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Inventory of plant material in forest nurseries by combining an ocular estimate and sampling measurements

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ABSTRACT: Two procedures of the plant material inventories in forest nurseries, used until now, are evaluated: ocular estimate and sampling. A new two-phase sampling procedure has been proposed on the basis of a suitable combination of estimation and counting and/or measurement of seedlings and plants. The optimum size of the sampling unit (length of bed segment) has been defined. The necessary number of bed segments on which the ocular estimation should be performed in the first phase (n_1), and subsequently a more exact assessment of the number of individuals and/or their other qualitative and quantitative traits should be done in the second phase (n_2), to achieve the required precision of results of ± 2 to 10% with reliability of 95%. A theoretical justification of the proposal as well as a detailed procedure of the accomplishment is presented. The frames have been specified where the proposed method is economically twice as beneficial as the classic sampling method.

Keywords: forest nurseries; plant material inventory; two-phase sampling method; combination of ocular estimate and exact assessment

PROBLEM

In forest nurseries in Slovakia and similarly in other countries, where the nursery stock is cultivated intensively, some ten million seedlings and plants of various tree species are produced annually representing a great material and financial value. It is therefore quite natural that the subjects providing and controlling this production are not only obliged to estimate both the quantity and the quality of the cultivated nursery stock as objectively as possible but also they are interested in this process. Both these characteristics show a relatively high variability depending on many factors, such as local conditions of nurseries, quality of the seed used, cultivation technique, kind and age of the cultivated nursery stock, weather conditions, occurrence of noxious agents, etc. Obviously, forest nurseries produce a great number of seedlings and plants and therefore the whole-area inventory of the nursery stock (e.g. counting, height measurement, assessment of the health state of all individuals in a nursery) would not be economically feasible. Due to this fact, the two following methods can be considered: qualified estimation or an appropriate sampling method.

The present paper gives an evaluation of the status quo and practical application of the two above-mentioned methods of the nursery stock inventory in Slovakia and in the neighbouring countries and proposes a new method based on the combination of an ocular estimate and sampling procedure. Presented results were obtained from the solution of VEGA1/7056/20 Research project.

EXPERIMENTAL MATERIAL

The experimental material comes from experimental plots of the Drakšiar forest nursery, forest office Beňuš. They were established in such a way that would make it possible to follow all the basic aspects of the nursery stock inventory in more variants. The research material includes 10 categories of seedlings and plants: spruce: 1+0, 2+0, 1+1, 1+2, 1+3, 2+/2, larch: 1+0, 2+0, beech: 1+0, 2+0. Seed beds from 100 to 300 m in length were chosen for each category. A wooden frame with the inner dimensions of 146 cm (= seed bed width) × 100 cm was made for the proper estimation. The shorter side was divided into four 25 cm-long segments by means of the wire. The frame was continuously placed along the whole seed bed and within each of the 25 cm-long segments, the numbers of plants by counting and estimate as well as the mean plant heights by measuring and estimate were determined. The time needed for individual performances was recorded (in min). This data base representing the basic set for each investigated category of plant material was the basis to create new data for the seed-bed segments of different lengths (25, 50, 75, ... 175, 200 cm) and repeated sampling of a smaller amount of segments in different combinations was performed. In this way, the investigation became more effective and objective because the difference between the sampling procedure and the ocular estimate compared with the correct value could be unambiguously determined for the whole seed bed even for more investigated alternatives.

EVALUATION OF CURRENTLY USED INVENTORY METHODS

OCULAR ESTIMATE

This is the oldest and currently the most frequently used method (Guidelines of the Ministry of Forestry and Water Management from 1975; KANTOR et al. 1975). At several places of a forest nursery the number of individuals is estimated per running metre of the seed bed and the result is calculated for the entire area (length) of the seed bed. Other traits of the nursery stock are estimated similarly, e.g. quality class, percentage of damage, etc. Such ocular estimate is very fast and cheap but it can considerably be loaded by the estimator's subjective influence. The magnitude of the estimation error is not known and it has not been studied either in our country or abroad. The first results concerning the accuracy of the ocular estimate were obtained from the evaluation of our experimental material. It has been shown that even after a very qualified estimation (for research purposes), the negative systematic errors prevail and represent –2.55% in the case of the number of plants and –1.55% as for the height of plants. In current practice, they can be much greater. This problem is dealt with in greater detail in the paper by ŠMELKOVÁ (1998).

SAMPLING METHOD

It belongs to newer and more objective procedures based on the principle of mathematical statistics. From the results obtained from a small number of samples, the conclusions can be drawn for the whole forest nursery. A part of the seed bed, e.g. one metre of seed bed or an area of 1 m^2, is chosen as a sample or a sampling unit. These are then evenly distributed over all seed beds. In each of the units, the respective value of the determined variable is found, e.g. $y_1, y_2, \dots y_n$ (number of plants, mean height of plants) and the sample arithmetic mean is calculated.

$$\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n} \qquad (1)$$

It is then used to determine the number of plants Y, or the mean height of plants $\bar{Y}$ of all the nursery stock of a given category in a forest nursery according to the following relations:

$$Y = \bar{y} \cdot N \pm \Delta Y \qquad (2)$$

$$\bar{Y} = \bar{y} \pm \Delta \bar{Y} \qquad (3)$$

where N is number of all possible sampling units, i.e. the entire length in running metres or area in m^2 of the respective inventoried seed beds. ΔY or $\Delta \bar{Y}$ is sampling error and defines the range the real difference between the sample result and the correct one does not exceed with 95%-probability. It is calculated according to the following formulas:

$$\Delta Y = 2\frac{s_y}{\sqrt{n}} \cdot N \quad \text{and/or} \quad \Delta \bar{Y} = 2\frac{s_y}{\sqrt{n}} \qquad (4)$$

where

$$s_y = \sqrt{\frac{\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2}{n-1}} = \sqrt{\frac{\sum_{i=1}^{n} y_i^2 - \bar{y}\sum_{i=1}^{n} y_i}{n-1}}$$

is standard deviation of sample values y_i (absolute variability rate) and n is number of all samples. In case that s_y in formula (4) is substituted by the coefficient of variation $s_y\% = (s_y / \bar{y})$. 100, the relative error $\Delta Y\%$ or $\Delta \bar{Y}\%$ is obtained in percent.

Compared with ocular estimate, the described sampling method is more professional and time-consuming; nevertheless, it has the advantage of being more representative (objective); furthermore, the confidence interval can be added to the obtained result and if the required accuracy is given before, the range of sampling estimation can be planned so that the total inventory will be carried out with the minimum cost.

The sampling principles of the plant material inventory were elaborated in detail in Germany (SCHUBERT, HOLLENDER 1986; SCHUBERT 1987). In the Czech Republic, some original suggestions resulted in a standardized methodical instruction for the application in practice (NOVOTNÝ 1965; PÁV et al. 1990; PÁV 1991). In Poland, SOBCZAK et al. (1992) contributed to the problem solution. However, all currently used sampling procedures suffer from some methodical drawbacks as they are based on general data on the nursery stock variability and the sampling estimation in a nursery is aimed at just one sampling unit size – 1 running metre, 1 m^2 or even at a seed bed of 2 running metres (in Germany).

The experience from our experiments enables to apply a much more varied approach to planning and carrying out the sampling inventory with regard to particular conditions in a forest nursery. It has been shown that instead of the sampling unit (1 running metre, 1 m^2) recommended until now, it is much more advantageous to use a smaller sampling unit – a seed bed block d = 25 cm; for seedlings with a high density of individuals only one half or one quarter of that block. Such a unit seems to be optimal from the point of view of accuracy and economy of estimation. This is also proved by the data in Table 1.

Determination of the number of spruce plants and larch seedlings with the required accuracy $E\% = \pm 5\%$ and reliability $P = 95\%$ is carried out on the chosen short units d = 25 cm in length with a higher number of sampling units on the one hand, but considerably lower total costs than it is with 100 cm-long sampling units on the other

Table 1. The effect of bed segment of different length (a = 25 cm, b = 100 cm) on primary parameters of sampling determination of the number of plants and seedlings with requested precision $E = \pm 5\%$

Plant material	Number of individuals $\bar{y}$		Variation coefficient $s_y\%$		Required sample size n		Time cost T		Indexes a:b for:			
	a	b	a	b	a	b	a	b	$\bar{y}$	$s_y\%$	n	T
Plants spruce 1+3	25	98	17	12	46	24	30	58	0.25	1.42	1.91	0.52
Seedlings larch 1+1	117	524	36	34	207	185	590	2,198	0.22	1.06	1.12	0.27

hand. Corresponding rates of relative variability were derived for sampling units defined in this way – coefficients of variation $s_y\%$ of the number and mean heights of plants and seedlings. It has been found that the $s_y\%$ values range within a considerably great interval from 10% to 45% and they can be relatively easily determined before the estimation beginning for every forest nursery and category of plant material by means of the ocular judgement of the density and height variability of the individuals on the seed bed area. In general, the coefficient of variation of plant number is lower (15–20%) than that of seedlings (30–40%) and the variability of mean heights between the seed bed blocks is approximately 1/3 of the variability of the number of individuals. The range of the sampling estimation depends on the variability of plant material. This is the reason why Table 2 gives numbers of seed bed blocks n (with a length of $d = 25$ cm) to the expected mean values $s_y\%$. The seed bed blocks must be chosen so that the sampling result with the error not exceeding the confidence limit of $E\% = 95\%$ will be reached. The obtained knowledge is recorded in greater detail and verified in practical applications in the papers by ŠMELKOVÁ (1996, 1997).

Table 2. Required sample size (n) for different accuracy of plant and seedling number and the average height estimates at a reliability of 95% and expected variation coefficient ($s_y\%$) of the inventoried plant material

$s_y\%$	n for $E\%$			
	± 2%	± 5%	± 10%	± 15%
5	27	10	–	–
10	100	18	10	–
15	225	37	12	–
20	400	64	18	10
25	625	100	27	14
30	900	138	37	18
35	1,225	188	49	24
40	1,600	246	64	30

PROPOSAL OF A NEW METHOD BASED ON THE COMBINATION OF OCULAR ESTIMATE AND CONTROL MEASUREMENT

BASIC PRINCIPLE OF THE METHOD

This method is based on a new principle of the two-phase sample survey recently applied more frequently with great advantages in forestry, e.g. in forest inventory, terrestrial surveying and where a complicated variable can be determined by another one that is determined more easily and is in close correlation to the resulting variable. The theory of the method was described by DE VRIES (1986) and SHIVER and BORDERS (1996) and for the application in forestry it was elaborated in several variants by ŠMELKO (1990).

Its application to nursery stock makes it possible to simplify and economize the preceding sample survey. The whole procedure can be divided into two phases. In the first phase, the estimated variable – number of plants or their mean height – is determined on n_1 seed bed blocks by the ocular estimation from which n_1 approximate (estimated) values y_o are obtained. In the second phase, a smaller part of n_2 seed bed blocks is chosen from the n_1 seed bed blocks and the respective variable is determined out of them in a more precise way – by counting or measuring. For these n_2 blocks, the matched pairs of the plant number or their mean heights (x_o – estimated and x_M – counted or measured) are obtained. These are then used for correction (precision) of all the n_1 estimated values y_o.

The correction can be carried out in several ways. Theoretically, most appropriate would be the regression estimate by means of which the regression equation $x_M = f(x_o)$ is calculated from the n_2 data of x_o and x_M and after substitution of $\bar{y}_O$ for $\bar{x}_O$ the more precise value $\bar{Y}_{kor}$ is derived. However, the calculations are relatively complicated. The ratio estimate would be easier where the precision is reached by means of the ratio

$$R = \frac{\sum x_M}{\sum x_O} \quad \text{so that } \bar{Y}_{kor} = R \cdot \bar{y}_O.$$

There are two basic conditions, i.e. the dependence x_M and x_o must pass through the beginning of coordinates and the variability x_M should grow proportionally with the increasing values x_o which our experiments did not however confirm unambiguously. Therefore, so-called "list sampling" is recommended for our needs. Although it expects the approximate estimation of the value y_o on all population units (i.e. on all nursery seed bed blocks with a length of

d = 25 cm) and sampling n_2 with unequal probabilities, which is difficult to apply reasonably in the inventory of nursery stock, however if modified, it gives nearly the same results as the regression estimation and is much more advantageous for practical application. For the evaluation of the data y_o, x_o, x_m the following steps are required.

– For each pair n_2 of the values x_o, x_M the quotients q_i are calculated

$$q_i = \frac{x_{M(i)}}{x_{O(i)}} \qquad (5)$$

and their basic statistical characteristics (mean value $\bar{q}$, standard deviation s_q and coefficient of variation s_q%):

$$\bar{q} = \frac{\sum_{i=1}^{n} q_i}{n_2} \qquad s_q = \sqrt{\frac{\sum_{i=1}^{n_2} q_i^{\,2} - \bar{q}\sum_{i=1}^{n_2} q_i}{n_2 - 1}}$$

$$s_q\% = \frac{s_q}{\bar{q}}100 \qquad (6)$$

– The estimated n_1 values y_o are corrected according to the relation

$$\bar{Y}_{kor} = y_O \cdot \bar{q} \qquad \bar{y}_O = \frac{\sum_{i=1}^{n_1} y_{O(i)}}{n_1} \qquad (7)$$

– The sampling error of the corrected value $\bar{Y}_{kor}$ (for the reliability of 95%) is determined in percent and in absolute value

$$\Delta\bar{Y}_{kor}\% = 2 \cdot \sqrt{\frac{s_{yO}^{\,2}\%}{n_1} + \frac{s_q^{\,2}\%}{n_2}} \qquad (8a)$$

$$\Delta\bar{Y}_{kor} = \bar{Y}_{kor} \cdot \frac{\Delta\bar{Y}_{kor}\%}{100} \qquad (8b)$$

where s_y% is the coefficient of variation calculated from n_1 estimated values of $y_{O(i)}$. The other symbols are already known. The first expression under the root represents the error due to ocular estimation, the second gives the error resulting from a mutual relation between the estimated and precisely determined data x_O and x_M. The total error $\Delta\bar{Y}_{kor}$ defines the limits which the real difference of the corrected value as against to the correct unknown (however existing) value $\bar{Y}$ does not exceed with probability of 95%.

– The interval is derived within which the real total number of the given category of seedlings and plants Y or their real mean height $\bar{Y}$ is to be expected with probability of 95%.

$$Y = \left(\bar{Y}_{kor} \pm \Delta\bar{Y}_{kor}\right) \cdot \frac{D}{d} \qquad \bar{Y} = \bar{Y}_{kor} \pm \Delta\bar{Y}_{kor} \qquad (9)$$

NECESSARY INPUT DATA AND THE METHODS OF THEIR ACQUISITION

It follows from the above mentioned that before the proposed procedure is used, it is necessary to decide on the number of seed bed blocks n_1 and n_2 on which the respective variables y_o, x_o, x_M are to be estimated. This question can be answered by deriving n_1 and n_2 from equation (8a) for the modulus of precision ΔY_{kor}% of the whole survey given in advance. However, it presupposes to roughly know the expected variability of ocular estimates of the variable s_{yO}% as well as the variability of the quotient q (s_q%). Both these characteristics depend on the quality of ocular estimates. Good-quality estimates are considered those that are more stable, less variable in spite of the fact that they have a systematic deviation (at each estimation by –5%). It is only important for them to have a low variability approaching their mean value ($\bar{y}_O$) and to show the closest possible correlation with the measured values. Then the low coefficient of variation s_q% will be obtained. A systematic deviation of the estimations from the correct value is less dangerous because using the proposed method, it can easily be eliminated by correcting the estimation by means of the mean value of the quotient $\bar{q}$ (according to equation [7.]). Of course, the range of sample survey of n_1 and n_2 is determined by the expenditure on estimations and measurements to be carried out.

– All the given input variables were derived from our experimental material, the result of which were the following general findings (Table 3, Fig. 1):
– Coefficient of variation for the estimations $s_{y(O)}$% in all examined categories of nursery stock coincides well in both the number of individuals and the mean heights with the coefficient of variation for the measured data $S_{x(M)}$% and in many cases, it is even lower.
– Coefficient of variation s_q% expressing the variability of the ratio of measured and estimated values ranges from 10 to 3% and it is always lower than that of the measured values. It represents only 1/2 or 1/3 of their value.
– Correlation coefficient of the linear correlation between measured and estimated values $r_{M/O}$ is surprisingly high (0.85), proving a very close correlation approaching the ideal functional relation when r = 1.00.
– Working time (T) needed for counting plants and seedlings including the measurement of their mean heights very much depends on the number of individuals (y) on a seed bed block. It increases simultaneously with the time consumption in a curvilinear way according to the following equation:

$$T = 0.0311 \,.\, y^{0.949} \qquad (10)$$

where the correlation index of this dependence reaches the value I_{Ty} = 0.955. The time needed for estimating the plant number is on average 5 times shorter and that for estimating the seedling number approximately 10 times shorter. From the above given time consumption, a substantial part (about 80 or 90%) is devoted to determination of the number of individuals; measurement and height estimation is less time consuming because it is aimed at finding the average individual rather than all individuals in the seed bed block.

Table 3. Characteristics of the relation between the estimated and measured indications for the number and average height of plants and seedlings on bed segments *d* = 25 cm in length

Size	*n*	$\bar{q}_{M/O}$	s_Q%	$s_{y(o)}$% Estimate	$s_{y(m)}$% Sizing	$r_{M/O}$
Number of plants	40	1.024	10.1	19.3	19.0	0.828
Height of plants	40	1.014	5.2	8.2	9.0	0.785
Number of seedlings	60	1.028	6.2	23.7	24.1	0.946
Height of seedlings	60	0.979	2.4	7.1	7.0	0.917

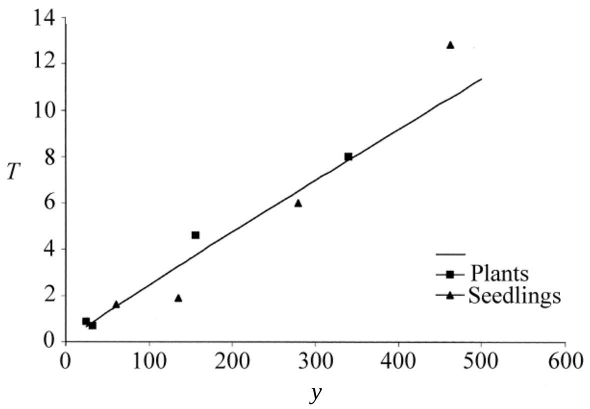

Fig. 1. Necessary time for counting the number of plants and seedlings (*T* in min) in dependence on the number of individuals (*y*) on bed segments of length *d* = 25 cm

– The required number of seed bed blocks n_1 for the first phase and n_2 for the second phase of the inventory is calculated from the acquired input data for different variability degrees s_y% of the number of plants and seedlings for different required precision *E*% of the total sampling result given in Table 4. In calculation, the data on variability $s_{y(O)}$ % and s_q%, correlation $r_{M/O}$, and on the mutual proportion of total costs *T* for estimations and measurements were considered. They were applied in formulas for planning the regression two-phase sampling but they are not presented here because of their complexity. They can be found in the paper: SHIVER and BORDERS (1996, pp. 208–209). If we compare the range of sample survey for the two-phase estimation-measuring procedure of n_1, n_2 with the one-phase procedure based kentirely on a measurement given in Table 2 of the preceding chapter, we will find that in the case of low variability of the nursery stock (s_y%) and high precision (*E%* = 2%), the total costs at two-phase procedure seem to be more unfavourable than at one-phase procedure. Therefore, in Table 4 a bold line defines the area in which the two-phase combination of estimation and measurement is more advantageous, whereas outside this area, a one-phase procedure of direct survey (without estimations) is recommended.

DIRECTIONS FOR THE APPLICATION OF THE METHOD IN PRACTICE

The method has been designed to be applied simply and unambiguously in practice. For planning the optimal procedure it is necessary to:

– Carry out the ocular estimate of nursery stock, mark off the seed beds according to the categories (species, age, plants, seedlings) and assess the variability degree (s_y%) of the number of individuals between the supposed sampling units (seed bed blocks).
– Choose the required inventory precision *E%* applying the general principle that higher precision (smaller error) should be used for rare species and a great amount of nursery stock of high quality (where even a small relative error represents the absolute great value, e.g. *E%* = ± 2% represents 20,000 individuals at one million plants) and on the contrary, lower precision will do for the lower-quality, cheaper, easily accessible material, just for random inventory.

Table 4. Required number of bed segments on which it is necessary to make both the ocular estimate (n_1) and counting, or measurement (n_2) of plant material in dependence on the expected variability (s_y%) and required precision (*E*%) of the inventory result using a combined method

s_y%	*E*% = ± 2%		*E*% = ± 5%		*E*% = ± 10%	
	n_1	n_2	n_1	n_2	n_1	n_2
10	165	80	30	15	10	5
20	660	200	105	35	30	12
30	1,770	270	285	45	70	14
40	3,150	485	505	75	125	20

Note: In cases limited rude line is combined method economic twice preferable than classic superior method

Table 5. Example of the realisation of a combined method in forest nursery. Size detecting: Y – number of Norway spruce plants (2+2), total bed length D = 300 m, expected variability $s_y\%$ = 20%, required precision E = ± 10%, selected bed element d = 25 cm, sample size for ocular estimate n_1 = 30, counting the number n_2 = 10

Segment No.	Estimate $y_{O(i)}$	Counting $x_{M(i)}$	$q_i = \frac{x_{M(i)}}{x_{O(i)}}$	Auxiliary calculation:
1	18			$n_1 = 30$
2	23	28	1.217	$\sum y_{O(i)} = 675$
3	20			$\sum y_{O(i)^2} = 15{,}549$
4	23			
5	24	27	1.125	
6	28			$\bar{y}_O = \frac{675}{30} = 22.5$
7	28			
8	28	28	1.000	$s_{y(o)} = \sqrt{\frac{15{,}546 - 22.5(675)}{30-1}} = 3.53$
9	22			
10	28			
11	19	18	0.947	$s_{y(o)}\% = \frac{3.53}{22.5} \cdot 100 = 15.7\%$
12	26			
13	26			
14	19	21	1.105	
15	16			$n_2 = 10$
16	24			$\sum q_i = 10.872$
17	22	21	0.954	$\sum q_i^{\,2} = 11.9003$
18	22			
19	21			
20	24	28	1.167	$\bar{q} = 1.0872$
21	23			
22	21			$s_q = \sqrt{\frac{11.9003 - 1.0872(10.872)}{10-1}} = 0.0944$
23	18	19	1.056	
24	20			$s_q\% = \frac{0.0944}{1.0872} \cdot 100 = 8.68\%$
25	28			
26	24	27	1.125	
27	24			
28	19			
29	17	20	1.176	
30	20			

Estimate correction and all beds generalization

$$\bar{Y}_{kor} = \bar{y}_O \cdot \bar{q} = 22.5 \cdot 1.0872 = 24.46 \text{ pcs}$$

$$\Delta\bar{Y}_{kor} = \bar{Y}_{kor} \cdot \frac{\Delta\bar{Y}_{kor}\%}{100} = 24.46 \cdot \frac{7.9}{100} = \pm 1.93 \text{ pcs}$$

$$\Delta\bar{Y}_{kor}\% = 2\sqrt{\frac{s_{y(O)}\%^2}{n_1} + \frac{s_q\%^2}{n_2}} = 2\sqrt{\frac{15.7^2}{30} + \frac{8.68^2}{10}} = \pm 7.9\%$$

$$Y = \left(\bar{Y}_{kor} \pm \Delta\bar{Y}_{kor}\right) \cdot \frac{D}{d} = \left(24.46 \pm 1.93\right) \cdot \frac{300}{0.25} = 29{,}332 \pm 2{,}316 \text{ pcs}$$

– Choose the size of a sampling unit which is in general a seed bed block d = 25 cm in length for plants (for setting out the plants under 15 individuals, the blocks should be prolonged to d = 50 cm), for seedlings with density up to 100 individuals the seed bed blocks with a length of d = 25 cm should be used, whereas the original seed bed block should be reduced to one half or even one quarter in the case of higher density.
– Take from Table 4, for the given variability $s_y\%$ and chosen error $E\%$, the necessary amount of seed bed blocks n_1 for ocular estimates and n_2 for counting the individuals. If their height inventory is taken simultaneously, the mean heights do not have to be determined on all n_1 and n_2 seed bed blocks, just on approximately 1/2 or 1/3 of them as the mean height variability of nursery stock on the seed bed blocks is substantially lower than that of their number.
– To calculate the distance s_1 for equal spacing of n_1 sampling units along the seed beds on which the estimates will be performed

$$s_1 = \frac{D}{n_1} \qquad (11)$$

where: D – total length of seed beds

and the step for n_2 sampling units will be determined from the ratio $k = n_1\ n_2$; on sampling units, both the estimate and the counting or measuring of the height of individuals will be carried out.

For carrying out the measurements it is necessary to:
– Make a light wooden frame with inner dimensions of seed bed width × 25 cm and for providing the inventory of seedlings with high density to stretch a wire in vertical direction in the half and also in the quarters of the longer frame side.
– Place the frame along the seed beds at distances s_1; the first location should be done at a distance of $s_1/2$ from the beginning of the seed bed, the others at a distance of the whole s_1; to do ocular estimations on all locations and on each k^{th} of them also a precise counting and measuring of the individuals. The distances s_1 can be measured by means of a tape measure or steps.
– Make a record of the results obtained from the successive locations $i = 1, 2, ... n_1$ in two columns so that the measured values $x_{M(i)}$ form pairs with the estimated values $y_{O(i)}$ on individual locations.

Evaluate the obtained data according to formulas (5–9); to calculate the quotients q_i and their statistical characteristics for the pair values $x_{M(i)}$ and $x_{O(i)}$; to determine the mean estimated value $y_{O(i)}$ of the number or heights of nursery stock and correct it by means of $\bar{q}$, to calculate the sampling units for the whole inventoried seed beds and to state the range of the reached precision.

Table 5 gives one example of a record and data evaluation of the inventory of spruce plants 2+2 by means of the proposed combined method on a seed bed length D = 300 m, estimated variability $s_y\%$ = 20%, chosen precision $E\%$ = ± 10%, range of sampling for ocular estimates n_1 = 30 and for counting n_2 = 10, chosen sampling unit (length of sampling block) d = 25 cm, distance for n_1 locations (estimations) s_1 = 300/30 = 10 m, sampling step for n_2 locations (counting) k = 30/10 = 3 (each third from n_1 locations in the succession 2, 5, 8, … 29). It follows from the results that the mean estimated number of plants on n_1 = 30 locations is $\bar{y}_O$ = 22.5 and the relative variability of individual estimates is $s_{y(O)}\%$ = 15.7%. The mean value of the precise counting of individuals on n_2 = 10 locations is higher $\bar{x}_M$ = 23.7 and their variability $s_{X(M)}\%$ = 17.8% has also increased. Mutual relation between the estimated and counted number of plants is expressed by the coefficient q_i and it ranges from 0.945 and 1.213. Its mean value is $\bar{q}$ = 1.0872. It means that the numbers of plants obtained by counting were on average by 8.72% higher than the estimated ones; the ocular estimate underestimated the real state systematically. The variability of q_i values is very low, $s_q\%$ = 8.7% and it decreased 1.8 times in comparison with $s_{y(O)}\%$ of the estimated values and 2.0 times in comparison with $s_{X(M)}\%$ of the counted values. It means that there is a very close correlation between the estimates and counting, even in spite of the fact that the estimates show a systematic deviation and are predominantly smaller. After a correction by means of $\bar{q}$, the originally estimated mean number of plants on the 25 cm-long locations y_O increased and represented $\bar{Y}_{kor}$ = 22.5 . 1.0872 = = 24.46 plants; after calculation for the whole length of D = 300 m of the inventoried seed beds it represents Y_{kor} = 24.46 · 300/0.25 = 29,352 plants. The relative sampling error of the corrected result is $\Delta Y_{kor}\%$ = ± 7.9%. It means that with 95% probability the total number of plants on seed beds ranges within the interval of 29,352 ± 2,316 pieces of plants, i.e. from 27,036 to 31,668 individuals. If we needed a more precise result, it would be necessary to enhance the range of sample survey of n_1, n_2, for the required E = ± 5% on n_1 = 105, n_2 = 35 seed bed blocks.

Besides showing the whole procedure of evaluating the obtained data and the interpretation of the results, the above given example also confirms that planning and carrying out the two-phase inventory was correct. The coefficient of variation for the estimations $s_{y(O)}\%$ = 15.7% was even lower than originally expected (20%) and the error of the inventoried number of a respective category of plants in a nursery $\Delta Y_{kor}\%$ = ± 7.9% did not exceed the required range of $E\%$ = ± 10% (it represented only 79%). As the example was applied on a seed bed where (for the sake of investigations) the precise number of plants by counting on all seed bed blocks (Y = 29,104 plants) was already known before, it was possible to determine the real error of the corrected sampling result Δ = 29,352 – –29,104 = +248 plants, i.e. +0.8%. If the ocular estimate of the number of plants (Y_O = 22.5 . 300/0.25 = 27,000) were not corrected in the second phase of inventory, the real error of determining the correct value would be Δ = 27,000 – 29,104 = –2,104 plants, i.e. even –7.2%.

SUMMARY

It follows from the previous chapters that at present three methods of the inventory of plant material in forest nurseries are used. Each of them has its own advantages and disadvantages. The ocular estimation of plant and seedling numbers, or also of some other characteristics, e.g. damage, mean heights, is cheap, however its accuracy is not known since it depends on the subjective properties of the estimators and is usually loaded by systematic errors (ŠMELKOVÁ 1998). Classical sampling replacing the ocular estimations by a direct inventory (counting, measuring) of the plant material at several places systematically distributed on all seed beds is more objective. It utilises the theory of statistical sampling and for the assumed variability of plant material (which can easily be judged according to the degree of density variability and other parameters of plants and seedlings on seed beds) it makes it possible to estimate the requested number of (places) measurements on seed beds to secure the inventory result with a given accuracy of e.g. ± 2, ± 5 or ± 10% (Table 2). After carrying out the inventory, the sampling result is derived from the measurements (e.g. number of individuals in the given category, percentage of damage, mean height, etc.) in the form of the reliability interval defined by the lower and upper limit, in which the real (exact) value in the total inventoried part of the forest nursery represents 95% probability. This procedure, however, requires higher technical skills of workers and 5 to 10 times higher costs than the ocular estimation. The present methodological procedure (ŠMELKOVÁ 1996) has been elaborated to such an extent that it is easy to be managed in the current nursery practice without any preliminary theoretical preparation.

The proposed two-phase sampling procedure combines the advantages of ocular estimation and direct inventory. It follows from the theory of regression sampling, which in the first phase determines quickly and cheaply, although less precisely, the required characteristics by the ocular estimation on a higher number of sampling units (n_1), and in the second phase on a smaller number (n_2) of sampling units even more precisely by counting or measurement. From n_2 data, the individual proportions of the measured and estimated values of the same characteristics are calculated and their value (multiplication quotient q) is used for the correction of all n_1 estimated and measured data (the correlation coefficient in plants is about 0.85 and in seedlings about 0.95). This fact is favourably reflected in the error (the interval of reliability) of the correct result and the economy of the entire inventory. As it is seen from Table 3, for ensuring the requested accuracy E% (± 2, ± 5 or ± 10%) at the given variability of plant material s_y% (10–40%), the number of the required ocular estimates n_1 increases in comparison with the classical sampling procedure while the number of the required direct estimates n_2 substantially decreases. Total time consumption necessary for this combined inventory is reduced by 50%. The whole working procedure is quite simple, calculations of the required formulas (5–9) are not difficult; they can easily be carried out using a pocket calculator, best of all the "scientific" type (example in Table 4).

For the sake of completeness it is necessary to mention that in the presented work, for all three above-mentioned inventory variants, the optimum sampling units were defined in a new way on the basis of large samples to which both the ocular and the direct inventories refer. Instead of 1 m^2 or 1m of the seed bed size it is recommended to use a smaller and more variable unit with a length of 25 cm of the seed bed, or with a higher density of individuals mainly seedlings, 1/2 or 1/4 of this distance. The required accuracy is thus provided at minimum costs (Table 1). Light wooden frames are best suited for the establishing of such a sampling unit that is placed along the inventoried seed beds at constant distances (s = total length of seed beds/number of seed bed lengths n).

There is no single reply to the question which of these methods is the best one. It depends on the inventory aim and on the type and quantity of planting material. The direct ocular estimation should be restricted only to acquisition of rough orientation information. In common practice, the classical sampling or combined sampling methods of inventory and measurements should be preferred. The latter is twice as effective (especially at a variability higher than 20%). The required inventory accuracy should be selected within the range from ± 2 to ± 10% with the aim to inventory more exactly the material that occurs in large quantities and that is of higher value (quality and price).

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Inventarizácia sadbového materiálu v lesných škôlkach kombináciou okulárneho odhadu a kontrolného merania

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ABSTRAKT: V práci sa hodnotia dva doteraz používané spôsoby inventarizácie sadbového materiálu v lesnej škôlke – okulárny odhad a výberová metóda. Navrhuje sa nový dvojfázový výberový postup, založený na vhodnej kombinácii odhadu a spočítavania, resp. merania semenáčikov a sadeníc. Definuje sa optimálna veľkosť výberovej jednotky (dĺžka záhonového úseku). Odvodzuje sa potrebný počet záhonových úsekov, na ktorých treba vykonať v prvej fáze (n_1) okulárne odhady a súčasne v druhej fáze (n_2) aj presnejšie zistenia počtu jedincov, resp. ich ďalších kvalitatívnych a kvantitatívnych znakov, aby sa dosiahla požadovaná presnosť výsledku ± 2 až 10 % so spoľahlivosťou 95 %. Predkladá sa teoretické zdôvodnenie návrhu i konkrétny pracovný postup jeho realizácie. Vymedzujú sa rámce, kedy je navrhovaná metóda ekonomicky (až dvojnásobne) výhodnejšia ako klasická výberová metóda.

Kľúčové slová: lesné škôlky; inventarizácia sadbového materiálu; dvojfázová výberová metóda; kombinácia okulárneho odhadu a presného zisťovania

V súčasnosti sú pre inventarizáciu sadbového materiálu v lesných škôlkach k dispozícii tri rôzne spôsoby, ktoré majú svoje výhody i nevýhody.

Okulárny odhad počtu sadeníc a semenáčikov, resp. aj niektorých ich ďalších znakov (napr. poškodenia, priemernej výšky) je rýchly a lacný, ale nie je známa jeho presnosť, lebo veľmi závisí od subjektívnych vlastností odhadcu a spravidla je zaťažený systematickými chybami (ŠMELKOVÁ 1998).

Klasická výberová metóda, ktorá nahrádza okulárny odhad priamym zisťovaním (spočítaním, meraním) sadbového materiálu na viacerých miestach rozložených pravidelne po všetkých inventarizovaných záhonoch, je objektívnejšia. Využíva teóriu štatistického výberu, takže pre predpokladanú variabilitu sadbového materiálu (ktorá sa dá dobre posúdiť podľa stupňa premenlivosti hustoty a iných parametrov sadeníc a semenáčikov po záhonoch) umožňuje stanoviť potrebný počet (miest) meraní na záhonoch tak, aby sa zabezpečil výsledok inventarizácie s vopred zvolenou požadovanou presnosťou, napr. ± 2, ± 5 alebo ± 10 % (tab. 2). Po vykonaní zisťovania sa zo získaných údajov odvodí výberový výsledok (množstvo jedincov danej kategórie, percento poškodenia, priemerná výška ap.) vo forme tzv. intervalu spoľahlivosti, vymedzeného spodnou a hornou hranicou, v ktorom skutočná (presná) hodnota v celej inventarizovanej časti lesnej škôlky leží s 95% pravdepodobnosťou. Samozrejme, že to vyžaduje vyššiu odbornosť a 5–10-krát väčšie časové náklady ako okulárny odhad. Súčasný metodický postup je však už natoľko prepracovaný (ŠMELKOVÁ 1996), že je veľmi ľahko zvládnuteľný v bežnej škôlkárskej praxi aj bez predchádzajúcej teoretickej prípravy.

Navrhovaná dvojfázová výberová metóda spája výhody okulárneho odhadu a priameho zisťovania v ich vzájomnej kombinácii. Vychádza z teórie regresného výberu, ktorý v prvej fáze na väčšom počte výberových jednotiek (n_1) stanoví zisťovanú veličinu rýchlo, lacno, ale menej presne okulárnym odhadom a v druhej fáze na menšom počte (n_2) týchto jednotiek aj presnejšie – spočítavaním, resp. meraním. Z n_2 údajov sa vypočítajú vzájomné podiely odmeranej a odhadnutej hodnoty tej istej veličiny a ich priemer (násobný kvocient $\bar{q}$) sa použije na korekciu všetkých n_1 odhadnutých hodnôt. Tým sa odstráni prípadná systematická chyba v okulárnych odhadoch a zároveň sa podstatne zníži variabilita výsledkov, pretože medzi odhadnutými a meranými údajmi existuje veľmi tesná korelácia (korelačný koeficient pri sadeniciach je okolo 0,85 a pri semenáčikoch 0,95). To sa priaznivo prejaví na chybe (veľkosti intervalu spoľahlivosti) skorigovaného výsledku a tiež na ekonomike celého zisťovania.

Ako vidieť z tab. 3, pre zabezpečenie požadovanej presnosti inventarizácie *E*% (± 2, ± 5, ± 10 %) pri predpokladanej variabilite sadbového materiálu s_y% (10–40 %) sa v porovnaní s klasickou výberovou metódou potrebný počet n_1 okulárnych odhadov o niečo zvýši, ale počet priamych zisťovaní n_2 sa podstatne obmedzí. Celkový časový náklad na vykonanie kombinovanej metódy inventarizácie sa preto zníži v priemere na polovicu. Celý pracovný postup je pritom pomerne jednoduchý, výpočty potrebných veličín podľa vzorcov (5–9) nie sú náročné, dajú sa ľahko zvládnuť na vreckovej kalkulačke, najlepšie typu Scientific (príklad v tab. 4).

Pre úplnosť treba poznamenať, že pre všetky tri spomínané varianty inventarizácie boli v práci na základe rozsiahlych rozborov novým spôsobom definované aj optimálne výberové jednotky, na ktoré sa okulárne odhady aj priame zisťovanie vzťahuje. Namiesto jednotnej veľkosti (doteraz 1 m^2 alebo 1 bm záhonu) sa odporúča používať menšia a variabilnejšia jednotka, a to záhonový úsek o dĺžke *d* = 25 cm, resp. pri väčšej hustote jedincov (najmä semenáčikov) polovica alebo štvrtina tohto úseku. Tým sa zabezpečí požadovaná presnosť výsledku s minimálnymi nákladmi (tab. 1). Na vymedzenie takejto výberovej jednotky sa najlepšie hodí ľahký drevený rám, ktorý sa ukladá pozdĺž inventarizovaných záhonov v konštantných odstupoch (*s* = celková dĺžka záhonov/počet záhonových úsekov *n*).

Na otázku, ktorý z troch spôsobov inventarizácie použiť, nejestvuje jednoznačná odpoveď. Závisí to od účelu zisťovania a od druhu a množstva sadbového materiálu. Čistý okulárny odhad by sa mal obmedziť iba na získanie hrubých, orientačných informácií. Bežne by sa mala v praxi preferovať klasická výberová metóda alebo ešte viac kombinovaná metóda odhadu a merania, ktorá je (najmä pri variabilite väčšej ako 20 %) až dvakrát efektívnejšia. Pritom požadovaná presnosť inventarizácie by sa mala voliť z rozpätia ± 2 až ± 10 % tak, aby sa presnejšie podchytil materiál, ktorý sa v škôlke vyskytuje vo veľkom množstve a má väčšiu hodnotu (kvalitu a cenu).

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