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ORIGINAL PAPER

Evaluation of the methods of tree height estimation on reference sample plots for the assessment of growing stock volume using airborne laser scanning

Radosław Kanabus, Stanisław Miścicki✉

Department of Forest Management, Dendrometry and Forest Economics, Warsaw University of Life Sciences; Nowoursynowska 159, 02-776 Warsaw

ABSTRACT

When estimating the volume of merchantable timber of stands using the airborne laser scanning (ALS) technique, remotely sensed wall-to-wall grid cells and ground (reference) sample plots are used. It is expected to calculate the growing stock volume (GSV) on sample plots (as a reference) as precisely as possible. For this reason, the height of all trees is commonly measured on ground sample plots, which is a labour-intensive process. In this study we attempt to investigate how a significant reduction in the number of trees on sample plots with measured height will affect the GSV estimation. Five methods of estimating the tree height based on the measurements of selected trees were described: H1 – constant height-diameter curves, i.e. dependence of tree height on diameter at breast height (dbh), taking into account average dbh and average height; measurement of the height of two trees with average dbh of the main species, one tree of other species; also trees with measured height were used to estimate the average dbh, H2 – same as in H1, but the average dbh was determined on the basis of all trees of a given species within a sample plot, H3 – Näslund function, i.e. the dependence of the height on dbh; curve coefficients obtained from all sample plots; number of trees with measured height same as in H1 and H2, H4 – Näslund function as in H3, but with the dependence of the height on dbh and age, H5 – same as in H1, but with coefficients for constant height curves obtained from the study area. The material used in this study included 28,948 trees of seven species measured on 897 sample plots of 500 m^2 located in the Milicz Forest District (SW Poland). The difference in the estimation of the GSV based on remotely sensed data was determined, while the total volume (total volume of individual trees) on reference plots was calculated using data of all measured (reference method REF) or estimated tree heights (H1-H5). H1 turned out to be the best method of estimating the height of trees. REF and H1, H2 and H5 methods application resulted in similar coefficients of independent variables in the model estimating the GSV based on the remotely sensed data. However, the differences in the GSV estimations between REF and those methods depended, only to a small extent, on the GSV. For practical reasons, it should be decided whether the found differences in the estimation of GSV based on remotely sensed can be accepted. The average difference was approximately 1 m^3/ha.

KEY WORDS

airborne laser scanning, constant height curve, Näslund function, wall-to-wall cell grid

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✉Tel. +48 22 5938208, e-mail: stanislaw_miscicki@sggw.pl

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Introduction

The method of determining some characteristics of forest stands – including the total volume of merchantable timber (i.e., the volume stock or growing stock volume related to a unit area) – using airborne laser scanning (ALS) data is considered an alternative and more economically solution to traditional inventories (Ene *et al*., 2013). The so-called point cloud, obtained from ALS data, is a three-dimensional visualization of the forest structure. However, direct estimation of growing stock volume (GSV) using such data is not possible. Among others, forest inventory with two-phase sampling and regression estimator is used as an indirect method (Naesset and Bjerknes, 2001; Næsset, 2002, 2014; Köhl *et al*., 2006; Even *et al*., 2015). In the first phase, the imaged forest area is divided into remotely sensed wall-to-wall grid cells (adjacent computational units) – mostly in the form of squares with a size in the range of 200-500 m^2 (taking into account the scale of imaging). Within each unit, the values of selected remotely sensed features are determined after ALS data processing from the set of computational units of the first phase, the second phase samples are drawn. Taking into account the field coordinates of the drawn samples, their boundaries are determined on the ground and within them the volume of merchantable timber and then the GSV is measured. Second phase sample units are the same size as first phase units. The relationship between GSV, treated as a dependent variable, and – treated as independent variables – remotely sensed features (usually in number of 2-4) within the computational units of the first phase is determined. The relationship calculated in this way allows the determination of the GSV in the individual computational units of the first phase and then, after appropriate calculation, of larger forest units.

Within the second phase sample units, also called reference (ground) sample plots, the feature under consideration (dependent variable) should be measured as accurately as possible. This is to maximize the strength of a relationship between it and the independent features. To achieve reliable GSV determination with the use of ALS data, it is common to measure the height of all trees within the boundaries of individual sample plots (Lisańczuk *et al*., 2020). Such measurements are time-consuming, because the sample plots are usually large (400-500 m^2) and – despite of the stand age – of the same size. This has led us to consider whether it would be acceptable to measure the height of only a part of trees (as in the inventory for the preparation of the forest management plan), approving the reduction in the accuracy of the GSV determination on the reference sample plots.

The purpose of this study was:

- to assess which is the best way to determine the height of the trees in the sample plot, when a few of trees are measured and the height of the rest is estimated;
- to assess which is the best way to determine tree height where only a small number of trees are measured and the results of their height estimation are used to determine the GSV on sample plots serving as reference in GSV inventory using airborne laser scanning data.

Material and methods

The research material was collected in the Milicz Forest District (Regional Directorate of State Forests in Wrocław). It is located in the 5th Silesian Natural Forest Region. The area of the forest is 7574 ha. Being the dominant species, pine stand consists of the largest part of the area (75%). Oak and beech stands consist of 11% and 6% of the forest area respectively. Other dominant species, spruce, birch and black alder, cover a total of 8% of the area.

Empirical data were collected in 2015 on 897 sample plots established in forest stands over 20 years old. Irrespective of the stand age, the size of the sample plot was 500 m^2. They were arranged systematically in a grid of 250×500 m. The data were collected by employees of the Bureau of Forest Management and Geodesy, Brzeg Branch Office, as part of their cooperation in the implementation of the research project.

Within the boundary of the sample plot, all trees with a diameter at breast height (dbh) of at least 70 mm were sampled. Their dbh (rounded to 1 mm) and height were measured (the latter using the Haglöf Vertex IV altimeter). A total of 29,799 trees were measured in height across all sample plots, including 28,948 of the seven species included in the study (Table 1). Based on the azimuth and distance from the centre of the sample plot, the location of each tree was determined. Using the formulas of Bruchwald *et al.* (2000), the volume of individual trees was calculated, followed by the GSV in individual sample plots.

It was decided to evaluate five ways of estimating tree height based on so-called height-diameter curves. Their characteristics are as follows:

– H1 – using constant height-diameter curves of the form:

$$h = 1{,}3 + (d\,/\,(a + b \cdot d))^2$$

where:

h – tree height [m],

d – diameter at breast height [cm],

a, b – coefficients of the equation determined as (Bruchwald *et al.*, 2000):

$b=o\times Hr$ (for birch $b=o+r\cdot H0{,}5$),

$a=D/(H-1{,}3)\cdot 0{,}5-b\times D$,

D – average breast height diameter in a forest stand,

H – the average height of trees in a forest stand.

For each sample plot D and H are determined for the dominant species on the basis of two average trees: the third and fourth in terms of dbh the group of six trees of the respective species nearest to the centre of the sample plot and for the admixture species on the basis of one average tree: the third in terms of dbh from the group of five trees of the respective species nearest to the centre of the sample plot.

– H2 – using fixed height-diameter curves as in method H1, with the difference that D was calculated based on all trees of a given species within the sample plot.

– H3 – using the empirically determined Näslund function $h=1.3+(d/(a+b\times d))^2$ for trees of a given species in all sample plots. Coefficients a and b were calculated on the basis of dbh

Table 1.

Number of trees of species included in studies with measured height (Ndrz), number of sample plots with the species concerned (Npow) and number of sample plots with at least two trees of the given species (Npow2)

Tree species	Ndrz	Npow	Npow2
Scots pine	24,451	703	692
European larch	666	169	109
Norway spruce	287	60	36
European beech	690	129	102
Silver birch	1,085	189	126
Oak + red oak	1,622	205	173
Black alder	685	59	53

and height of three trees from each sample plot: the first one counting from azimuth 0°, one drawn from the group of 20% thinnest and one from the group of 20% thickest trees of a given species in the sample plot.

- H4 – using the empirically determined Näslund height function for a given species on all sample plots with tree age w as an additional variable $h=1.3+(d/(a+b\times d+c\times w))^2$. The same trees as in method H3 were used to calculate the coefficients a, b and c.
- H5 – using formulas as in method H1, for which the coefficients of equation a and b were calculated for the species in question using data from the study area. D and H values from individual sample plots were used, determined on the basis of one average tree (the third in breast height from the group of five trees of a given species closest to the centre of the sample plot) and the breast height and height of an additional tree (the first one after the 0° azimuth).

In each method analysed, GSV was calculated for each sample plot. Data for pine, larch, spruce, oak, beech, birch and black alder were used. Other species were not included that occurred: (1) only singly in sample plots or (2) more numerous but only in one sample plot. In the first case, the result of estimating the tree height of such a sparse species would be the same in methods H1, H2 and H5. In the second case, the small amount of data would not allow to apply them in methods H3-H5.

The following indicators were used to evaluate the different ways of estimating tree height, which was then used to calculate GSV:

– Root Mean Square Error:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}{n}} \qquad [1]$$

where:

y_i – actual (reference) GSV on sample plot i,

$\hat{y}_i$ – estimated GSV (obtained using the estimated tree heights on sample plot i),

n – number of observations (sample plots);

– average systematic error:

$$\mathrm{BIAS} = \frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)}{n} \qquad [2]$$

– mean percentage bias:

$$\%\mathrm{BIAS} = \frac{100}{\overline{y}} \cdot \frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)}{n} \qquad [3]$$

where:

$\overline{y}$ – average reference value,

other designations as for formula 1.

The significance of differences between the mean GSV determined using the method and the mean GSV according to the reference data was determined using Student's t-test for paired samples.

The Akaike Information Criterion (AIC) (Akaike, 1974) was used to select the best way to determine tree height:

$$\mathrm{AIC} = -2\log\hat{L} + 2k \qquad [4]$$

where:

$\hat{L}$ – reliability function,
k – number of model parameters.

It was decided that once the evaluation of the different tree height estimation methods was completed, a second phase of research would be conducted. Its purpose was to determine the differences in GSV estimations of remotely sensed computational units when using reference sample plots to determine GSV: (1) data on individually measured heights of all trees (this method was called REF), (2) data on estimated heights of individual trees using the H1-H5 method. In case of this analysis, all trees within the boundaries of the reference sample plots were considered, so also trees of admixture species occurring singly.

The GSV of the remotely sensed computational units was estimated using a point cloud obtained in 2015 from airborne laser scanning data using the ABA-ITD (Area Based Approach – Individual Tree Detection) method (Parkitna *et al.*, 2021). It performs segmentation of tree crowns on LiDAR imagery, which allows to estimate, among others, the number of trees, the ground covering by tree crowns, the height of tree tops, and, based on the difference in position in relation to the ground, the height of trees. In the present study, three variables were used to estimate the GSV of remotely sensed computational units *(y')*: mean tree height (*Avg_H*), sum of tree heights (*Sum_h*), and sum of crown projection area *(Sum_p_crown*). The formula used was:

$$y' = 3000/(1 + \exp(b_0 + b_1 \cdot \ln(Avg\_H) + b_2 \cdot \ln(Sum\_h) + b_3 \cdot \ln(Avg\_H \cdot Sum\_p\_crown))$$

STATISTICA ver. 13.3 and the Stats package of the R environment were used for analyses.

Results

The GSV determined in the sample plots when tree height was estimated using the H1 method was the only one that was not statistically different from the GSV taken as reference (Table 2). Method H1 proved to be the best, as the value of AIC was the smallest among the tested methods. The RMSE was also the smallest (13 m^3/ha) and the BIAS was very small (1 m^3/ha). Over

Table 2.

Comparison of tree height estimation on reference sample plots using H1-H5 methods for growing stock volume estimating and reference data (all trees were measured)

		H1	H2	H3	H4	H5
Average systematic error BIAS	[m^3/ha]	1.0	–3.8	–2.8	–3.0	–0.6
	[%]	0.28	–1.10	–0.81	–0.88	–0.16
Root mean squere error	[m^3/ha]	13.0	14.0	28.8	29.0	13.2
Standard deviation of relative error	[%]	3.5	3.9	9.4	8.5	3.9
Extreme negative error	[m^3/ha]	–65.0	–60.0	–128.4	–129.2	–69.4
	[%]	–14.2	–25.2	–21.4	–21.5	–24.9
Extreme positive error	[m^3/ha]	60.4	51.0	120.4	88.2	57.0
	[%]	12.2	11.4	69.3	43.5	22.5
Median of relative errors values	[%]	0.23	–1.11	0.55	0.46	–0.06
47.5% negative deviation	[%]	–7.2	–9.6	–13.8	–13.1	–8.2
47.5% positive deviation	[%]	7.2	5.9	23.4	19.8	6.6
t-student value		1.45	–9.49	4.50	3.09	–2.30
Significance level		0.148	<0.001	<0.001	0.002	0.022
AIC Criterion		1,748	1,902	3,097	3,143	1,778

45% cases of the secondary percentage errors were in the range (–2; 2%) (Figs 1-2). The 95% interval of the secondary percentage errors around the median was the narrowest among the methods tested (Table 2). Over 65% of the absolute errors were within ±10 m^3/ha (Fig. 3).

For the related H2 method, worse results were obtained (Figs 1-3). The systematic error was the largest among the methods tested (–3,8 m^3/ha). Mean GSV was significantly different from the mean for the reference data (Table 2).

Using method H5, a very small value of bias was obtained – the smallest among the tested methods (Table 2). The value of AIC was not much higher than that for method H1. However, the mean GSV was significantly different from the mean for the reference data.

The worst results were obtained using methods H3 and H4. The bias was relatively high (–2.8 and –3.0 m^3/ha, respectively). The scatter of negative and positive errors was also large – much larger than for the other methods (Figs 1-3). Adding information on tree age (in method H4) only slightly improved the obtained GSV estimation results (Table 2).

In the estimation model of GSV in remotely sensed computational units, the values of the coefficients relating to the *Avg_H*, *Sum_h and Sum_p_crown* features were similar when the H1, H2 and H5 methods and the REF method were used to determine tree height (and further GSV) in the reference sample plots (Table 3). The strength of the relationship between the GSV

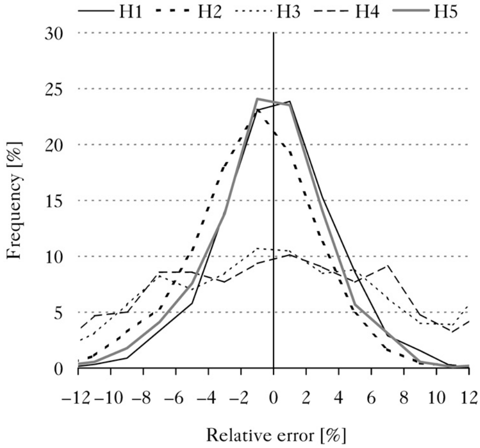

Fig. 1.

Distribution of relative errors in estimating the growing stock on reference sample plots using different tree height estimation methods

H1 – constant height-diameter curves (dependence of tree height on dbh, taking into account average dbh and average height; measurement of the height of two trees with average dbh of the main species, one tree of other species; also trees with measured heights were used to estimate the average dbh), H2 – as in H1, but the average dbh was determined on the basis of all trees of a given species within a sample plot, H3 – Näslund function (the dependence of the height on dbh; curve coefficients obtained from all sample plots; number of trees with measured heights as in H1 and H2), H4 – Näslund function as in H3, but with the dependence of the height on dbh and age, H5 – as in H1, but with coefficients for constant height curves obtained from the study area

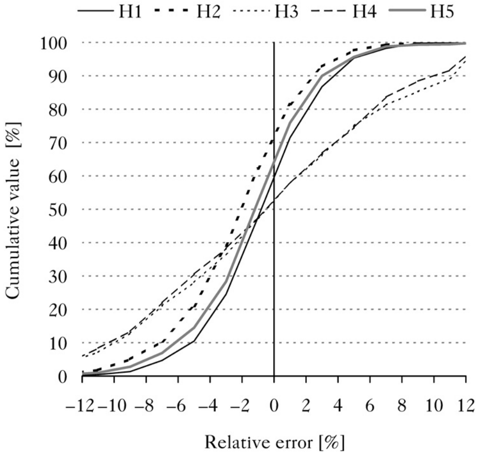

Fig. 2.

Distribution of cumulative relative error in estimating the GSV on reference sample plots using different tree height estimation methods

notes as in Fig. 1

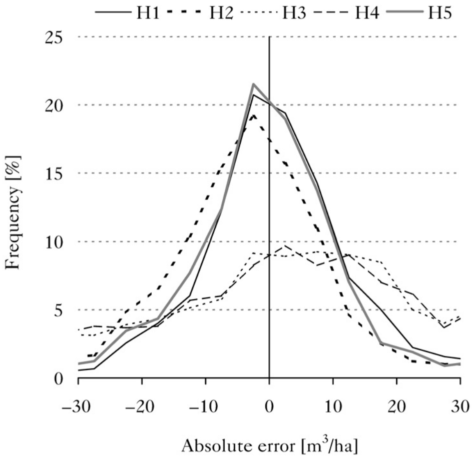

Fig. 3.

Distribution of absolute errors in estimating the GSV on reference sample plots using different tree height estimation methods
notes as in Fig. 1

Table 3.

Coefficients in the model of growing stock volume estimation on wall-to-wall calculation units (b_0-b_3), coefficient of determination for a given model (R^2), difference between estimated GSV and value of the reference model (345.8 m^3/ha) (Δ [m^3/ha]) as well as *t* test value (*t*) and its significance assessment (** p<0.01; *** p<0.001)

	b_0	b_1	b_2	b_3	R^2	Δ	*t*
REF	13.53	–1.058	–0.118	–0.808	0.726	–	–
H1	13.70	–1.033	–0.116	–0.837	0.716	0.96	19.3***
H2	13.67	–1.046	–0.100	–0.838	0.722	–3.80	56.1***
H3	11.99	–0.674	–0.033	–0.831	0.647	–2.34	3.26**
H4	12.11	–0.705	–0.039	–0.828	0.654	–2.47	3.71***
H5	13.68	–1.045	–0.111	–0.833	0.719	–0.54	12.8***

regression model: $y'=3000/(1+\exp(b_0+b_1\cdot\ln(Avg\_H)+b_2\cdot\ln(Sum\_h)+b_3\cdot\ln(Avg\_H\cdot Sum\_p\_crown))$
Avg_H – mean tree hight, *Sum_h* – sum of tree hights, *Sum_p_crown* – sum of crown projection areas; (mean of the remotely sensed sample plots: *Avg_H*=23.73 m, *Sum_h*=501,2 m/500 m^2 (=10024 m/ha), *Sum_p_crown*=443 m^2/500 m^2 (=88.6%))

in the reference sample plots and the GSV estimated for the remotely sensed computational units that mapped the individual sample plots was also similar. The GSV of these units differed when using reference data obtained after determining the height of trees according to the tested methods and when using the data of the REF method. The value of these differences depended on the GSV (Fig. 4). The smallest absolute difference in mean GSV of remotely sensed computational units (relative to the REF method) occurred for method H5, slightly larger H1, and largest for H2 (Fig. 5, Table 3). The differences were significant, due in part to the large number of observations.

Discussion

In the present study, the question was asked as to which of the methods of estimating tree height, based on measurement of only a small number of trees, would make it possible to obtain the GSV in the sample plot most similar to the reference value (accepted as true). Such an objective made the study different from earlier studies of volume tables (Grochowski, 1953; Gieruszyński, 1956; Głąbiński, 1958, 1960; Rieger, 1960; Makowski, 1978; Bruchwald and Rymer-Dudzińska, 1996; Socha, 2003) methods of determining the GSV (Nowakowska *et al.*, 2010; Jabłoński, 2012) as well as ways to estimate the height of trees (Socha, 2004; Ochał *et al.*, 2016). A second difference from the cited studies was that the interest was not in the accuracy of the

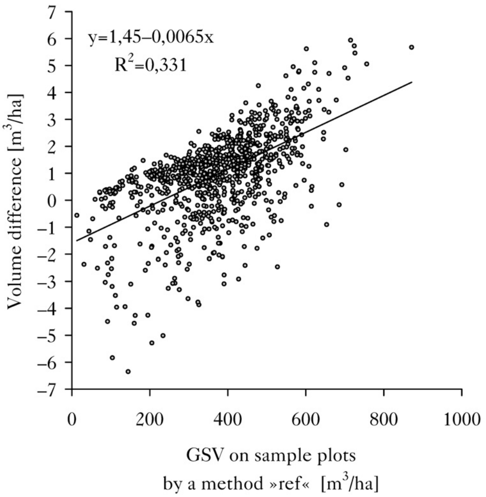

Fig. 4.

Relationship between GSV estimated in variant 1 and difference between GSV estimated in variants 1 (measurement of the height of all trees on reference sample plots) and (measurement of the height of selected trees and estimation of the heights of trees by height-diameter curve) on reference sample plots

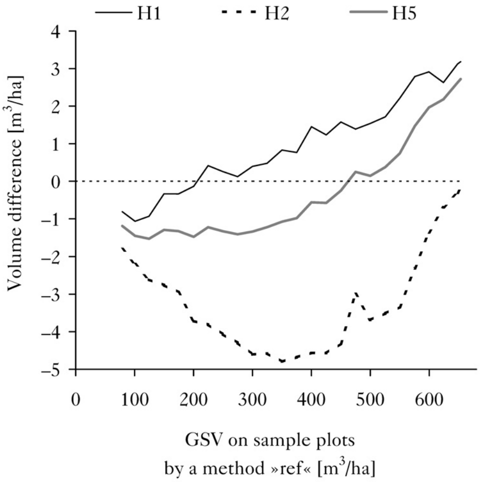

Fig. 5.

Relationship between the GSV estimated in the REF method (height of all trees on the reference plots measured) and difference between GSV estimated with H1, H2 and H5 methods (height of only a part of the trees measured) on reference sample plots in GSV classes

method of estimating the height of a single selected tree species, but in the effect on the estimate of GSV in the sample plot of using a particular method of determining tree height.

In spite of using more and more perfect tools for measuring the height of trees, their measurement is still a costly and labour-intensive activity (Bruchwald and Rymer-Dudzińska, 1986); Huang *et al.*, 2009; Lisańczuk *et al.*, 2020). In traditional GSV inventories, it is common to measure the height of selected trees and use such data to estimate the height of all trees, e.g., within a sample unit. However, prior to the present study, it was uncertain whether, when determining the GSV in reference sample plots used in inventories using airborne lidar scanning data, reducing the number of trees with measured heights would significantly degrade the results of such inventories. It appeared that the H1 method could be used in preparing data from reference sample plots. It uses constant height-diameter curves models developed for different species (Rymer-Dudzińska, 1978, 1982, 1994; Zasada, 2000; Bruchwald *et al.*, 2001; Bruchwald and Żybura, 2002).

In the second stage of the study, it turned out that the H5 method of determining tree height in the reference sample plots was the best. When the data obtained after applying this method were used, it was possible to obtain a result of estimating the GSV of remotely sensed measurement units close to the reference result (i.e., obtained according to the REF method, when the heights of all trees were measured in the reference sample plots). A slightly worse result was obtained using the determination of tree height according to method H1. Although in the case of both methods the mean values in relation to the reference data differed significantly, it remains to be decided whether for practical reasons the differences found in the GSV estimates of the remotely sensed computational units can be accepted. Indeed, the average absolute difference when using data from methods H5 and H1 did not exceed 1 m^3/ha.

Conclusions

- Due to the accuracy of tree height determination, when only a part of the trees was measured within a given reference sample plot (1-2(3)) of each species, stratum and age group), H1 was the best method. However, due to the accuracy of determining the GSV of remotely sensed computational units (created from airborne laser scanning data), method H5 was found to be slightly better than method H1.
- Due to the use of parameters of constant height curves developed by other authors (rather than parameters calculated individually for each tree species in a given forest district – as in the case of method H5) to determine the height of unmeasured trees, method H1 seems better for practical reasons. In method H5, for sparsely occurring tree species, the parameters of the constant height curves may be calculated inaccurately.
- Methods H3 and H4, which used a height curve common to trees of a given species throughout the forest, were inappropriate.
- It is inadvisable to use method H2, which is related to H1 and H5 but different in that it determines the average dbh of a given species. It has a practical meaning, because this way is used so far in the inventory for preparing the forest management plan in Poland.

Author's contributions

R.K. – investigation, data curation, methodology, analysis, writing – original draft, visualisation;
S.M. – conceptualisation, methodology, investigation, analysis, writing – review and editing.

Conflicts of interest

The authors declare no conflicts of interest.

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STRESZCZENIE

Ocena metod określania wysokości drzew na referencyjnych powierzchniach próbnych wykorzystywanych do szacowania zapasu z użyciem lotniczego skanowania laserowego

Szacując miąższość grubizny drzewostanów z wykorzystaniem danych lotniczego skanowania laserowego, stosuje się teledetekcyjne jednostki obliczeniowe oraz naziemne (referencyjne) powierzchnie próbne. Dąży się do tego, aby na tych ostatnich suma miąższości grubizny drzew – jako wartość odniesienia – była określona możliwie dokładnie. Z tego powodu na powierzchniach próbnych naziemnych często mierzy się wysokość wszystkich drzew, co jest czynnością pracochłonną. Celem pracy było: (1) dokonanie oceny, który sposób określania wysokości drzew na powierzchni próbnej jest najlepszy w przypadku, gdy mierzy się tylko niewielką liczbę drzew i szacuje się wysokości pozostałych, (2) dokonanie oceny, który sposób określania wysokości drzew jest najlepszy w przypadku, gdy mierzy się tylko niewielką liczbę drzew, a wyniki oszacowania ich wysokości są wykorzystywane do określenia zasobności na powierzchniach próbnych służących jako referencja w inwentaryzacji zasobów drzewnych z użyciem danych lotniczego skanowania laserowego.

Rozpatrywano pięć sposobów szacowania wysokości drzew na podstawie danych z pomiaru tylko części z nich: H1 (stałe krzywe wysokości określane z wykorzystaniem wzorów pochodzących z polskiej literatury – zależność wysokości od pierśnicy była ustalona z uwzględnieniem przeciętnej pierśnicy i przeciętnej wysokości; wykonany był pomiar wysokości dwóch drzew gatunku głównego o przeciętnej pierśnicy, a jednego drzewa pozostałych gatunków; drzewa z mierzoną wysokością służyły także do oszacowania przeciętnej pierśnicy), H2 (podobny do H1, ale przeciętna pierśnica była określana na podstawie wszystkich drzew danego gatunku w obrębie powierzchni próbnej), H3 (krzywa Näslunda – zależność wysokości od pierśnicy danego gatunku była określana z użyciem współczynników obliczonych na podstawie danych ze wszystkich powierzchni próbnych; w obrębie powierzchni próbnej mierzono wysokość trzech drzew danego gatunku – jednego losowo wybranego i po jednym z grupy drzew najcieńszych i najgrubszych), H4 (krzywa Näslunda jak w H3, ale określano zależność wysokości nie tylko od pierśnicy, ale i od wieku drzewa), H5 (podobny do H1, ale współczynniki do stałych krzywych wysokości zostały obliczone według danych z terenu badań). Wykorzystano dane z pomiaru wysokości 28 948 drzew siedmiu gatunków na 897 powierzchniach próbnych o wielkości 500 m^2 w Obrębie Milicz (tab. 1). Po wykonaniu oceny poszczególnych sposobów szacowania wysokości drzew określono różnicę oszacowania zasobności na teledetekcyjnych jednostkach obliczeniowych, gdy do obliczenia sumy miąższości drzew na powierzchniach próbnych referencyjnych użyto danych o wysokościach: (1) zmierzonych wszystkich drzew (tak uzyskane rezultaty nazwano REF) lub (2) oszacowanych według jednego ze sposobów H1-H5.

Najlepszym sposobem szacowania wysokości drzew okazał się H1 (tab. 2, ryc. 1-3). Określając wysokość drzew według sposobów H1-H5, a na tej podstawie miąższość grubizny drzew, uzyskano podobne wartości współczynników w modelu szacowania zasobności na teledetekcyjnych jednostkach obliczeniowych (tab. 3). Jednak wartość różnic wyników szacowania zasob-

ności pomiędzy tymi wariantami zależała, choć w niewielkim stopniu, od zasobności (ryc. 4). Gdy użyto wysokości drzew oszacowanych według sposobu H5 do określenia miąższości grubizny drzew na powierzchniach referencyjnych, uzyskano najlepszy wynik (w stosunku do danych odniesienia REF) szacowania zasobności teledetekcyjnych jednostek obliczeniowych. Niewiele gorszy wynik uzyskano, używając oszacowania wysokości drzew według sposobu H1 (ryc. 5). Wprawdzie w przypadku sposobów H1 i H5 wartości średnie w stosunku do danych odniesienia REF różniły się istotnie, ale do rozstrzygnięcia pozostaje, czy z powodów praktycznych można akceptować stwierdzone różnice oszacowania zasobności teledetekcyjnych jednostek obliczeniowych, bowiem średnia bezwzględna różnica w przypadku stosowania danych uzyskanych sposobami H5 i H1 nie przekroczyła 1 m^3/ha. Ze względu na wykorzystywanie parametrów stałych krzywych wysokości zaczerpniętych z literatury (a nie parametrów obliczanych indywidualnie dla każdego gatunku drzewa w danym inwentaryzowanym obrębie leśnym – jak w przypadku sposobu H5) do szacowania na powierzchni próbnej wysokości niezmierzonych drzew sposób H1 wydaje się lepszy ze względów praktycznych. W sposobie H5, w przypadku gatunków drzew występujących nielicznie, parametry stałych krzywych wysokości mogą być obliczone niedokładnie. Niewskazane jest stosowanie sposobu H2 – pokrewnego w stosunku do H1 i H5 – ale różniącego się ze względu na określanie przeciętnej pierśnicy drzew danego gatunku. Ma to znaczenie praktyczne, bowiem ten sposób jest wykorzystywany dotychczas w inwentaryzacji zapasu dla sporządzania planu urządzenia lasu w Polsce.