Optimization of parameters of sampling units in Lithuanian national forest inventory

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Kuliešis A., Kasperavičius A. 1998. Optimization of parameters of sampling units for national forest inventory in Lithuania. *Baltic Forestry*, 2: 40-50.

Variance of timber volume in stands of different species as well as expenses to allocate sampling plots of various size have been studied. Minimizing expenses per inventory object, optimal size (500 m²) of a plot has been ascertained. For permanent observation a complex sampling unit has been determined, consisting of circular plots 500 m² in size for trees thicker than 14 cm, 100 m² – thicker than 6 cm, its quarters – for thicker than 2 cm and all planted saplings, strip 3 x 20 m in size for sampling undergrowth, underbrush and regeneration, two angle-count plots for the estimation of the mean parameters in a stand.

In the result of analysis of the ratio between expenses to attain the object (driving and walking) and make measurements in plots, the purposefulness of grouping plots in 4 was determined. In order to raise representation of sampling design by minimizing probability of occurrence of more than one plot on the same site and taking into account the average size of a stand compartment, its configuration, the length of tract edge in Lithuanian forests was estimated to be 250 m. Irregular distribution both by distance and direction was ascertained for linear objects: block lines, roads, ditches, streams, which are able to affect the changing parameters of stands and tracts by the wave principle. This served as the basis for systematic with random start allocation of groups of plots – tracts and orientation of their edges towards the main parts of the world.

Key words: plot, optimization, expenses, variance, grouping, tract, regularity.

Introduction

In carrying out national forest inventory by sampling method the main unit is a sample plot. Most often circular plots with constant radius are used. Their size depends on measured parameters, their variance, and time input needed to find and measure the plots. This is preconditioned by species diversity in the forests, stand composition peculiarities, management intensity of the forests. The plots are usually joined into groups (Ranneby, 1987; Schieler, 1995, Kuliešis, 1989) when looking for optimum between the level of object representation and expenditures to reach and measure the plots. The number of plots in a group and the distance between plots in it depend on forest accessibility, stand area, diversity of sites. Only in rare cases (study on European forestry information and communication systems, 1997) sample plots in the country forests are allocated individually.

Hitherto in Lithuania there were used in practice sample plots of different size but with equal number of trees in them, on average 20 - 30 trees (Kuliešis, 1971; Antanaitis, 1973, Juknys, 1975). Sample plots of varying radius in the inventory object carry a subjective element using them for area estimation, as far as the size of a plot and representation of different land categories during sampling will depend on a subjective decision of the surveyor. Using plots of different radius, the area of plots becomes the weight while estimating the main characteristics – volume, increment, due to which the results having one meaning are impossible (Kuliešis, 1994, Payendeh, 1986).

Sample plots with changing area are least suitable for permanent measuring. Trees occurring in sampling when enlarging the plots may be interpreted as temporarily measurable.

For the national forest inventory by sampling method the main task arises to base the size of sampling units, their construction and grouping.

Aim of investigation

In order to create an optimal sampling design for Lithuanian forest inventory, to carry out inventory with minimal labour expenditures at determined accuracy, it is necessary to optimize the size of sample plots, their construction and joining into groups – tracts, tract form, length of edges, their orientation.

Investigation object, extent

Studies on tract edge length have been conducted in the forests of the Biržai forest enterprise arranged on the GIS basis. In the forests there were evenly allocated 10 squares 2x2 km in size with edges oriented in NS-EW directions. In the study object 30-80-year-old mixed broadleaved stands with spruce and mixed spruce stands with admixture of softwood deciduous trees prevail. The average stand compartment size varies within the range of 1.7-2.2 ha.

To ascertain tract form and edge orientation, the regularity of distribution and direction of the most common linear objects in the forests were studied in all Lithuanian forests. The direction and distribution regularities of block lines, roads, streams and ditches were assessed using digital data basis of satellite image map with an added layer of forests at the Forest Inventory and Management Institute. To select the study objects a scheme of dividing the map of Lithuanian territory (S 1: 50000) into squares of 25x25 km was applied. Of 136 squares 20 evenly distributed on the whole territory were chosen for the study.

The size and structure of a sample unit were studied according to test inventory data in Jūrė forest district of the Kazlų Rūda training forest enterprise (Kuliešis, 1996; Kasperavičius, 1997) as well as experimental measurements in Lithuanian forests. With the aid of pilot study national forest inventory was carried out in the Kazlų Rūda forests in 1996 on an area of 4263 ha by allocating on forest land 142 permanent sample plots (Table 1). In accordance with species composition the object of pilot inventory is close to Lithuanian forests, except a somewhat greater prevalence of black alder stands. In the object of pilot inventory pine (40%), black alder (20%), spruce (19%), and birch (16%) stands prevail. Other species comprise only 5%. Quite productive sites prevail in the object. Pine and spruce stands are characterized by 29 m height index, black alder – 26 m, birch stands – 25 m. A lot of overmoistured and marshy sites have been drained. Well-formed 49-year-old (pine – 56, spruce – 54, softwood deciduous – 43), stands of higher than the average stocking level (pine stands 0.8, spruce and black alder stands – 0.73, birch stands – 0.67) predominate with slightly pronounced second storey.

After elaboration of a preliminary sampling design for Lithuanian NFI, in the autumn of 1997 test measurements were made in different regions of Lithuania covering forests with possibly more diverse species composition, structure and site conditions (Table 1). In the Kaunas region 8 sample plots were measured, Telšiai – 6, Kuršėnai – 4, Varėna – 14 and Ukmergė – 19. A total of 51 sample plots were measured, quite sufficiently representing stands of different species composition, age, stocking level and site conditions (Table 1).

Table 1. Distribution of study sample plots (PI – pilot inventory object, LT – rest region of Lithuania)

Methods

Edge length of the tracts was studied within 125 - 400 m range. In each of squares of 10 2x2 km in size on the digital map of the Biržai forest enterprise forests plots of 500 m^2 were allocated by using 125, 250 and 400 m network. In each case the occurrence of plots of the same tract on the same site was recorded.

In ten squares of 25x25 km in size allocated on the Lithuanian territory all section lines were identified, their starting, intersection with other linear objects or turning points were ascertained. For each segment the direction and length were estimated. To assess the direction, all section lines were divided into 2 groups: oriented towards NS and EW direction. In order to ascertain distribution regularities of other linear objects, in each square the largest forest tract was selected. Its centre was crossed by two perpendicular lines directed towards NS and EW, the distances between crossing the lines routes, roads, ditches and streams were determined. The mean distances among linear objects, their standard deviations were calculated for each tract separately and then for the whole Lithuania.

In the experimental Kazlų Rūda object evenly on the whole area every 1000 m square tracts of 400x400 m have been allocated. On each edge every 200 m one main permanent and one auxiliary – temporal plot have been singled out. In permanent plots of 400 m^2 in size all trees more than 10 cm in diameter in them have been measured. Trees with less than 10 cm in diameter have been measured in plots of 100 m^2. Measurements have been made using compass, 50 m measuring tape, ultrasound distance measurer to estimate the distance to the tree at 1 cm accuracy; Swedish calliper to measure the diameter at 1 mm accuracy and Silva heightmeter to measure the height at 0.5 m accuracy.

During test measurements in other regions of Lithuania the area of plots was enlarged up to 500 m^2. Trees with 14 cm in diameter and thinner ones were measured in plots of 100 m^2. In accordance with unified methods of dendrometric estimation (Kuliešis, 1989) in plots of any size the volume of trees and other parameters were estimated. For a group of i-size plots the variance of tree volume was estimated.

$$V_{Mi} = \frac{\delta_{Vi}}{M_i} \cdot 100\%, \tag{1}$$

where:

δ_{vi} - standard deviation of tree volume,

$$\delta_{vi} = \sqrt{\frac{\sum\left(M_{ij} - \overline{M_i}\right)^2}{n_i}}, \tag{2}$$

M_{ij} - volume of trees in plots j,
$\overline{M_i}$ - the mean volume of trees of i-size plot group,
n_i - number of plots of size i

Photography of operation time allows us to estimate time input for various measurement operations. Total time consumption to inventory an object at chosen accuracy by using i-size plots

$$L_i = n_i \cdot l_i, \tag{3}$$

where:

l_i - time input to find and measure one i-size plot,
n_i - number of i-size plots.

$$n_i = \frac{V_{Mi}^2}{P^2} \cdot t^2, \tag{4}$$

P - accuracy of object inventory,
t - Students statistic value.

Plot size requiring least time input for inventory at settled accuracy is held optimal.

Results

Optimizing size and structure of a tract and sample plot, division of forests into sites, their size, location, direction of linear objects, distribution regularity, time and labour expenses to measure and reach plots of different size, as well as volume variance in sample plots were estimated.

Tract edge length

The average stand compartment size in Lithuanian forests is nearly 2 ha. Having square sites with insignificant changes in their size it would suffice to allocate plots every 140 m and thus ensure falling of each plot into a different site. As far as stand compartments are changing in their size and form, the distance of plots allocation was studied in a wider range – from 125 to 400 m in length. Plots on the border of two and more different compartments are divided into two or more sectors. Plots situated inside the compartment are complete, i.e. without sectors.

Variation in the number of plots per site measured by standard deviation from the average is quite stable both in a separate object (square of 2x2 km) and whole experiment – among objects. When tract edge length is 125 m, the standard deviation of the number of plots per site from the average makes up 4% both taking the mean number of all plots with sectors and mean number of complete plots without sectors. Under edge length enlarged by 250 - 400 m, variation in the number of complete plots per site decreases up to 3-4%. The least variation in the number of plots without sectors per site comprises 1% under tract edge length of 400 m.

When tract edge length is 125 m, on average 1.34 plots without sectors of the same tract fall per one site. Under edge length enlarged up to 250 m, the number of plots per site decreases up to 1.06. In case edge length is 400 m practically every plot occurs in a different site. The number of all plots, including sectors, per site is 20 - 25% less than the number of plots without sectors falling per site. It means that every fourth plot falls on the border of two or more sites. When tract edge length is 125 m, the total number of plots, including sectors, falling per site is 1.14. Under edge length enlarged up to 250 m, the number decreases up to 0.82, while under 400 m in length the total number of plots per site decreases up to 0.75. In all cases the line of plot number variation depending on tract edge length turns at 250 m point (Fig. 1). This shows that further enlarging of tract edge length has little effect on the number of plots falling per site.

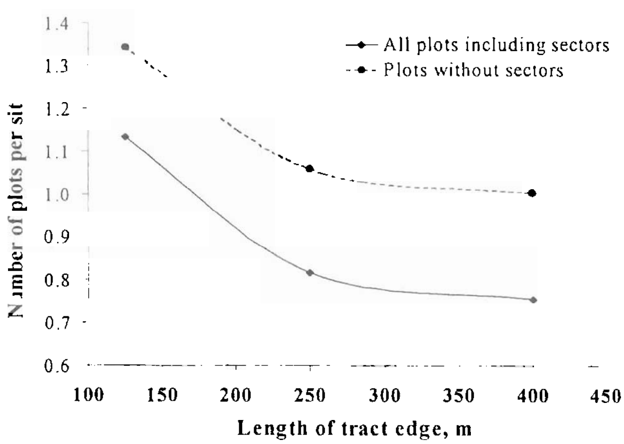

Fig. 1. Number of plots per site depending on tract

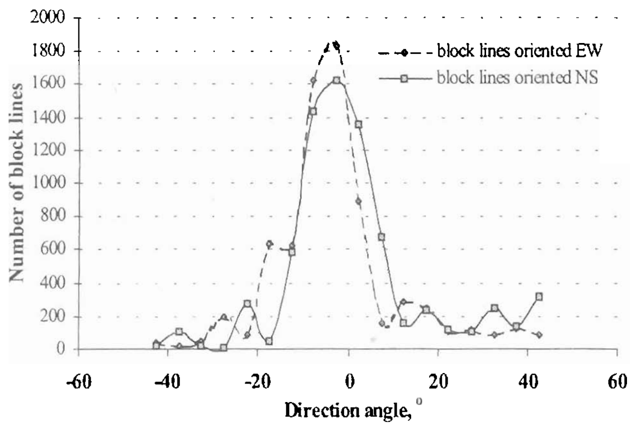

Fig. 2. Distribution of the number of block lines by the edge length size of direction angle

While carrying out state forest inventory in 1969, sample plots in a tract were allocated every 200 m, on average 1.1-1.2 plots fell per the same stand compartment (Kuliešis, 1971). In our test, after edge length had been enlarged up to 250 m, the number of plots falling per site decreased up to 1.06. Therefore, the results of our studies conducted on the forests of the Biržai forest enterprise are close to these of the inventory in 1969. This proves that the results obtained in the Biržai forest may be applied for the inventory of the whole country.

Direction of block lines

A total of almost 15 thous. lengths of block line segments were measured, half of them in NS direction and slightly less in EW direction. Most NS block lines are oriented in NW 2.1° direction, while these being perpendicular to them – in NE 88.7° direction. In each square the angle of section line direction changes from 5 to 20 degrees. Distribution of the number of lines according to the direction angle size (Fig. 2) shows, that a considerable portion of lines on both sides deviate 10-15 and more degrees from the average.

Thus, even if the general mean angle of lines direction is close to NS and EW directions, variation in direction angle is quite great in a concrete location. Variation in the direction angle of lines is great among different regions as well. Here it reaches nearly 5 degrees on both lines of NS and EW direction. The most distant from the republic's average are the angles of NS block line direction in the forests near Balbieriškis (+8.7°), Telšiai (+6.5°), Ramygala (+6.9°), Taujėnai (-5.4°), Dūkštas (-6°), Aukštadvaris (-6.1°), Eišiškės (-8.5°). In the greater part of regions studied (16 from 20) block lines of NS and EW direction are almost perpendicular to each other. In the rest regions the angle of crossing of block lines deviates 3 - 7 degrees from 90%. Great variation in the direction of block lines cannot create a situation for an increased occurrence of plots on block lines and it is quite acceptable to orientate the direction of tract lines in NS and EW directions.

Estimation of distribution regularity of linear objects

A total of 240 intervals among linear objects crossing lines in NS direction and 239 lines in EW direction drawn in the largest tract of each of 20 squares of 25x25 km were measured. The length of lines drawn in NS direction and used to check the intersection of various linear objects ranged in different squares from 3.2 to 19.1 km, while in EW direction from 1.8 to 21.8 km. The length of lines checked on both directions as well as the number of linear objects crossing them differed insignificantly. It shows that linear objects in studied regions are equally oriented both in EW and NS direction.

In objects studied section lines occur most frequently. The average distance between block lines oriented towards EW and crossing NS line is equal 634 m, while between those oriented NS and crossing EW line equals 565 m. Variation in distances between section lines in both directions comprises 47%. EW oriented ditches and streams are located every 1233 m, roads – every 1648 m. 40% of studied linear objects (roads, ditches and streams) were recorded not more than once. Great variation is characteristic of the location distances of roads and ditches. Variation in distances among EW oriented roads is 1358 m (82 %), while among streams and ditches of the same direction – 1938 m (157%). In NS direction roads are located more sparsely (1771 m), streams and ditches – more densely – every 1137 m. Variation here is less as compared to roads oriented EW and makes up 985 m (56%), while that in distances among ditches and streams is similar, as compared to EW oriented ones – 1747 m (154%).

The most frequent reiteration period of linear objects oriented in both directions is 375 m, however, quite a large number of intervals was ascertained for reiteration intervals up to 2.6 km (Fig. 3.).

Practically no essential differences in the number of linear objects directed NS and EW, in distances among them and in variation in the distances have been found. The results of this study confirm that square form of a tract is most appropriate.

The results of the study have shown a great variation in distances among linear objects in Lithuanian fo-

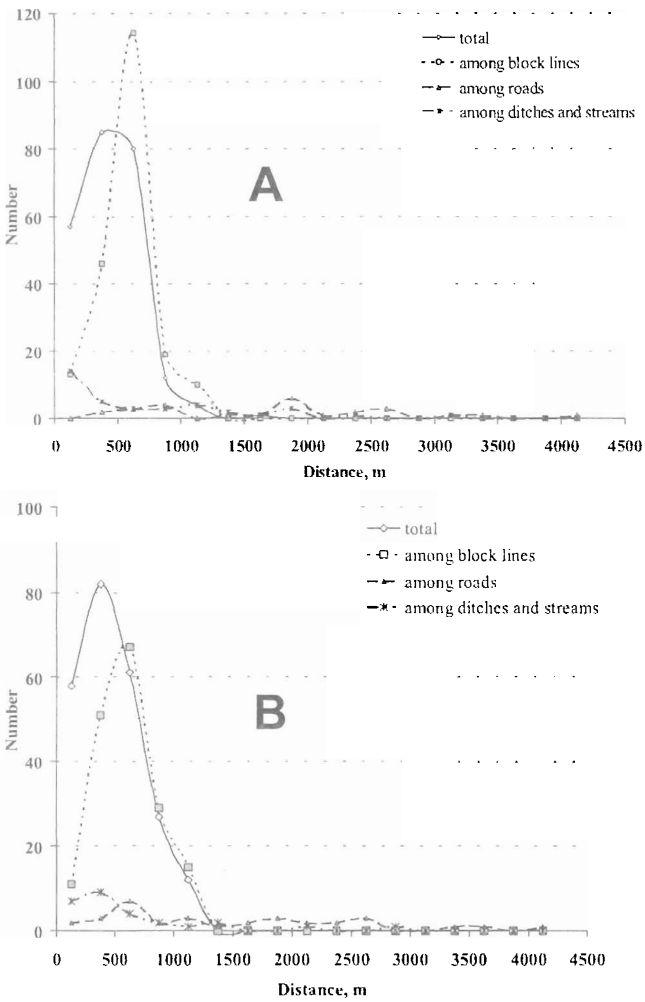

Fig. 3. Distance among linear objects crossing EW (A) and NS (B) lines

rests. Most frequent distances among linear objects are not multiples for a planned in the sampling design 250 or 400 m in length of tract sides. Most important is the fact that linear objects have no prevailing orientation, they are evenly met in NS and EW directions, and as the direction variation in block lines, the most frequently occurring linear objects, shows, it is so even in all the rest of directions.

Thus, tracts should be located according to systematic with random start network, uniform for the whole Lithuania. Individual forest tracts on the territory of Lithuania are located quite randomly. The direction of block lines and other linear objects and distances among them are projected in each forest tract independing of each other. All this preconditions that a uniform systematic location of tracts on the entire territory of Lithuania will represent the whole diversity of forest and forest lands as well as its categories. A very pronounced variation in the direction and distribution frequency of linear objects requires no special conditions for the location regularity or direction of sampling units. These parameters should be ascertained in such a way that sampling units were not concentrated too much and it would be convenient to realize practically such sampling design. Distances among sample plots (250 m) were determined taking into account the average site size in Lithuanian forests. Under the absence of regular location reiteration of streams, roads, ditches, it is practically most convenient to allocate sampling units on the edges of a square oriented in NS – EW directions.

Dependence of tree volume variance on plot size and stand peculiarities

Tree volume variance dependence on tree species, age, stocking level and site productivity was compared according to plots measured in the Kazlų Rūda forests with the measurements made in the forests of other Lithuania's regions (Fig. 4).

In the Kazlų Rūda forests the least volume variance is characteristic of pine and black alder stands, then follow spruce, birch and other broad-leaved stands while analysing volume variance in different regions of Lithuania i.e. under different conditions, less volume variance in pine and broad-leaved stands may be explained by insufficient number of plots (Table 1) and insufficient representation of diversity.

The greatest volume variance (coefficient of variation over 100%) is peculiar to stands aged 20 years. With increasing age variation in tree volume decreases in the Kazlų Rūda forests constantly, while in the whole Lithuania only up to 60 years of age. Stands aged up to 60 years are less affected by irregular thinning, windbreaks and other factors having negative impact on stand structure, and, growing intensively they smooth down the consequences of this impact. Later stand structure starts worsening irreversibly, thus, volume variation increases.

With increasing stand stocking level from 0.25 to 0.65 volume variation decreases 2-3 times. In stands with greater than 0.65 stocking level volume variation stabilizes. In stands of the Kazlų Rūda forests with greater than 0.95 stocking level the variation in volume increases due to accidental and unforeseen formation of gaps in them. This shows that the most stable spatial structures are stands with 0.7-0.9 stocking level. Volume variation here is within 30 - 40% range. While grouping stands by stocking level it is possible to decrease the dependence

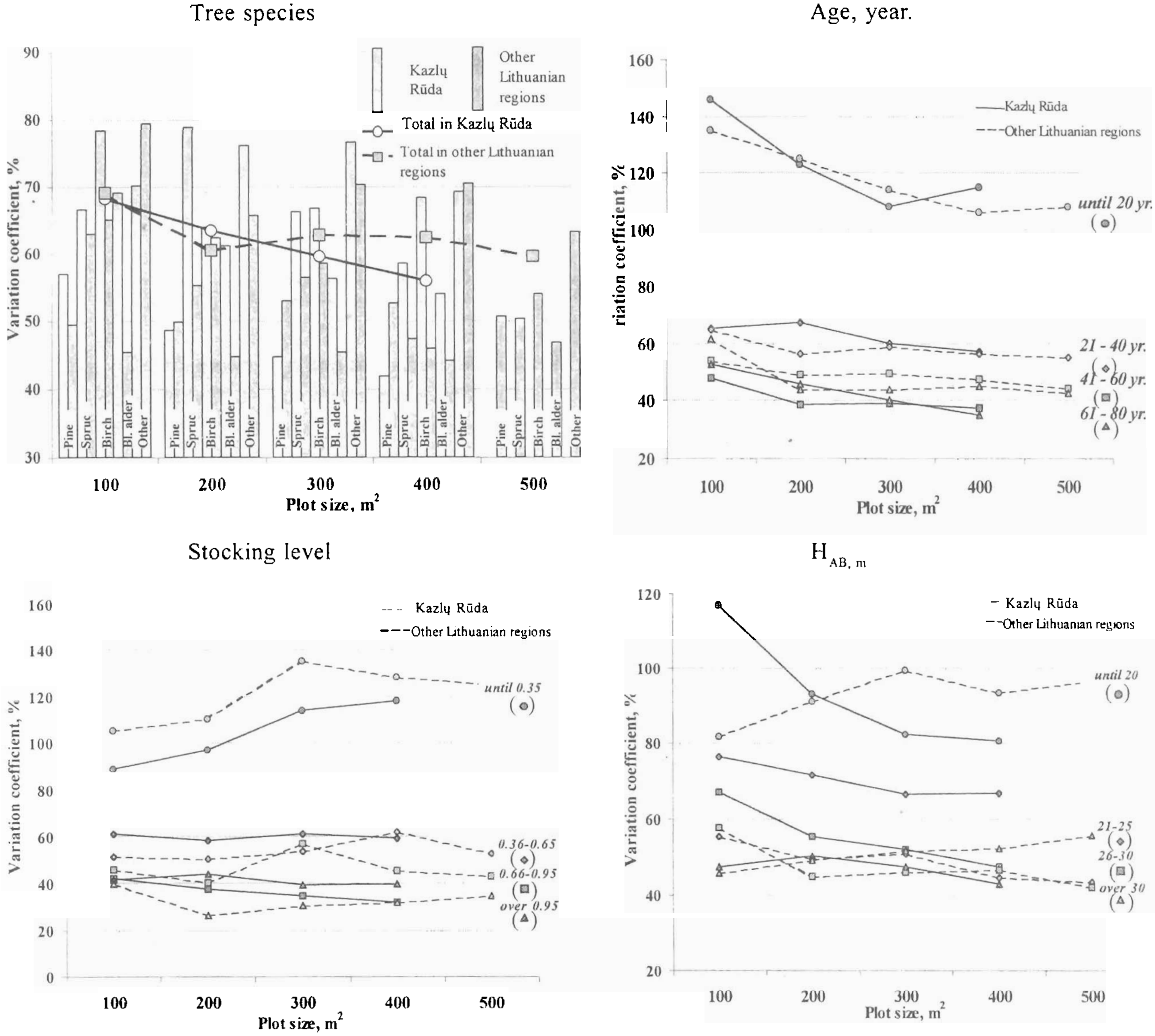

Fig. 4. Dependence of tree volume (I + II storey) variation on tree species, age stocking level, site productivity index in Kazlų Rūda and other Lithuanian forests

of variation in tree volume on sample plot size. In groups of stands homogeneous according to stocking level the impact of plot size on volume variation is minimal. On plot area increasing from 100 to 500 m² the coefficient of volume variation on average decreases 2-5%, while in stands with 0.3 stocking level even increases 25-30%.

The highest volume variation is observed on sites of low productivity. It is the consequence of greater site fertility variation. With increasing site productivity volume variation decreases, whilest in very productive sites of Lithuanian forests it starts increasing. This is the result of the most uneven and insufficient utilization of productive sites.

Volume variation tendencies depending on plot size in Kazlų Rūda and other Lithuanian forests are very similar (Fig. 4). The coefficient of variation in the Kazlų Rūda forests on plots of 300-400 m² in size is 3 - 5% less as compared to that of volume variation in other Lithuanian forests. It demonstrates that only bigger plots may reliably reveal volume variation and diversity of stand structure in a region. Overall tree volume variation in Lithuanian forests is greater than the variation in forests of an individual region.

Different authors (F.Freese, 1961) quite often point out that the ratio of squares of coefficient of variation in plots of differing area is adversely proportional to the square root of their area ratio. In Lithuanian forests this peculiarity is expressed in a quite weaker way. If plot area increases 5 times, the ratio of squares coefficients of volume variation decreases 1.4 times instead of foreseen 2.2 times. Tree volume variation in Lithuanian forests differs very slightly in plots of 100 and 200 m^2. With increasing plot area from 400 to 500 m^2 volume variation in spruce and birch stands fails to decrease, sometimes even increases (Fig. 4). In stand groups with equal stocking level as well as in stands growing on sites of the same productivity volume variation is practically independant on plot size. In stands of low stocking level it is vice versa – volume variation increases with increasing plot size. These peculiarities show, that the specific structure of Lithuanian forests, which especially in recent years have been forming under unfavourable factors: wind, drought, pests, being characterized by high volume variation, (50 – 80%) require special attention during inventory.

Time input

General time input may be divided into 2 parts: tract and plot. Tract input comprises time expenses for driving to the tract, finding it, marking in nature and registering on maps and schemes. Plot input comprise direct measurements in the plot and walking among plots.

Estimation of time input per tract

Time input per tract depends on the average distance between the tract and campsite of the working group as well as distances among tracts. In Kazlų Rūda experimental object tracts were on average 7.4 km away from the object (Kuliešis, 1996, Kasperavičius, 1997). Travelling to the tract took on average 17.4 min. With different distance from the campsite to the tract changes the time required to travel 1 km. In case the distance is greater than 10 km the mean speed of driving car (Niva) approaches 30 km/h. For the sake of convenience campsites of working groups are situated in the centres of forest enterprises or regions. Given possible number of campsites (40 – 45), difficulties arise in researching tract directly. The mean way from campsite to tract in Lithuania was estimated 30 km, while the way between two adjacent tracts – 23 km. Therefore, time input necessary to reach tracts in Lithuanian forest will essentially differ from that required in the Kazlų Rūda forests due to increasing distance. Other expenses remain constant (Table 2).

Table 2. Comparison of time input required to find and measure tract in Kazlų Rūda and other Lithuanian forests (3 surveyors)

No.	Operation	Time input per tract, min.	
		Kazlų Rūda	Lithuania
1.1	Preparation for work	13.4	13.4
1.2	Driving to the tract	17.4	60.0
1.3	Preparation for survey	7.3	7.3
1.4	Finding the tract	6.4	6.4
1.5	Control of adequacy starting and finishing points at tract	6.4	6.4
1.6	Return to the car	10.2	10.2
	Total	61.1	103.7

Of 392 tracts planned to measure annually in Lithuania 81 (21%) has one sample plot, 78 (20%)-2, 59 (15%)-3 sample plots and only 175 (44%) are complete, i. e. have 4 sample plots. It is obvious that not less than 2 objects will have to be measured per day, thus, it is urgent to estimate time required for driving between two tracts. Taking into account the distance between tracts (23 km) and the contents of operations (remains unnecessary preparation for the workday), the duration of 76.3 min. was estimated to drive from one tract to another and to find it.

Estimation of time input per plot

Time input in permanent plots was estimated separately for Kazlų Rūda and other Lithuanian forests (Table 3).

Table 3. Comparison of time input required to single out and measure sample plot (400 m^2 in Kazlų Rūda and 500 m^2 in other Lithuanian forests (3 surveyors)

No.	Operation	Time input per plot, min.	
		Kazlų Rūda	Lithuania
2.1	Walking	10.6	8.0
2.2	Marking of the centre	4.9	3.7
2.3	Delimitation of circular plot and measurement of tree diameters	20.5	19.1
2.4	Sampling of trees in angle count plots	9.5	5.0
2.5	Measurement of tree heights	6.9	6.9
2.6	Measurement of tree age and increment	6.8	6.8
2.7	Description of soil, site	3.2	2.5
2.8	Counting and description of underbrush and undergrowth	4.0	2.8
2.9	Filling in the card	8.4	6.3
2.10	Finishing	2.4	3.2
	Total	77.2	64.3

Time variance of most operations per plot, expressed by the coefficient of variation is found to be 55-60%, its sampling error estimated 7-10%. In accordance with estimated time consumption to perform different operations, the structure of time input to measure sample plot was elaborated. Time input to measure sample plot with the aid of three surveyors in the Kazlų Rūda forests comprises 77.2 min., in other Lithuanian forests – 64.3

min. A decrease in time input by almost 20% may be explained by reduced volume of measurements in Lithuanian forests. Instead of allocating 3 angle count plots in the Kazlų Rūda forests in other forests of Lithuania tžo angle count plots have been allotted. The area of a circular plot in Lithuanian forests was enlarged up to 500 m², but the number of measurable trees was reduced by increasing their diameter from 10 to 14 cm.. After experience had been gained and skills acquired, the organizational work, walking from one plot to another (mean walking speed 1875 m/h), marking the centre of a plot, describing soil, underbrush, filling in the card, etc. were improved.

Most measurement operations are independent of plot size. Only tree diameter measurement in circular plots, tree height measurements in circular and on angle count plots as well as tree age and increment measurement on them depend on plot size. Taking into account time input necessary to measure one tree diameter, height, age increment (Kuliešis, 1996, Kasperavičius, 1997), as well as the dependance of the number of trees on their number per plot, time input required to carry out these operations in plots of differing size was estimated (Table 4)

Table 4. Time input required to measure plot depending on its size (3 surveyors)

No	Operation	Plot size, m² — Kazlų Rūda / Lithuania; Time, min: 100	200	300	400	500
2.3	Allocation of circular plot and tree diameter measurement	14.2 / 11.3	16.6 / 13.7	18.7 / 15.8	20.5 / 17.6	— / 19.1
2.5	Tree height measurement	5.9 / 4.5	6.2 / 5.1	6.6 / 5.7	6.9 / 6.3	— / 6.9
2.6	Tree age and increment measurement	5.7 / 4.8	6.1 / 5.3	6.4 / 5.8	6.8 / 6.3	— / 6.8
	Total	25.8 / 20.6	28.9 / 24.1	31.7 / 27.3	34.2 / 30.2	— / 32.8

Bearing in mind that the number of angle count plots is reduced up to two, greater diameter (14 cm) of measurable trees in plot of 500 m², in Lithuanian forests has been estimated 4 % less time input as compared to analogous input in the Kazlų Rūda forests.

Plot size optimization

To estimate optimal plot size in Lithuanian forests, volume variance per plot has been simulated (Table 5). It has been found, that the coefficient of volume variation decreases from 68 to 58 % while plot size increases 5 times – from 100 to 500 m².

Table 5. Estimation of time input to detrmine volume per object at the 5 % accuracy

Characteristics	Plot size, m²: 100	200	300	400	500
Coefficient of variation per plot, %	68.2	64.2	61.2	59.2	58.0
Number of plots to estimate volume at 5 % sampling error	186	165	150	140	135
Time input per plot, min	52.1	55.6	58.8	61.7	64.3
Time input for walking per plot, min	25.9	25.9	25.9	25.9	25.9
Time input for measurement and driving per plot, min	78.0	81.5	84.7	87.6	90.2
Total time input to inventory object					
in plots without walking and driving	9691	9174	8820	8638	8680
in plots, including walking and driving	14508	13448	12705	12264	12177

In accordance with the coefficient of tree volume variation the number of plots needed to estimate the volume in an object was calculated at the 5 % accuracy. To obtain the same accuracy per object, it is necessary to have almost by 38 % less plots of 500 m² as compared to the number of plots of 100 m². Time input required to measure plots of different size was ascertained. With greater size of plots from 100 to 500 m² time input increases almost by 20 % (Fig. 5, B). By including driving time falling per plot, time input increases only by 13 % while plot size increases even by 5 times. This accounts for the fact that most time consuming operations (driving, walking, determination of general plot characteristics) are independent of plot size. Including only work in the plot, the least time input was obtained in the whole object by using plots of 400-500 m² in size (Table 5, Fig. 5, C), while together with driving – minimal time input results from using plots of 500 m². By using plots of 500 m², as compared to these of 100 m², time input approximately is reduced 12 %, while including walking and driving – more than by 19 %, i. e. rather significantly.

In Lithuanian forests, taking into consideration their configuration diversity, incomplete tracts will be allocated as well. A considerable part will be singled out individually (7 %), in pairs (14 %) and in three (16 %) plots. Thus, after optimal plot size, optimal construction of complete tract had been estimated, it was important to estimate time input required to measure tracts of varying size, driving to the tract, driving from one tract to another, i. e. excluding time of preparation for the work (Table 6).

While analysing time input required to measure tracts of different size it has been found, that one day is enough to measure tract of any size together with preparation and measurement of additional tract with missing plots up to 5. By measuring tracts with 1 plot, only 3-4 plots can be measured per day. Thus, in allocating plots individually time input should be raised 50 %. By measuring tracts with 2 plots it is possible to measure 4 plots per day. Due to application of this sampling design in all Lithuanian forests, time input would increase 25 %.

Table 6. Estimation of time input to define volume in an object at 5 % accuracy

Time input	Number of plots per tract			
	1	2	3	4
	Number of plots per object, %			
	7	14	16	63
	Time input, min.			
Preparation for work	13.4	13.4	13.4	13.4
Driving to tract and finding it	90.3	90.3	90.3	90.3
Driving from one tract to another and finding it	76.3	76.3	76.3	76.3
Walking among plots	4.0	12.0	20.0	32.0
Measurements within plots	56.3	112.6	168.9	225.2
Total per tract				
- with preparation for the day	164.0	228.3	292.6	360.9
- with driving from one tract to another	136.6	200.9	265.2	333.5
Portion of time input per plot within total expenses, %				
- with preparation for work	34	49	58	62
- with driving from one tract to another	41	56	64	67

Work in the plot when measuring complete tracts and driving from the campsite constitutes 62 %, while driving from tract to tract – time input per plot increases up to 67 % of the whole time. While working in tracts with one plot, measurements in plot would comprise 34 and 41 % of the time respectively, and the rest of time would be taken by driving. Having in mind, that on average per day 2 tracts with 2 – 3 or 1 and 4 plots would be measured, time input per working day is distributed in the following way: 50 – 60 % for measurement of the plot and 40 – 50 % for driving and walking between the tracts and plots. During remeasurement time consumption within plot will decrease, and the ratio of driving to walking as well as work in the plot will approximate each other.

The analysed sampling design, thus, is optimized in respect of an individual plot measurement, its structure and grouping. Sample plot of 500 m² is optimal taking into account time input required to do the work in a plot, walking among plots and driving among groups of plots. After B. Zeide's, 1980 the optimum criteria are: "time input for plot measurement and for driving, as well as walking in an optimal sampling design must be equal, our sampling design is also close to optimal.

Sampling design has been optimized also in respect of tract size. Maximal number of plots per tract is 4, it ranges from 1 to 4, on average in Lithuania being equal to 2. 8. Each plot grouped in this way has a probability to enter a different stand compartment or site. In the Biržai experimental object in case division of plots into sectors is included the average occurrence of one plot per 1. 22 site has been ascertained.

Most frequent linear objects (streams, ditches, roads, block lines), being able to affect forest formation on a regular wave principle, are located irregularly. Variation in their direction and reiteration frequency often exceed 100 %. By applying systematic sampling design with random start, it allows us to avoid possible natural and artificially created consequences of forest changes.

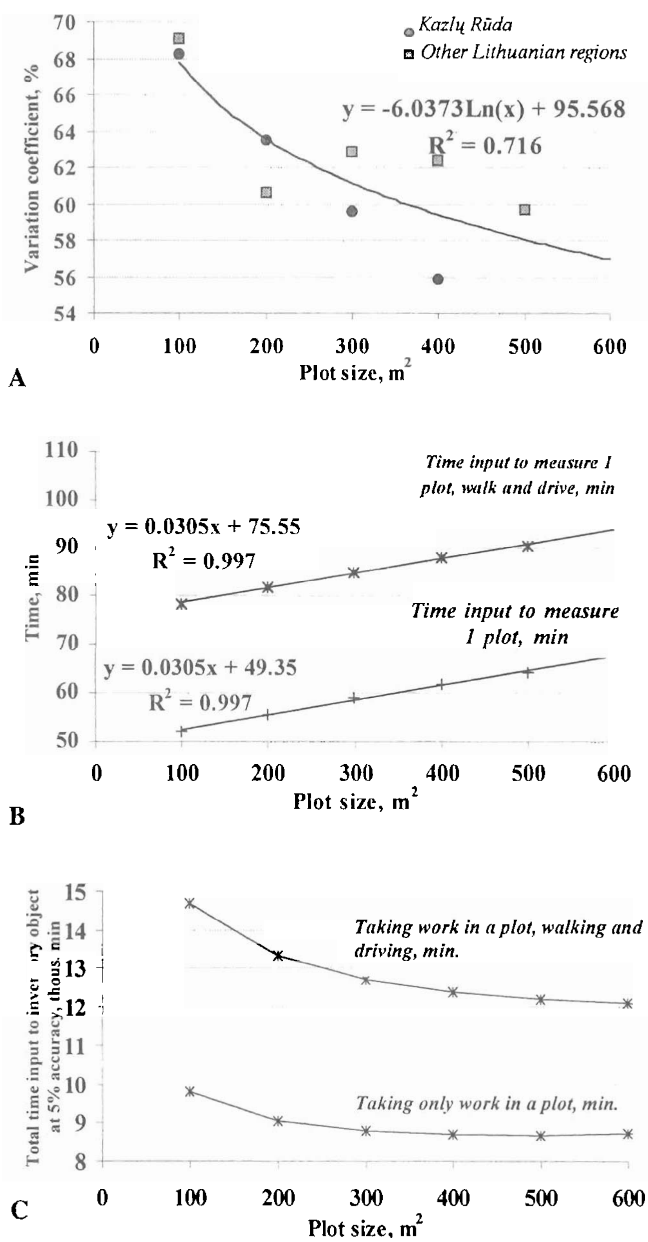

Fig. 5. Optimization of plot size
A – dependence of tree volume variance on plot size;
B – dependence of time input to measure plot on plot size
C – dependence of time input to inventory object on plot size

Conclusions

1. Studies of tree volume variance resulted in optimizing, time input to measure plots and reach them, as well as the structure of forests in respect of stand size, distribution of linear objects and their location, the size

and structure of sampling units for Lithuanian forest inventory.

2. The average size of Lithuanian forest stand compartment is 2 ha. After allocation of plots in groups every 250 m, a sufficiently high representativeness of sampling scheme and occurrence of each plot on a different (on average 0.82 of a plot or its sector fall per one site) site is ensured.

3. Linear objects (rivers, streams, ditches, roads, block lines) being able to affect the formation of forest location on a regular wave principle vary both in their direction and duration of reiteration period.

4. The most acceptable in respect of time input, its structure, optimization of work, stand compartment size, form direction of linear objects and regularity is a square tract with 250 m long edges oriented in NS, EW directions with evenly distributed sample plots in it.

5. The least tree volume variability in plots is observed in pine stands, in all 50 – 70 – year old stands with 0.7 – 0.9 stocking level and average yield sites (H_{AB} = 25 – 30 m).

6. The coefficient of tree volume variation decreases 20 % and more under enlarged plot size by 5 times (from 100 to 500 m^2). The coefficient of volume variation in the Kazlų Rūda forests is 3 – 5 % less, as compared to that of volume variation in other Lithuanian forests. In groups of stands homogeneous according to the stocking level, age, site yield the variation in volume slightly depends on plot size.

7. In order to minimize time input per object sampling units have been optimally constructed. They consists of circular plots of 500 m^2 for measurement of trees with more than 14 cm in diameter, circular plots of 100 m^2 for measurement of trees with more than 6 cm in diameter and these of 25 m^2 for trees with more than 2 cm and for planted trees of different diameters. Also 2 plots of angle count have been set up for estimating stand parameters.

8. Optimized construction of national forest inventory sampling units ensures the ratio 55 : 45 of time input for work within plot and driving among plots and their groups, as well as allocation of 5 permanent sampling plots during working day by a field team consisting of 3 surveyors.

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Received 15 July 1998

ОПТИМИЗАЦИЯ ПАРАМЕТРОВ ВЫБОРОЧНЫХ ЕДИНИЦ УЧЕТА ДЛЯ НАЦИОНАЛЬНОЙ ЛЕСОИНВЕНТАРИЗАЦИИ ЛИТВЫ

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Резюме

Изучена изменчивость запаса древесины в древостоях разных пород и определены затраты на закладку учётных площадок различной велечины. Путём минимизации затрат на объект инвентаризации установлена оптимальная величина площадки 500 м^2. Для постоянного наблюдения в лесу определена комплексная учётная единица в составе круговых площадок 500 м^2 для деревьев толще 14 см, 100 м^2 – толще 6 см, 25 м^2 – толще 2 см или всех деревьев культурного происхождения. Учёт подроста, подлеска и лесовозобновления ведётся на ленте 60 м^2. Средние характеристики древостоев, возраст и прирост деревьев при первом обмере орпеделяется на двух угловых площадках.

В результате анализа соотношения затрат на сообщение (переезды и переходы) между площадками и измерение деревьев на площадке определена целесообразность их группирования по 4 площадки в одной группе (тракте). С целью повышения репрезентативности схемы выборки путём снижения вероятности попадания более одной площадки в тот же выдел до минимума и с учётом средней величины выдела, его конфигурации, в лесах Литвы определена длина стороны тракта 250 м. Установлено отсутствие регулярности размещения линейных объектов: квартальных просек, каналов, рек, способных исказить оценку лесных ресурсов при регулярном размещении единиц учёта. Этим была обосновано систематическая со случайным началом размещение группы площадок – трактов, с ориентацией их сторон на север-юг, запад-восток.

Ключевые слова: площадка, оптимизация, затраты, группирование, изменчивость, тракт, регулярность.