areas for similar stands could be estimated. Therefore, objective gap area assessment is possible only using a proper sampling square size.

All the above mentioned facts show, that the most important parameter in gap area assessment is the sampling square size. The precision of gap area assessment depends on this parameter, because with decreasing sampling square size the number of sampling squares per tree increases too. At the same time a more detailed view of the area used by every tree is available. Data on the number of sampling squares per plot, number of sampling squares per ha and number of sampling squares per tree is shown in Table 2.

Table 2. Main parameters in gap area assessment

Plot No, area, ha	Measurement No	Density, trees/ha	Sampling square number per plot				Sampling square number per tree			
			1	*2*	*4*	*9*	*1*	*2*	*4*	*9*
			Size of sampling square							
Highly stocked middle age stands										
1 0.25	1	2328	9216	4096	2304	1024	15,8	7,0	4,0	1,8
	2	2076	8281	3600	2025	900	16,0	6,9	3,9	1,7
	3	1836	7225	3249	1764	784	15,7	7,1	3,8	1,7
	4	1384	5476	2401	1369	576	15,8	6,9	4,0	1,7
2 0.25	1	1560	6084	2704	1521	676	15,6	6,9	3,9	1,7
	2	1324	5184	2304	1296	576	15,7	7,0	3,9	1,7
	3	1268	5041	2209	1225	529	15,9	7,0	3,9	1,7
	4	1088	4225	1849	1024	441	16,0	7,1	3,8	1,6
3 0.25	1	1644	6561	2916	1600	729	16,0	7,1	3,9	1,8
	2	1400	5476	2401	1369	576	15,6	6,9	3,9	1,6
	3	1328	5184	2304	1296	576	15,6	6,9	3,9	1,7
	4	1092	4356	1936	1089	484	16,0	7,1	4,0	1,8
Moderately stocked premature stands										
1 0.43	1	1011	6724	3025	1681	729	15,7	7,1	3,9	1,7
	2	871	5776	2601	1444	625	15,7	7,1	3,9	1,7
	3	740	4900	2209	1225	529	15,7	7,1	3,9	1,7
	4	707	4761	2116	1156	529	15,9	7,1	3,9	1,8
2 0.49	1	716	5476	2401	1369	576	15,6	6,8	3,9	1,6
	2	614	4761	2116	1156	529	15,8	7,0	3,8	1,8
	3	586	4489	2025	1089	484	15,6	7,1	3,8	1,7
	4	549	4225	1849	1024	441	15,7	6,9	3,8	1,6
3 0.36	1	925	5184	2304	1296	576	15,6	6,9	3,9	1,7
	2	792	4489	2025	1089	484	15,8	7,1	3,8	1,7
	3	731	4096	1849	1024	441	15,6	7,0	3,9	1,7
	4	631	3600	1600	900	400	15,9	7,0	4,0	1,8

The data of our calculations show, that the number of sampling squares per ha increases with decreasing sampling square size. Using the smallest sampling square sizes in sample plots, from 3600 to 9216 sampling squares were allocated. Using the 2nd sampling square size, the number of sampling squares per plot decreased to 1600-4096, using the 4th sampling square size – 900-2304 and the 9th sampling square size – only 400-1024 sampling squares per one plot. This diversity is dependent not only on sampling square size and the density of trees, but also on plot area. After calculating the average number of sampling squares per one tree, a nearly stable number of sampling squares was stated. In the calculation with the smallest sampling square size there were 15,6-16,0 sampling squares per tree, 6,8-7,1 sampling squares per tree of the 2nd sampling square size, 3,8-4,0 of the 4th sampling square size and 1,7-1,8 of the biggest sampling squares.

During the research, time expenditures for manual revision of the calculation data were measured. At present there is only step, i.e. data revision, requiring manual work. The data of this assessment is shown in Figure 3. It was ascertained, that the least work expensive revisions were necessary for the calculation data where the biggest sampling square size was used (9th data set). It takes only 6 minutes per data set. Revision time of the 4th data set increases up to 8 minutes (sampling square size - 2 times smaller). Revision of the 2nd data set (sampling square size - 4 times smaller) took 15 minutes. Increase in work expenditures for the 1rst data set (sampling square size - 9 times smaller) obtained using the smallest sampling square size was insignificant. It increased only by 1 minute and totally took 16 minutes. Thus, the largest increase was found comparing the data where the 4th and the 2nd sampling square sizes were used. Work expenditures here increased almost 2 times due to an increased volume and data complexity.

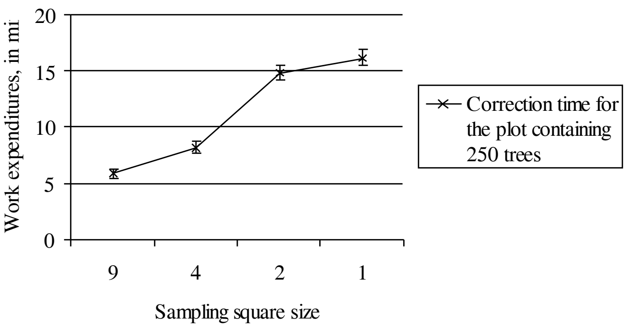

Figure 3. Average work expenditures for manual data revision using different sampling square sizes.

The accuracy of gap area assessment was ascertained comparing the variability of the data of two groups of pine stands using different sizes of sampling squares. There were used 4 sizes of sampling squares related to the average growth area for gap area assessment. A necessary range of data standard deviation for this comparison was used. The data is shown in Figure 4. Higher standard deviation was characteristic of the data obtained using the largest sampling square size, which was 9 times larger as compared to the smallest one. In highly stocked stands the standard deviation comprised 16,4%, while in stands of medium stocking it made up 8,2%. In the assessment using the 4th size of sampling squares the standard

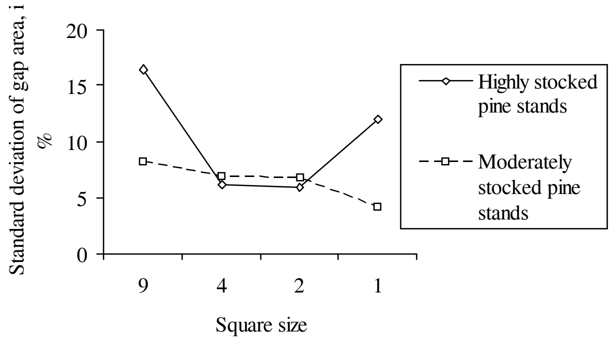

Figure 4. Dependence of gap area standard deviation on sampling square size

deviation comprised 6,2 and 6,9% respectively. In the assessment using the 2nd size of sampling squares, the standard deviation decreases insignificantly – just by 0,2-0,3%. Using the smallest sampling squares in highly stocked stands, the standard deviation increases up to 11,9%, while in stands of medium stocking it decreases to 4,1%. It shows, that according to the standard deviation in highly stocked stands the most suitable are 2nd and 4th sampling square sizes. In moderately stocked stands optimal sampling square size according to standard deviation was not found. The most reliable assessment was achieved using the 1rst size sampling squares.

The above mentioned data allowed summarizing advantages and disadvantages of different sizes of sampling squares as the main parameter in gap area assessment. For a more precise assessment of gap area, we have also involved the average stocking level of pine stands in Lithuania. Moderately stocked stands are the most widely spread in Lithuania, while highly stocked stands are less common.

For the selection of optimal sampling square size, all sampling square sizes in different stands were ranked. The rank of each assessment depends on its accuracy parameter, i.e. standard deviation. The most suitable size was ranked as the 1st, second suitable as the 2nd and so on. The assessment was ranked according to standard deviation, time expenditures for manual data revision and the spreading level of differently stocked stands in Lithuania for both moderately and highly stocked pine stands. Afterwards, all the ranks were summarized (Table 3).

After summarizing the ranks, it was estimated, that according to all above mentioned parameters the best sampling square sizes in moderately stocked pine stands are the 1st, 4th and 9th, while for highly stocked stands optimal sampling square size is the 4th sampling square size. Thus, for the assessment the 4th sampling square size should be used, which is suitable for both

Table 3. Assessment of ranking of different in size sampling squares for selection of optimal sampling square size

Stocking level of stands	Sampling square size	Ranking				
		Assessment accuracy (1)	Spreading level of stands (2)	Time expenditures (3)	Sum of ranks (1+2+3)	**General rank**
Medium stocked stands	9	2	1	1	4	**1**
	4	2	1	1	4	**1**
	2	2	1	2	5	**2**
	1	1	1	2	4	**1**
Highly stocked stands	9	4	2	1	7	**3**
	4	2	2	1	5	**1**
	2	2	2	2	6	**2**
	1	3	2	2	7	**3**

moderately and highly stocked pine stands according to its standard deviation and time expenditures for manual data revision.

Discussion

The area of gaps in forest stands is very important both from ecological and economical point of view. Gaps without trees increase the biodiversity of forest stands and at the same time decrease the yield of stands. Unfortunately, until now the assessment of forest gaps in most cases was done visually and subjectively. The aim is to answer the question – are there in stands large gaps without trees or not? According to some of these assessments, it is not clear even what gaps are considered to be large. Difficulties in the numerical assessment of gap area cause use of the subjective assessment methods. A more precise assessment could be made only using forest measurement data. The measurements could be made according to two methods – by parallel transects or non-used sampling squares.

Assessing the gap area by parallel transects (Liu, Hytteborn 1991, Battles *et al* 1995, Gray, Spies 1996, Williams 1996) the percentage of transects in gaps was calculated. Using transect method the area of each gap in a transect was estimated as a regular geometrical shape, such as an ellipse, rectangle or rhomb, after measuring the longest distance of gap and perpendicular to lines. This method allows us to obtain data for big areas, but it is not precise (Liu, Hytteborn 1991). It is accepted, that the accuracy of assessment is sufficient when 20-30 % accuracy is achieved. The authors have not explained and it is not clear, how this accuracy could be assessed.

Assessing gap area by the non-used square method (Bussing, White 1997, Morisita 1959, Saladis 1996, 1999), the area to be researched is divided into sampling squares. These sampling squares according to special rules are assigned to gap (non-used) or stand (used) area. Bussing and White described one more category – the edge of a gap. Non-used square method is more sophisticated, more time-consuming, but it allows assessing gap area more precisely. Using this method, the most important question is the size of sampling squares. Bussing and White used fixed sampling squares 10x10 m in size. This size has no relation to stand parameters. In our previous research (Saladis 1996, Kuliešis, Saladis 1998, Saladis 1999) we used sampling square size related to medium tree growth area. Sampling square size equal to one quarter of medium tree growth area in the selected area was used.

Our data showed how sampling square size influences the data of gap area assessment. The bigger sampling squares are used, the less gap area is assessed on the area. Using different sampling square sizes for the assessment of the same plot we get results that differ almost twice (Fig. 2). It leads to a dilemma – which of the results is reliable? To answer this question, the standard deviation of two different stand groups was researched. This research could help us choose optimal parameters (Smith 1938, Juknys 1974) According to the results of Smith (1938) with changing sampling square size, their standard deviation changes not randomly, but regularly. Thus, a specific sampling square size, allowing to reduce errors, could be found.

For research, two groups of stands with different stocking levels were chosen. Stocking level is very closely related to the gap area (Saladis 1999). In each group gap area estimation was made using the same methodology and different sampling square sizes related to medium tree growth area. After assessment the standard deviation inside of each stand group was calculated for all the sampling square sizes. Increasing standard deviation shows a decrease in accuracy. Additionally to standard deviation, the data on time expenditures for manual revision was used. These data have shown us, that this revision is not only a mechanical review, which depends on the size of data file, but also on the complexity of the data structure (Figure 3). This structure shows the location of gaps, “windows” and productive areas in the stand.

The results of our research have shown that an optimal sampling square size could and must be chosen using statistical parameters, such as the standard deviation inside of a stand group. To choose an optimal sampling square size, we used not only standard deviation, but also the data on time expenditures for manual correction and the spreading level of differently stocked stands in Lithuania. According to the above-mentioned parameters, it is most worthwhile to use for gap area assessment sampling squares, the area of which equals a quarter of an average tree growth area *F*. It ensures optimal accuracy of assessment and time expenditures for manual data revision in most Lithuanian Scots pine stands. Of course, this article cannot answer all related questions. This estimation is valid for the time being, but using improved calculation programs, including more and more data and assessment of specific stands it will be validated again and again. This is very important, because this method of gap area estimation could be useful not only for sample plot research, but also for the analysis of remote sensing data on the spatial structure of stands as well as other features.

Conclusions

1. Gap area assessment using different sampling square size strongly affects the results. With increasing sampling square size, gap area decreases.

2. The most precise data in moderately stocked stands could be obtained using the smallest sampling square sizes. In highly stocked stands the most precise data were obtained using sampling squares equal to ¼ and 1/8 of the medium tree growth area.

3. Time expenditures for manual data revision fluctuate out of proportion to data file size. The highest time expenditures for manual data revision are obtained using sampling square sizes equal to 1/8 and 1/16 of medium tree growth area.

4. According to the standard deviation of gap area, time expenditures in manual revision and the spreading of differently stocked stands, under Lithuanian conditions sampling square size equal to ¼ of an average tree growth area should be used gap area assessment in pine stand.

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ОПТИМИЗАЦИЯ ПАРАМЕТРОВ ОЦЕНКИ ЛЕСНЫХ ПОЛЯН

Й. Саладис

Резюме

Исследовалось установление площади полян в сосняках средней и большой полноты. При изменении величины квадратов, меняется получаемые результаты – при увеличении квадратов уменьшается площадь полян. Для выбора оптимальной величины квадратов использован метод минимизации изменчивости площади поляны, учитывая затраты труда на ручное пересмотрение данных и распространение древостоев разной полноты. Установлено, что при оценке лесных полян в сосняках средней полноты, минимальная изменчивость площади полян достигается применяя квадраты прировненные 1/4 и 1/8 площади роста среднего дерева, а во высокополнотных сосняках – применяя квадраты прировненные 1/16 площади роста среднего дерева. Учитывая результаты анализа изменчивости, затрат труда для пересмотрения данных и распространения сосняков разной полноты, для оценки площади поляны рекомендуется использовать квадраты прировненные 1/4 площади роста среднего дерева.

Ключевые слова: поляны, изменчивость, затраты труда, оптимизация параметров.