Some methodological aspects of the National Forest Inventory and Monitoring in Slovakia

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ABSTRACT: The work presents the conceptual information about the National Forest Inventory and Monitoring in Slovakia. It introduces some methodological approaches to the field data collection (determination of tree heights by two-phase method, regression formulas for tree volumes and assortments of forest tree species, quantification of deadwood volume in sample plots) and biometrical models prepared for data processing and generalisation of the results. The design and conception of Slovak National Forest Inventory and Monitoring were set with the aim to enable providing complex and integrated information about the state and changes of production and ecological characteristics of the forest ecosystems.

Keywords: tree heights; tree volume; deadwood volume; biometrical models; Slovak forestry

Basic conception of the National Forest Inventory and Monitoring in Slovakia

In Europe, Slovakia belongs to the countries with a relatively high proportion of forestland (40%), rich in tree species composition, with variable natural conditions, and with intensive forest management. It has a long tradition in detecting the forest conditions. At present, three different systems exist for assessing the forest state – survey of natural conditions and forest ecology, detection of forest stands condition for forest management needs, and the national monitoring of forest health conditions executed yearly in a grid of 16 × 16 km. Lately, the fourth system was established, namely National Forest Inventory and Monitoring (NFIM) in Slovakia, which was first executed in 2005 and 2006. Its aim is to detect the conditions of all components of forest ecosystems periodically and to observe the changes on national and regional levels, as by other NFIs. In the presented paper, we provide information on the basic conception of the Slovak NFIM and on some methodical aspects, which can be interesting for a wider expert society in this field.

National Forest Inventory and Monitoring in Slovakia 2005–2006 was executed upon the decision of the Ministry of Agriculture from July 1, 2004. It was performed on all lands covered by forest tree species, i.e. on forest lands and on other forested lands including the protected areas. Slovak NFIM was drawn up as a combined aerial-terrestrial sampling method with a systematic distribution of sample units over the whole country. In the aerial images, sampling units are circular plots of the size of 2,500 m^2 distributed in a grid of 2 × 2 km, which serve for the distinction between the land categories Forest/Non-forest and for the determination of the forest area. The terrestrial inventory plots are established in a grid of 4 × 4 km. In these plots, information covering the whole information spectrum is collected. The information spectrum is broad, as it consists of more than 100 variables, while four different types and sizes of sample plots (Fig. 1) are optimised to their attributes. In the terrain, the plots are permanently invisibly fixed, which enables periodical observations of all attributes and variables by the same method and at the same place over a longer time period. Data is collected using the computer-

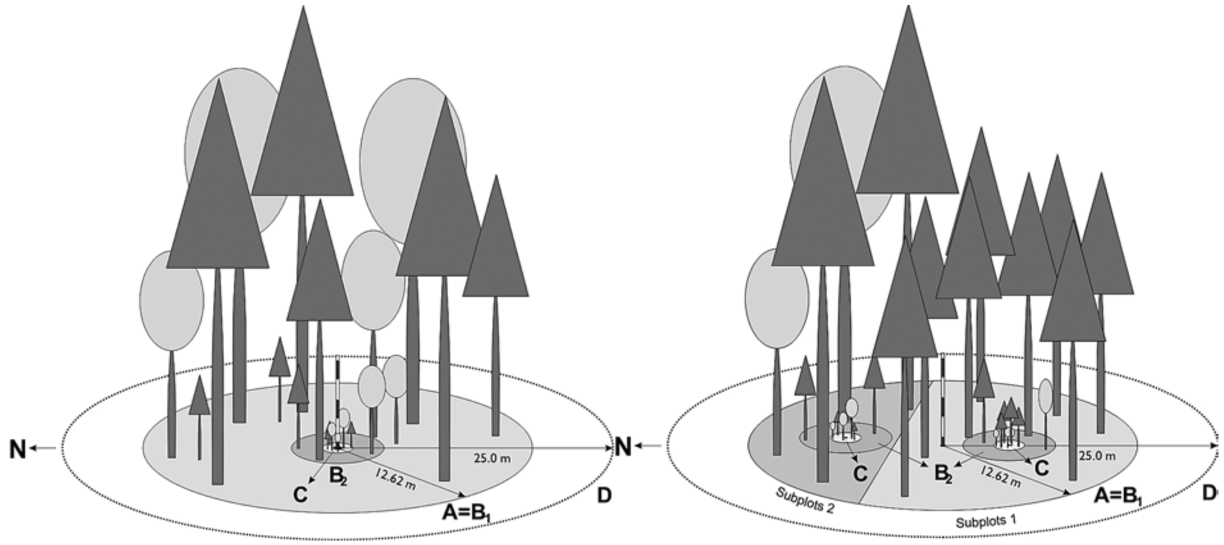

Fig. 1. Scheme of the sample plot (on the left-hand side without subplots, on the right-hand side divided into 2 subplots): A – a constant circle with radius r = 12.62 m, on which terrain, site, stand and ecological characteristics, food sources for animals are detected and lying deadwood and stumps are inventoried, B – two concentric circles (r = 12.62 m and 3 m) for detecting tree characteristics on trees with diameter at breast height $d_{1.3} \geq 12$ cm (B_1) and $d_{1.3}$ = 7–12 cm (B_2), C – a variable circle for thin trees with diameter $d_{1.3} < 7$ cm, its radius r = 1.0 m, 1.41 m or 2.0 m is chosen according to tree density, D – an enlarged constant circle with radius of 25 m established for the inventory of forest edges, forest roads and water sources

based Field-Map Technology (IFER 1999–2006). The whole implementation of NFIM is ensured by the National Forest Centre in Zvolen in accordance with detailed methodological instructions (Šmelko et al. 2005, 2006).

Slovak NFIM in its form fulfils the latest scientific and practical requirements for the complex detection and periodical comparison of the forest condition. Its precision level is restricted to a large extent by the lack of financial resources, and thus the grid of the sample plots (4 × 4 km) is relatively sparse. This will ensure sufficient precision of the final data only on the national level (by forest area 1%, by timber volume 1.5%), while on the regional level the precision will be 2–4 times lower. The next Slovak NFIM is presumed to be carried out in years 2014–2016 in a denser grid (terrestrial 2 × 2 km, and in low forested areas 1.41 × 1.41 km, and an aerial grid of 1 × 1 km, or 500 × 500 m) to obtain more exact data.

Determination of tree heights by two-phase method – a combination of estimation and measurement

The determination of tree heights in the sample plots belongs to serious methodological problems. On one hand, "one tree principle" is in general pushed forward, i.e. the requirement to know the heights of all trees in a sample plot, which enables to record the forest height structure in its whole variation range and is also optimal for the derivation of other variables (tree volume and its increment, assortments etc.). On the other hand, from the economical point of view, one is forced to consider the measurement of tree heights on a smaller number of trees (sample trees), and to assign to the rest of the trees the average height value from the local height curve derived from the sample plot or from the general height tariff. This method has several disadvantages – it reduces the real variability of heights and can cause deviations in the height of individual trees by several metres.

Based on our previous research (Šmelko 1994), a two-phase method, i.e. the combination of estimation (E) and measurement (M), was chosen for the Slovak NFIM. First, the heights of all n_1 trees in the sample plot are estimated (qualified ocular estimation is ensured by previous training). Next, a subsample of n_2 trees is determined, and the heights of these trees are measured. For example, each second or third tree is selected preferably from higher trees (according to the principle of unequal probabilities). It is specified that a minimum of 10 trees have to be measured. If there are less than 20 trees in the sample plot, all trees are measured. During the subsequent data processing, the estimated heights h_E are rectified using the PPP-sampling theory with a multiple quotient $\bar{q}$ as follows:

$$h_{i(korig)} = h_{i(E)} \times \bar{q} \Rightarrow \bar{q} = \frac{\sum_{i=1}^{n_2} q_i}{n_2},$$

$$q_i = \frac{h_{i(M)}}{h_{i(E)}}, \quad i = 1, 2 \ldots.. n_2 \qquad (1)$$

The necessity for rectification is examined by a statistical test. In the case that the quotient $\bar{q}$ does not differ from 1.00 significantly, the rectification is not needed, and the height estimated is considered to be equal to that measured (i.e. deviations are not systematic, but have a random character and are in tolerance with natural measurement variability).

The presented method meets both above-mentioned requirements – it provides tree heights in the whole variation range, while its work and time demands are acceptable and the results are sufficiently precise. The experience obtained from the database showed that only in 21% cases the height estimations deviated from the measurements systematically (i.e. they were biased), in general they very closely correlated with the measurements, the variability of q_i (s_q%) being only 9.8%.

Set of regression formulas for tree volumes and assortments of forest tree species

Timber volume determination and its assortment structure is a key task of every NFI, while several specific conditions must be met. For automated data processing, appropriate mensurational relations expressed in a mathematical form are required. The results obtained are to be stated in the volume units used in national conditions, and at the same time comparable on a wider international scale. The results should also provide effective background information for more comprehensive utilisation.

Considering these demands, the following solution was taken for the NFIM of the SR. The suitability of the existing volume and assortment tables and of their mathematical models was verified with regard to the purpose of the NFIM. It was shown that the volume regression formulas $v = f(d_{1.3}, h)$ for 12 forest tree species (Petráš, Pajtík 1991) satisfactorily describe the tree volumes (v) over the whole range of diameters ($d_{1.3}$) 0.1–100 cm and heights (h) 1.3–45 m (see Fig. 2). Only small corrections or substitute solutions were necessary. In the case of less frequent tree species, the volume formulas for related tree species (in accordance with morphological stem similarity) were used. It was decided, that the tree volumes would be determined in three volume units as follows:

(1) commercial timber (i.e. wood with minimum diameter at the top end 7 cm) inside bark, which is usually used in home practice,
(2) commercial timber outside bark used in most European NFIs,
(3) total tree volume outside bark, which will be used for determining the carbon content in woody biomass and in its basic components (tree, stem, branches, bark).

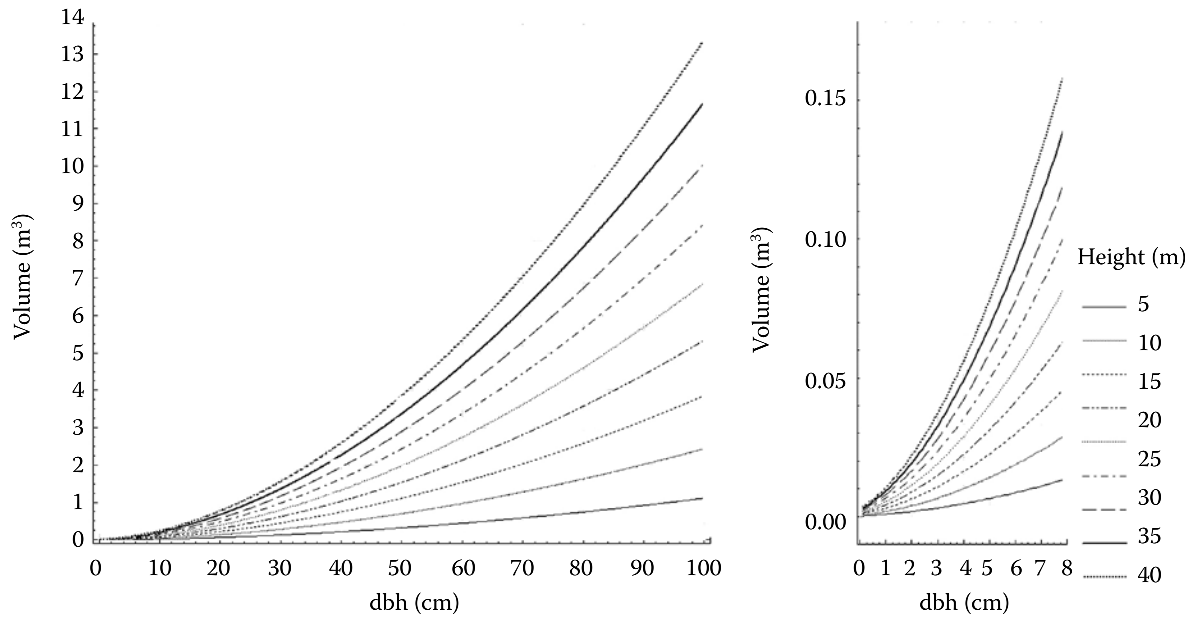

Fig. 2. Course of the volume formula $v = f(d_{1.3}, h)$ for spruce and its stem volume outside bark

The differences in those three volume units are actually rather high – e.g. standing volume per 1 hectare for all tree species from the NIML database resulted in 266–298–334 m^3, i.e. their relative indeces, being 1.00–1.12–1.25, respectively. Mathematical models for the partition of tree volume into 6 different assortment types (Petráš, Nociar 1991) were also shown as usable. They are derived for all main tree species, the input data being the tree diameter and height, quality of the bottom third of the stem (A, B, C), stem damage (yes, no), and in the case of the beech also the age and growth area (flysch). In the outputs of the Slovak NFIM, aggregated assortment types will be used, and for monitoring the changes in the quality structure of the forest stands relative proportions of trees in individual quality classes will be determined. Information about tree volumes from the models of volume and assortment tables is interconnected. By now, the use of another diameter d_k from a higher part of the stem in the model $v = f(d_{1.3}, h)$ has not been considered. Although also in Slovak conditions Ďurský and Šmelko (2002) found that adding another diameter d_{7m} or $d_{0.3h}$ improves the description of an actual stem shape of the tree and increases the precision of the tree volume determination (standard error will decrease by 0.62), the necessary three-argument volume modules $v= f(d_{1.3}, h, d_k)$ are not available at the moment.

Quantification of deadwood volume in sample plots

Lately, standing and lying deadwood in forest ecosystems has become more and more significant and hence, its detection was included within almost all NFIs in Europe. The assessment methods for obtaining necessary information vary between the countries; they differ in the definitions of individual parts of this wood, in the lower limit from which it is recorded, and in detection details. While in the case of small-sized wood only the estimation of its coverage in the sample plot is usually carried out, for larger deadwood its volume is also determined.

In the Slovak NFIM, the chosen methodology allows to quantify the volume of all deadwood, both large and small-sized. Standing dead trees are inventoried by the same method as living trees. In the case of the lying large deadwood (with minimum top diameter outside bark 7 cm), its length and diameter at both ends of the piece situated within the sample plot are measured, and its volume is calculated by Smalian's method. The stumps from felled or dead trees are recorded if their diameter is 7 cm or more (at the standard height of 0.2 m above ground), their height and diameter on the cut section are measured, their volume is determined by stereometry, while the shape of the bottom stem part is considered in a simpler form (using the models of morphological curves for all main tree species).

For the lying small-sized wood, two-phase detection was tested:

(1) The first phase is carried out on each sample plot, or a subplot. The following characteristics are estimated: relative coverage of small-sized lying deadwood, prevailing group of tree species (coniferous, broadleaved), its average diameter (with precision of 1 cm), and average decomposition grade. Relative coverage stands for the percentual proportion of the total area of the sample plot, which would be covered by small-sized lying deadwood if all pieces were placed side by side. In the case that deadwood is huddled together, or placed into a pile, it is estimated what area this wood would cover after its dismantling.

(2) The second phase of detection is carried out only on each fourth sample plot (with a random start, e.g. on sample plots No. 2, 6, 10, etc.). Its aim is to determine the volume of small-sized wood in m^3, which corresponds to the area, or to the relative coverage of small-sized wood estimated during the first detection phase. This is achieved on the basis of sample piles taken as follows:

- From the occurring small-sized wood with the diameter of 1–7 cm, a sample pile with dimensions W (width) and L (length) is created in the selected sample plot. Individual pieces of small-sized wood are placed side by side as densely as possible, while the width W of the sample pile should be approximately 1 m and its length L should correspond to the average length of pieces with the diameter of up to 1 cm at the top end. The pieces can be placed once from the bottom end and once from the top end.
- For each sample pile, which is delimited by the range poles, the following characteristics are assessed. Its width W and length L are measured with precision of 0.05 m, the prevailing tree species and prevailing decomposition grade are estimated, and the diameters of all small-sized wood pieces are measured in the half of their average length $L/2$ with a simple measuring tool (Fig. 3).
- Using the data obtained, a biometric model is derived, which expresses the real wood volume of densely placed small-sized wood in an area of 1 m^2 as a function of the tree species and average small-sized wood diameter, and if necessary,

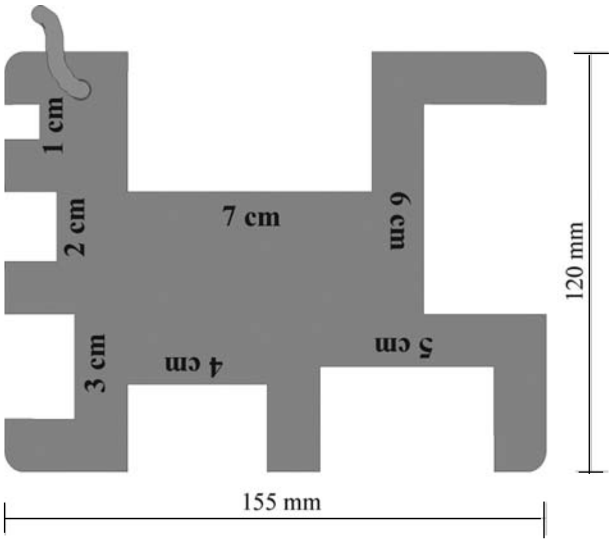

Fig. 3. Simple measuring tool used for measuring diameter of small-sized wood

also of other attributes influencing the given relation. Using this model, the volume of small-sized lying deadwood will be estimated also on other NFIM sample plots. Fig. 4 presents such a model derived from the 2005 and 2006 database. As can be seen, the relation between the volume and average diameter is tight and hence, well applicable.

Apart from the described second phase, another alternative was also tested, namely the line intersect sampling (Shiver, Borders 1996). In each fourth sample plot, two perpendicular lines were established, one in the direction North-South, the other in the direction West-East. With all pieces of small-sized lying deadwood, diameter d_i was measured at the point of intersection with the line with a simple measuring tool, with precision of 1 cm. The volume of small-sized deadwood T in m^3 per 1 hectare was directly derived from the measured diameters m of small-sized wood pieces using the formula

$$T = \frac{\pi^2}{8L} \sum_{i=1}^{m} d_i^2 \qquad i = 1, 2 \,..... \, m \qquad (2)$$

(valid regardless of wood pieces length). This variant showed to be less suitable for the volume estimation than the first one, probably because of the insufficient length L of lines set for this purpose (quadruple the radius of the sample plot = 50.48 m).

Biometrical models used to generalise the results from sample plots for the whole inventoried territory

The data obtained from the sample plots have to be numerically processed and generalised for the whole inventoried territory using specific mathematical-statistical (biometrical) models, which cannot be universal but have to correspond to the used sampling design of the NFI and the properties of detected variables. First, it is necessary to consider if the sample plots are equal or variable in size, if they are distributed at random or systematically over the inventoried territory, and if the variables are quantitative or qualitative (categorical). The aim is to derive parameters applicable to the entire country or its parts on the basis of a relatively small sample size (from n sample plots), and to determine the precision frames of their determination.

In this contribution, we discuss only two of such parameters – total and mean values of the stand quantitative variable, and the relative proportion of the tree qualitative variable. The models are derived

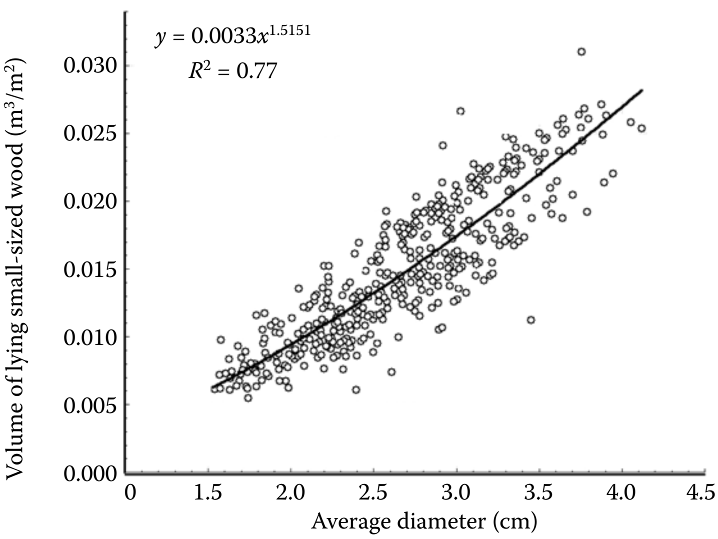

Fig. 4. Volume of small-sized lying deadwood (m^3) placed at 1 m^2 as a function of its average diameter

with regard to the fact that the Slovak NFIM has a systematic sampling design and that the stand and tree variables of trees with diameter $d_{1.3}$ equal to or above 12 cm were determined in the sample plot B_1, which is of a constant size of 500 m^2. However, in the cases where the sample plots were situated on the boundary Forest/Non-forest or encompassed different forest categories (different age, ownership category etc.), the sample plots were divided into smaller parts – subplots, resulting in a variable area of the sample units.

Estimation of parameters of the stand quantitative variable

Let us assume that we evaluate the stand quantitative variable Y, e.g. timber stock, the number of trees etc. The target parameter, which has to be determined, is τ_Y – actual total value of variable Y in the whole forest area A. This is equal to the sum of values y_i of all $i = 1, 2 \ldots N$ individuals (trees) in the population

$$\tau_Y = \sum_{i=1}^{N} y_i \qquad (3)$$

or to the forest area A multiplied by average μ_Y related to l ha

$$\tau_Y = A\mu_Y \qquad (4)$$

In the Slovak NFIM, model (4) is used. Area A is determined from the sample results of aerial and terrestrial inventory. Average μ_Y is estimated by sample mean $\bar{Y}$ obtained by measuring the variable Y on m_i trees situated in n sample plots, each of an area X_i. Standard error of estimation $\bar{\tau}_Y$ from the sample results is:

$$S_Y = \sqrt{A^2 S_Y^2 + \bar{Y}^2 S_A^2} \qquad (5)$$

The estimation of μ_Y by $\bar{Y}$ can be executed by either of the two methods described below.

A) The method "Ratio of Means". This model is generally valid for random sampling (Loetsch, Haller 1973; Cochran 1977; Schaeffer et al. 1990, etc.). It is based on the averages, or on the sums of values of the quantitative variable Y_i and the area of the sample plot X_i, where the average μ_Y is estimated from the proportion $\bar{R}$ with standard error $S_{\bar{R}}$

$$\bar{R} = \frac{\bar{Y}}{\bar{X}} = \frac{\sum_{i=1}^{n} Y_i}{\sum_{i=1}^{n} X_i} \qquad (6)$$

$$S_{\bar{R}} = \sqrt{\frac{\sum_{i=1}^{n}(Y_i - \bar{R}X_i)^2}{n(n-1)\bar{X}^2}} = \sqrt{\frac{\sum_{i=1}^{n}(Y_i^2 + \bar{R}^2 \sum_{i=1}^{n} X_i^2 - 2\bar{R}\sum_{i=1}^{n} X_i Y_i}{n(n-1)\bar{X}^2}} \qquad (7)$$

The magnitude of standard error (7) is influenced by the variability of Y_i and X_i values, as well as by their correlation (r_{YX}). Similarly, the relative standard error is derived from the relative standard errors of these components according to the relation

$$S_{\bar{R}}\% = \sqrt{(S_{\bar{Y}}\%)^2 + (S_{\bar{X}}\%)^2 - 2r_{YX}S_{\bar{Y}}\%S_{\bar{X}}\%} \qquad (8)$$

B) The method "Mean of Ratios". This model was recommended by Saborowski and Šmelko (1998), and Šmelko and Saborowski (1999) for systematic sampling of unequally sized sample plots. On the basis of the theoretical analysis and computer simulations, the authors found that in the case of systematic design, the probability to be selected into the sample is higher for larger sample plots than for smaller plots, what causes a systematic deviation (bias) in the estimations. Therefore, in each sample plot (i) the sample data Y_i need to be recalculated to equal area (1 ha) using the following formula:

$$Y_{ha}(i) = \frac{Y_i}{X_i} \qquad (9)$$

These hectare values $Y_{ha}(i)$ are used for the estimation of μ_Y and $S_{\bar{Y}}$ as follows:

$$\bar{Y}_{ha} = \frac{\sum_{i=1}^{n} Y_{ha(i)}}{n} \qquad (10)$$

$$S_{\bar{Y}ha} = \sqrt{\frac{\sum_{i=1}^{n}(Y_{ha(i)} - \bar{Y}_{ha})^2}{n(n-1)}} =$$

$$= \sqrt{\frac{\sum_{i=1}^{n}(Y_{ha(i)}^2 - \frac{\left(\sum_{i=1}^{n} Y_{ha(i)}\right)^2}{n}}{n(n-1)}} \qquad (11)$$

A preliminary assessment of the data from the Slovak NFIM by both methods provided e.g. for commercial timber (i.e. wood with minimum diameter at the top end 7 cm) inside bark with all tree species these results:

$\bar{R}$ = 266.2 m^3, $S_{\bar{R}}$ = ± 5.15 m^3 and $\bar{Y}_{ha}$ = 263.9 m^3, $S_{\bar{Y}ha}$ = ± 5.16 m^3.

The differences in the average value 2.3 m^3 (0.9%) and in standard error 0.01 m^3 (0.2%) are not very high. Further spatial analyses, e.g. geostatistics and correlation analyses, did not reveal any significant systematic trends in the distribution of the values of basic variables over the whole country. For example, the correlation coefficients calculated for basal area per hectare within the distance of 50 km fluctuate between –0.12 and 0.34. This shows that the spatial autocorrelation between the values is low and practically negligible. Due to these facts, the first model A, was applied in the evaluation of NFIM data.

Estimation of parameters of tree qualitative variable

Let us assume that we evaluate a tree qualitative variable, for example the relative proportion of trees π in quality classes A, B, C. We estimate the proportion π_A by, the sample proportion p_A and its standard error S_{PA} based on the number of trees a_i belonging to class *A* and on the total number of trees m_i on individual sample plots $i = 1, 2 \ldots n$. This is a typical cluster sampling with unequal numbers of individuals because the number of trees m_i will always vary, even if the area of the sample plots is constant. Thus, the proportion p_A and its standard error S_{pA} has to be determined using the model "Ratio of Means":

$$p_A = \frac{\sum_{i=1}^{n} a_i}{\sum_{i=1}^{n} m_i} \tag{12}$$

$$S_{pA} = \sqrt{\frac{\sum_{i=1}^{n} a_i^2 + p_A^2 \sum_{i=1}^{n} m_i^2 - 2p_A \sum_{i=1}^{n} a_i m_i}{n(n-1)\bar{m}^2}} \tag{13}$$

It can be proved, that in this case the estimate derived from binomial distribution cannot be used

$$p_A = \frac{\sum_{i=1}^{n} a_i}{\sum_{i=1}^{n} m_i} \tag{14}$$

$$S_{pA} = \sqrt{\frac{p_A(1-p_A)}{\sum_{i=1}^{n} m_i - 1}} \tag{15}$$

as this is applicable only to one-tree sampling (sampling of individual trees over the whole area). Although this method gives a good estimate of p_A, the calculated standard error is incorrect, having a much lower value. Likewise, the approach based on the proportions $p_{A(i)}$ assigned to each sample plot individually is not applicable

$$p_{A(i)} = \frac{a_{A(i)}}{m_i} \quad \Rightarrow \quad p_A = \frac{\sum_{i=1}^{n} p_{A(i)}}{n}$$

$$S_{pA} = \sqrt{\frac{\sum_{i=1}^{n} (p_{A(i)} - p_A)^2}{n(n-1)}} \tag{16}$$

This method could be used only if the total number of trees m_i in the sample plots were the same in all sample plots. The discrepancy in the results obtained from these three methods is documented in the following example. The results document the proportion of spruce trees in quality class A calculated from the Slovak NFIM database:

	Ratio of means	Binomial distribution	Method ad (16)
p_A =	0.1235	0.1235	0.1411
S_{pA} =	± 0.0162	± 0.0056	± 0.0158

The presented considerations demonstrate that the data processing of the Slovak NFIM 2005–2006 varies with regard to the model characteristics and features of the evaluated variable.

CONCLUSION

The presented article gives information on the basic characteristics of the Slovak NFIM, which was first executed in years 2005–2006 as a pilot project and its implementation at the same time. We also present some methodological approaches to the field data collection and biometrical models prepared for data processing and generalisation of the results. The NFIM methodology makes use of the existing international experience and knowledge from our own research at a maximum rate. It is characterised by a high variation in the selection of the design of sample plots, in the assessment of variables, and in their biometric evaluation. The aim was to optimise the methods in such a way that they may best suit the features of the detected variables, applied sampling design, and economical requirements.

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Niektoré metodické aspekty národnej inventarizácie a monitoringu lesov na Slovensku

ABSTRAKT: Príspevok prezentuje základnú koncepciu Národnej inventarizácie a monitoringu lesov (NIML) Slovenska, ktorá sa po prvýkrát uskutočnila v rokoch 2005–2006. Opisuje niektoré metodické princípy terénneho zberu údajov (určovanie výšok stromov dvojfázovou metódou, regresné rovnice uplatnené pri stanovení objemu a sortimentácii stromov lesných drevín, spôsob kvantifikácie objemu mŕtveho dreva na skusných plochách) a biometrické modely pripravené pre spracovanie údajov a zovšeobecnenie výsledkov. Výberový dizajn a celá koncepcia NIML boli navrhnuté tak, aby umožňovali vo zvolených časových intervaloch poskytovať komplexné a integrované informácie o stave a zmenách produkčných a ekologických charakteristík lesných ekosystémov na celoštátnej i regionálnej úrovni.

Klúčové slová: výška stromov; objem stromov; objem odumretého dreva; biometrické modely; slovenské lesníctvo

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