Assessment of tree layer biomass and structure using aerial photos in lake catchments of the Šumava Mts.

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ABSTRACT: The combination of georeferenced colour aerial photos and limited field measurements of individual trees was used to determine tree stand biomass in forests of prevailing Norway spruce. The technique was carried out in two localities – small catchments of natural lakes in the Bohemian Forest (56 and 76 ha in size, respectively). This method is not so expansive as the inventory based on sample plots, namely in the terrain of high dynamics in the mountains. Tree crown diameters were determined semi-automatically on the basis of orthophotos. The catchment of Plešné jezero Lake can be described by these average values: crown diameter 4.5 ± 1.35 m, mean tree height varying between 19.6 and 30.2 m depending on altitude (tree average and standard deviation are 25.5 ± 3.9 m), tree density 154 ± 67.7 ha and stand biomass 197 t/ha. The Čertovo jezero Lake catchment shows somewhat different values: crown diameter 4.9 ± 1.35 m, mean tree height varying between 20.9 and 25.1 m (dependence on altitude is weak; tree average and standard deviation are 25.6 ± 2.0 m), tree density 200 ± 65.7 ha (all parameters for Norway spruce only), and stand biomass 156 t/ha (Norway spruce) + 17 t/ha (European beech). Some features are common to both catchments: a regular to random tree pattern prevails. Tree clumping is typical of the most extreme stands. Minimum tree density occurs in the zone of the altitudes 1,200–1,250 m a.s.l. The crown diameter to dbh ratio is independent of altitude. Tree height decreases linearly with altitude. The distribution of trees according to crown diameter is skewed to higher values.

Keywords: allometry; altitudinal gradient; Bohemian Forest; crown diameter; lake catchment; orthophoto; *Picea abies* L.

The canopy – the tree layer plays the most important role in dynamics and functioning of a forest ecosystem. The structure of the canopy (e.g. species structure represented by species diversity, age composition, tree distribution according to size) is reflected in a wide set of productivity (Pretzsch 2005) and biogeochemical cycling (Jones et al. 2005) functions. The spatial structure of tree canopy is linked with natural forest dynamics (Vrška et al. 2002; Emborg et al. 2007). The canopy gap dynamics has been in the focus of interest of numerous authors for a long time (Runkle 1981; Hara 1985; Reiners 1986; Canham 1988; Hytteborn et al. 1991; Yamamoto 1992; Foster, Friend et al. 1993; Christensen et al. 2007, etc.). The importance of tree canopy assessment arises from determining the role of canopy and other processes.

Environmental conditions may change very rapidly in a short distance regarding the topography. Such examples can be found in mountain regions. The anemo-orographical system (sensu Jeník 1961) is an extreme landscape complex of this feature. Tree growth is very variable under these conditions. It is problematic to assess stand biomass in such area even if it is relatively small. A typical method consists in the measurement of a set of sample plots. The number of sample plots should be high regarding the changing stand features. The whole measurement is

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very expansive; furthermore it is carried out in an impassable terrain. A modern approach may be based on the exploitation of remote sensing data. The use of aerial photography has a long tradition in forestry (Žíhlavník 1999). Such data must be combined with a land survey, typically on sample plots. The results can be more precise but field work is essential. One possibility is grounded in a selection of single trees which are identifiable in the aerial photography. The most comprehensive analysis of this approach is presented in Korpela (2004).

Both forest managers and ecologists require accurate and timely data that describe vegetation conditions. Needs for such data are increasing with current emphasis on ecosystem management, escalating silvicultural treatment costs, evolving computer-based decision support tools, and demands for greater accountability. Deficiencies associated with field survey methods of data acquisition (e.g. high costs, subjectivity, and low spatial and temporal coverage) frequently limit decision-making effectiveness. The potential for remotely sensed data (aerial photographs) to supplement field-collected forest vegetation management data was evaluated in literature as the most suitable (Pitt et al. 1997).

Similar problems arise during the evaluation of forest ecosystems in catchments of two lakes in the Šumava Mts. (Bohemian Forest). Some results were published earlier without detail method description (Svoboda et al. 2006a, 2009). This paper demonstrates the comparison of growth conditions in both catchments on top of it.

METHODS

Study sites

Catchment of Plešné jezero Lake

Research was carried out in the catchment of Plešné jezero Lake (48°46'35''N, 13°52'0''E; the altitude ranges between 1,090 and 1,375 m a.s.l.; total forested area is 56 ha) in the Bohemian Forest Mts. Basic information describing the lake, its watersheds and the forest stands is provided by Kopáček et al. (2002a). Environmental conditions are represented mainly by higher altitudes (median altitude is 1,187 m a.s.l.). Slopes are steep: 50% of the area is with slopes up to 0.36 (20°), 75% of the area up to 0.57 (30°), 95% of the area up to 1.17 (49°) and 99% of the area up to 2.23 (66°). Geological bedrock is built of porphyric muscovite-biotite granite (Eisgarn type) according to the Geological map of the Czech Republic (1:50,000).

Main forest types according to the typological map give the first insight into vegetation conditions [the Czech Ecosystem (Site) Classification system has been employed (Viewegh et al. 2003)].

The area around the Plešné jezero Lake lies in 8th (88.1%) and 7th (11.9%) forest vegetation zone. Groups of forest types in the catchment are as follows (the values quantify the relative representation of the group in the area):

6V	0.02%	*Piceeto-Fagetum fraxinosum humidum*
7K	1.17%	*Fageto-Piceetum acidophilum*
7N	9.29%	*Fageto-Piceetum lapidosum acidophilum*
7V	0.51%	*Fageto-Piceetum acerosum humidum*
7Y	0.90%	*Fageto-Piceetum saxatilis*
8N	25.26%	*Piceetum lapidosum acidophilum*
8V	1.59%	*Acereto-Piceetum humidum*
8Y	45.03%	*Piceetum saxatile*
8Z	16.24%	*Sorbeto-Piceetum* (*humilis*)

The 8th forest altitudinal zone reaches to the lowest part of the catchment. It results in a rougher climate. Almost all trees in the catchment are represented by Norway spruce (*Picea abies* L.). The locality is surrounded by a wide belt of forests without any strong human activity. The spruce was also planted at lower altitudes around the catchment.

Catchment of Čertovo jezero Lake

The Čertovo jezero Lake catchment (49°9'55''N, 13°11'50''E; the catchment altitude ranges between 1,027 and 1,343 m a.s.l.; 76 ha in total of forested area) is described by Kopáček et al. (2002b) in detail. Median altitude is 1,136 m. Slopes are gentler: 50% of the area is with slopes up to 0.30 (17°), 75% of the area up to 0.49 (26°), 95% of the area up to 0.82 (39°) and 99% of the area up to 1.07 (47°). Geological conditions are not so simple. Near the lake, the glacial (Pleistocene) sediments are found. The north-eastern part of the catchment is represented by mica schist with garet and andalusite. It is changed to muscovite-biotite paragneiss with sillimanite in the western to south-western part (according to the Geological map of the Czech Republic).

The area is covered by the 7th (as spruce with beech zone; 81.3% of forested area) and 8th (originally dominated by Norway spruce; 18.7%) forest vegetation zone. The following groups of forest types are represented within the catchment:

7K	4.36%	*Fageto-Piceetum acidophilum*
7N	8.89%	*Fageto-Piceetum lapidosum acidophilum*
7V	9.68%	*Fageto-Piceetum acerosum humidum*
7Y	57.37%	*Fageto-Piceetum saxatilis*
7Z	1.03%	*Fageto-Piceetum humilis*

8K	10.12%	*Piceetum acidophilum*
8N	0.07%	*Piceetum lapidosum acidophilum*
8R	0.38%	*Piceetum turfosum* (*montanum*)
8Y	1.27%	*Piceetum saxatile*
8Z	6.83%	*Sorbeto-Piceetum* (*humilis*)

The 7th forest altitudinal zone is more important in comparison with the first catchment mentioned above. The tree layer is constituted by prevailing Norway spruce (*Picea abies*) with European beech (*Fagus sylvatica*) partly contributing in the lower part of the catchment. Silver fir (*Abies alba*) is represented, but it is not distinguishable from Norway spruce in aerial photos.

Aerial photos

Colour aerial photographs were prepared by Argus Geo System Ltd. (Hradec Králové, Czech Republic) on the 18th June 2000 (scale of 1:7,000). A digital orthophotograph, 0.2 m in pixel size, together with a digital elevation model (DEM) and topographical/hydrographical GIS data, was processed by GEOREAL Ltd. (Plzeň, Czech Republic) and the Institute of System Biology and Ecology AS CR together with Hydrobiological Institute – Biological Centre AS CR (České Budějovice, Czech Republic; J. Žaloudík).

Sample tree measurement

Sample trees of Norway spruce were randomly selected in the field in 2004. Each sample tree was identified in the aerial photo before measurement. The tree selection was done to represent all objectively selected partial plots stratified according to the elevation and forest-site conditions in both catchments. Both the tree height (*H*) and the diameter at breast height (dbh) were measured for each sample tree. Altitude and terrain inclination of each tree site were obtained from DEM. A total of 158 sample trees were measured in the Plešné jezero Lake catchment. In the catchment of Čertovo jezero Lake, Norway spruce was represented by 217 trees, and 66 European beech trees were measured additionally without localization under random selection (Svoboda et al. 2008).

Measurement of tree crown diameters using program PlotOA

A special transformation equilibrates pixels with different illuminations. If (R, G, B) is the colour vector of three colour components for red, green and blue, transformed components are calculated as *r, g, b* according to the equations

$$r = R/(a_R \times R^\alpha + a_G \times G^\alpha + a_B \times B^\alpha)^{1/\alpha}$$
$$g = G/(a_R \times R^\alpha + a_G \times G^\alpha + a_B \times B^\alpha)^{1/\alpha} \quad (1)$$
$$b = B/(a_R \times R^\alpha + a_G \times G^\alpha + a_B \times B^\alpha)^{1/\alpha}$$

The procedure seeks a homogeneous circular area around the determined point – the centre of tree crown. An average diameter of the homogeneous area is reported as tree crown diameter (*D*). The homogeneity measure is calculated as a three dimensional variance. It is the sum of the weighted variances for three colours red, green, and blue. The square root of this variable for an area of determined size is referred to as *L*:

$$L(\rho) = \sqrt{(w_r \times \mathrm{var}_\rho(r) + w_g \times \mathrm{var}_\rho(g) + w_b \times \mathrm{var}_\rho(b))} \quad (2)$$

where:
w_r, w_g, w_b – weights of three colour components.

Variances (e.g. $\mathrm{var}_\rho(r)$ for red) are calculated over all pixels with distance to the tree centre less or equal to radius ρ. *L* is the function of ρ. The crown edge is represented by a sharp change of colour properties of respective pixels. It should be depicted as a sudden increase in the *L* variable. The employed program PlotOA (Matějka 2006) is able to calculate such radius ρ_0 ($2\rho_0 = D$) as the inflexion point of *L*, $L(\rho_0)$ = LIMITVAL, respective.

Each sample tree was described by a set of parameters: *H*, dbh, altitude, *D*, LIMITVAL, and averages of transformed values for the red, green and blue components over all pixels representing the crown circle. Variable relationships were studied using principal component analysis (PCA). It is necessary to reiterate that colour parameters (average values over all pixels within the selected circle) and LIMITVAL are independent of tree size variables (Svoboda 2006a).

Data processing

Relationships between any two variables were quantified using standard linear or quadratic regression analysis. The sum of least squares was used to calculate the regression equations. Biomass of the compartments of a single tree was calculated using the following general allometric equation:

$$W = a\,(\mathrm{dbh}^2 \times H)^b$$

where:
W – weight of any particular tree compartment (stem wood, stem bark, live branches, and foliage in kg of dry matter),

values a, b – empirical constants, specific for the dry matter of tree biomass in Norway spruce forests of the Czech Republic (Černý 1990),
dbh (cm), H (m).

This form of equations is the only one acceptable in the study data set because only two tree dimension variables are accessible. Other relationships can be compared with literature (Dimitris et al. 2005). The total stem dry matter was calculated as the sum of *Wsw* (stem wood), *Wsb* (stem bark), *Wb* (branches), and *Wf* (foliage), which were calculated using the respective *a* and *b* constants (Černý 1990), and root biomass. Root (belowground) biomass of Norway spruce trees (*Wr*) was related to the stem and branch biomass using the empirical relationship derived from data published by Vyskot (1981):

$$Wr = 0.173\ (Wb + Ws)$$

where:
Wb, Ws – weight of branch and stem biomass, respectively.

The value of *Wr* includes the coarse roots only.

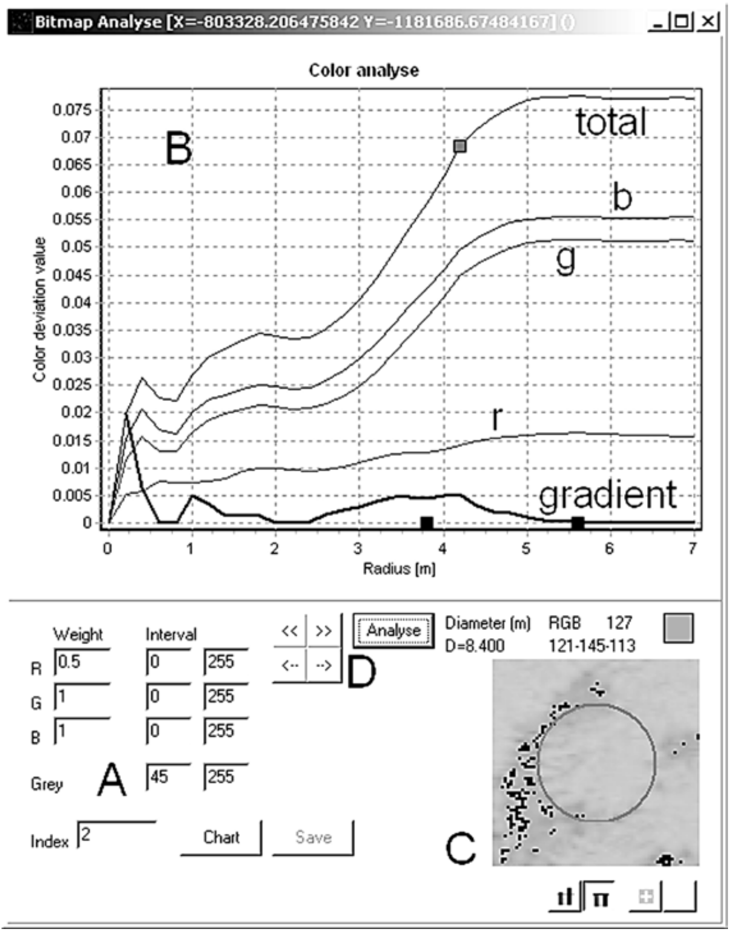
Stand spatial properties

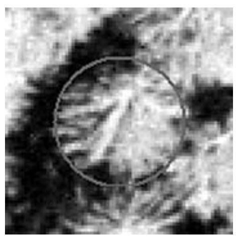
Distribution of single trees in each sample square was described by Clark-Evans' statistics (CE; e.g. Cressie 1991, p. 602–613). The values CE < 1 indicate tree clumping (aggregated pattern) by contrast to the values CE > 1 which are peculiar to near to regularly distributed trees (regular pattern).

RESULTS AND DISCUSSION

Catchment of Plešné jezero Lake

The prevailing part of sample squares demonstrates a random to regular pattern of trees. The tree aggregation is visible in the most extreme environmental conditions around the rock face (Fig. 2). Average density is 154 trees/ha (standard deviation





1 a

Fig. 1. Program PlotOA – an example of the bitmap analysis window employed to measure the tree crown diameter. Values in part A are decided to setting (weights of single colour channels, intervals of their permissible values, index – power value (α) of the equation (1). Graph (B) shows variances of single colour channels (curves r, g, b), total variance – L variable defined by equation (2) and gradient of total variance. An equalized bitmap slice can be visible in part C: black pixels are too dark for analysis – their grey colour values are out of the set intervals. The fitted circle is drawn. Buttons in part D serve for a shift of border points of the interval within which the limit diameter should be calculated

Fig. 1a. The original bitmap slice of the orthophoto analyzed in the example of Fig. 1. It can be shown in the bitmap analysis window after the switch button pressing

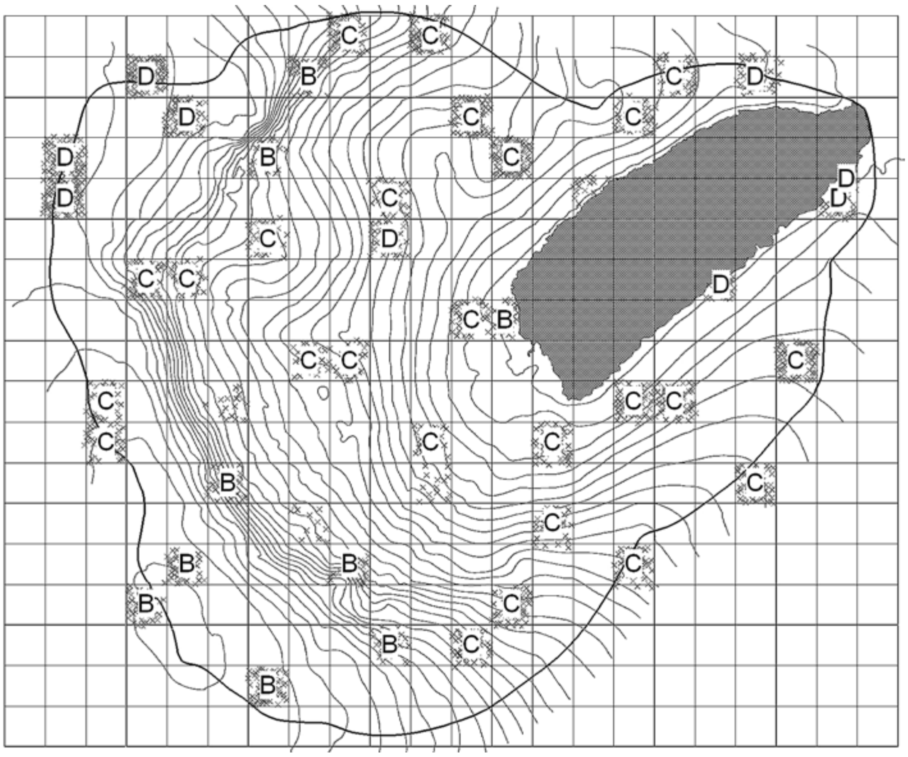


Fig. 2. Catchment of the Plešné jezero Lake with sample squares (50 m × 50 m in size) classified according to Clark-Evans' statistics: A – CE < 0.8; B – 0.8 ≤ CE < 1.2; C – 1.2 ≤ CE < 1.4; D – CE ≥ 1.4. The position of each tree in the sample square is indicated by a small cross. Terrain elevation is indicated by contour lines with 10 m interval

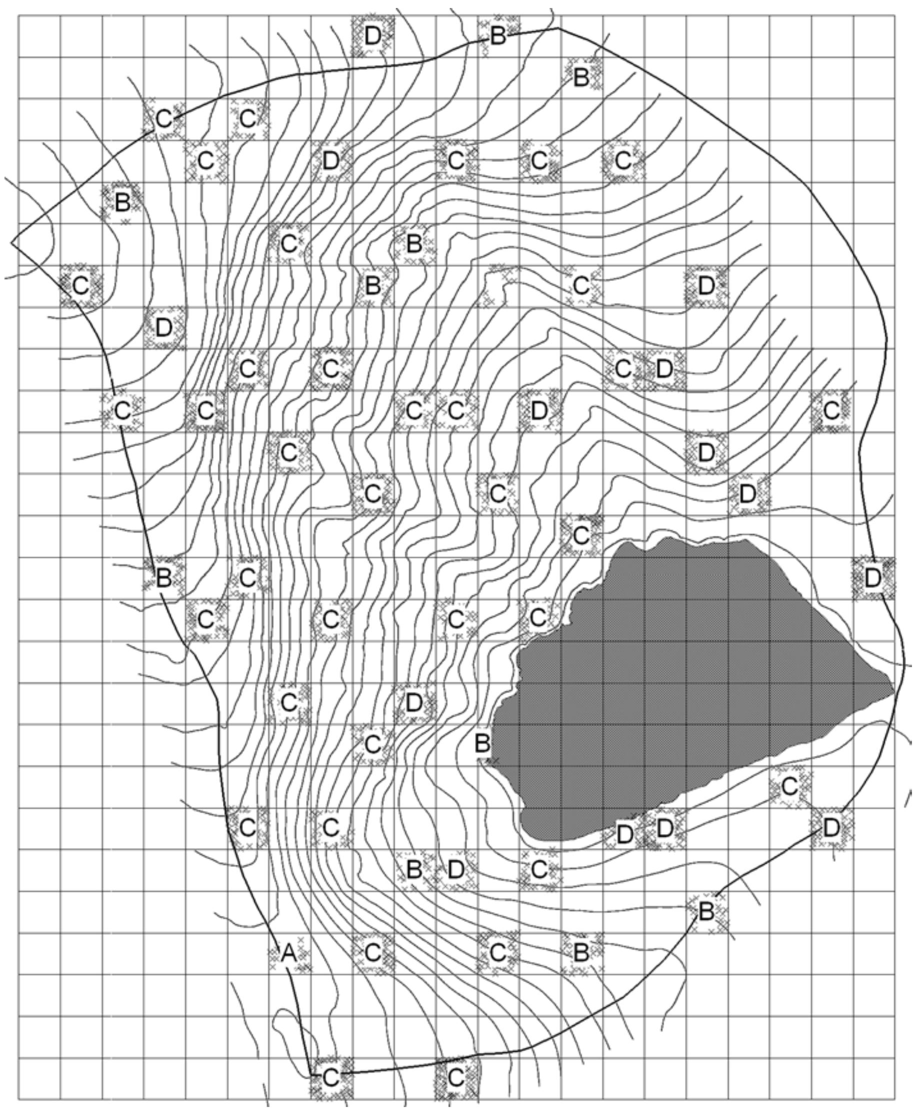


Fig. 3. Catchment of the Čertovo jezero Lake with sample squares (50 m × 50 m in size) classified according to Clark-Evans' statistics: A – CE < 0.8; B – 0.8 ≤ CE < 1.2; C – 1.2 ≤ CE < 1.4; D – CE ≥ 1.4. The position of each tree in the sample square is indicated by a small cross. Terrain elevation is indicated by contour lines with 10 m interval

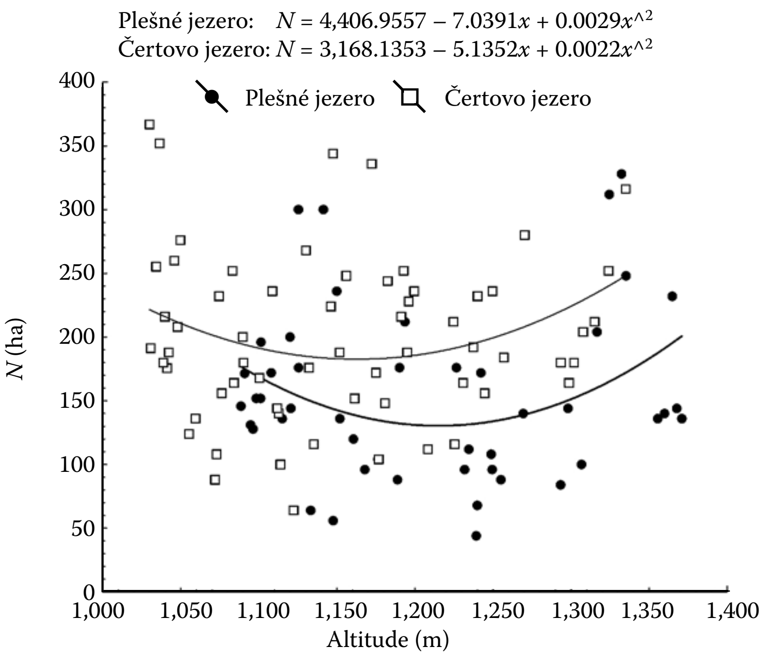


Fig. 4. The relationship of tree density and altitude in the datasets of analyzed catchments (coefficients of determination r^2 are 0.090 and 0.064 in the Plešné and Čertovo Lake, respectively)

67.7). This density is related to both the site altitude (Fig. 4) and the inclination (Fig. 6). The steepest slopes show more declined density. The spruce crown diameter is more reduced at higher altitudes (Fig. 5). Tree height is related to altitude (Fig. 7). Less suitable growth conditions are reflected by lower height increases (Fig. 8) – the drawn line is slightly rotated to horizontal direction.

Crown diameter as the basic tree size parameter measured on the basis of aerial photos has the average of 4.5 m, standard deviation 1.35 and skewness 0.69 (very important deviation from 0 on the level $\alpha < 0.1\%$).

Size parameters of individual trees in sample squares were assessed according to regression in the set of terrain sample trees (dbh = 39.9 + 3.01 × D; H = 63.5 – 0.0352 × ALTITUDE + 1.07 × D). These values represent the basic data set for assessment of individual tree biomass (Table 1) which can be recalculated to stand biomass (Table 2). The average total stand biomass was calculated as 197 t/ha. The stand biomass is higher than reported by Svoboda

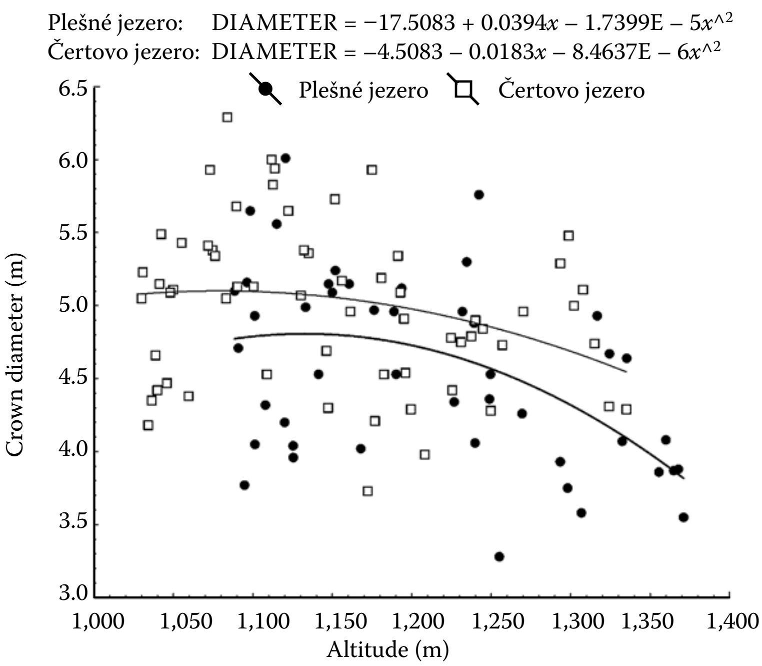


Fig. 5. The relationship of mean crown diameter (D) and altitude in the dataset of analyzed catchments (coefficients of determination r^2 are 0.24 and 0.07 in the Plešné and Čertovo Lake, respectively)

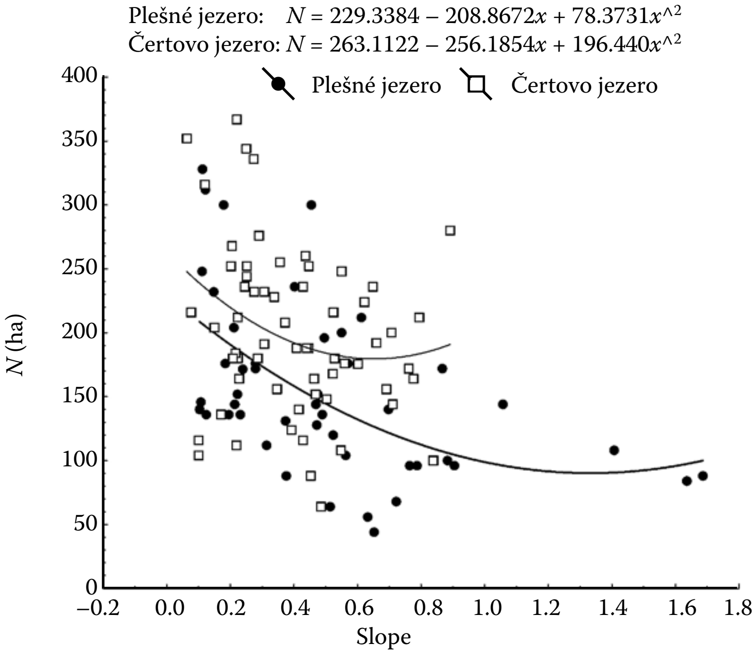


Fig. 6. The relationship of tree density and inclination (slope gradient) in the datasets of analyzed catchments (coefficients of determination r^2 are 0.29 and 0.08 in the Plešné and Čertovo Lake, respectively)

et al. (2006a) because different calculation was carried out.

Catchment of Čertovo jezero Lake

Trees demonstrate a random to regular pattern in the prevailing part of sample plots (Fig. 3). The first signs of aggregation are visible dispersed in width border strip by the edge of the catchment as a consequence of tree damage.

Average density is 200 trees/ha (standard deviation 65.7). Tree density is less dependent on altitude, nevertheless, the relationship is similar to that from the previous catchment (Fig. 4). A similar situation can be found in relation to inclination (Fig. 6). The whole curve is shorter because the inclination is dispersed in a narrower interval. Norway spruce trees have bigger crown diameters than in the catchment of Plešné jezero Lake. The relation of tree height to altitude is flatter (Fig. 7).

Basic statistics for crown diameter are the mean of 4.9 m, standard deviation 1.27 and skewness 0.45 (very important deviation from 0 on the level $\alpha < 0.1\%$). Larger crowns of trees with slenderer stems point to more favourable growth conditions and younger stand around the Čertovo jezero Lake compared to the Plešné jezero Lake. Lower values

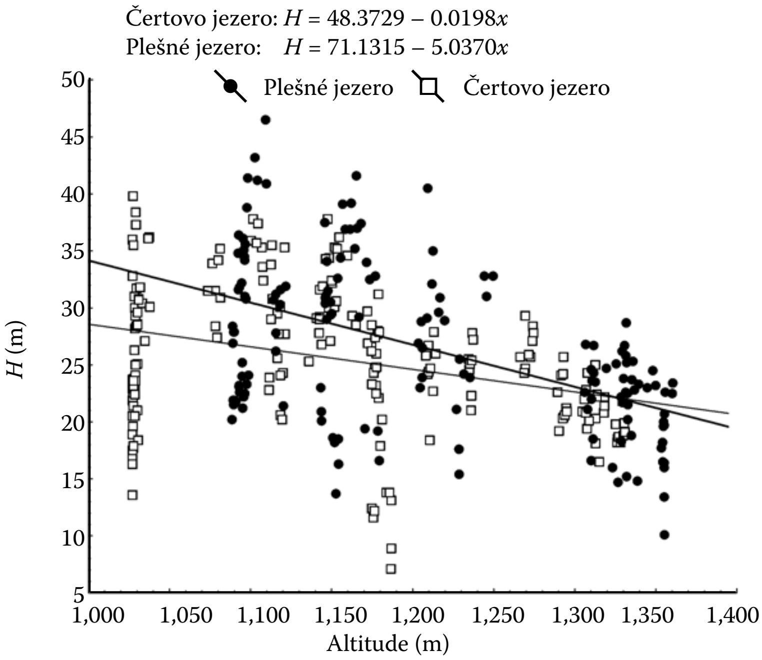


Fig. 7. The relationship of tree height (H) and altitude for the sampled trees in the datasets of analyzed catchments (correlation coefficients r are –0.51 and –0.31 in the Plešné and Čertovo Lake, respectively)

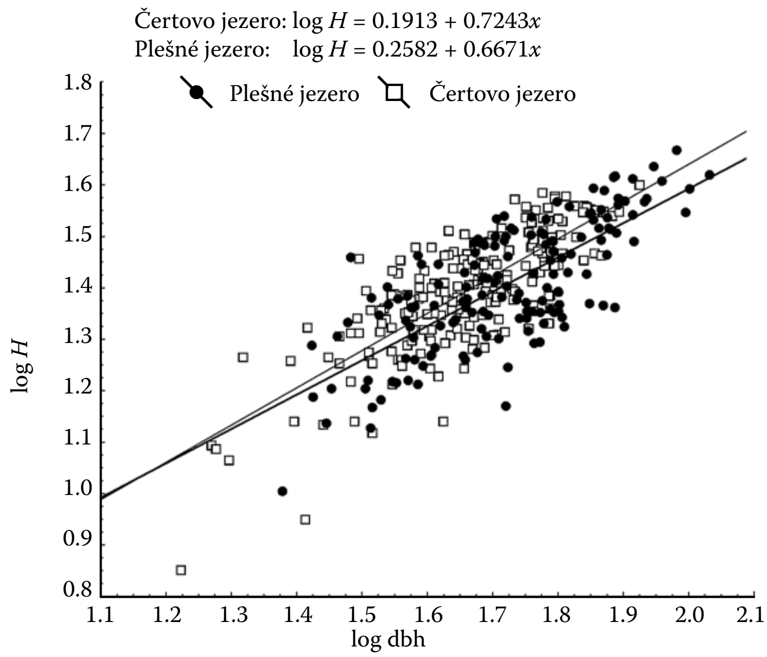


Fig. 8. Tree height versus tree diameter at breast height in both catchments on the basis of sampled trees (correlation coefficients *r* are 0.74 and 0.78 in the Plešné and Čertovo Lake, respectively)

describing size variability are typical of forests under planting. The numerical differences can be confronted with graphical means – histograms (Fig. 9).

Size parameters of individual spruces in sample squares were assessed according to regression in the set of terrain sample trees (dbh = 25.2 + 4.58 × D; H = 23.3 – 0.0045 × ALTITUDE + 1.52 × D). These equations are similar to regression in the Plešné jezero Lake catchment. Individual tree biomass (Table 3) is lower than in the first catchment. The average total stand biomass of spruce was 156 t/ha (Table 4). Accompanying beech is less important because the size of individual trees is smaller (Table 5, data from Svoboda et al. 2009). Beech reaches up to 1,250 m a.s.l. It is in agreement with determining the lower altitudinal limit of the natural spruce belt (8th zone), which lies between 1,150 and 1,250 m in the region of the Bohemian Forest Mts.

It is necessary to remember tree cutting in the past. This fact moderates parameters of the canopy – tree composition (increase in spruce), (higher) tree density and, as assumed, even the age. Sites are probably impoverished of the nutrient content resulting in the poorer herb layer (Svoboda et al. 2006b).

Comments on the method used

The combination of aerial photos and land survey aimed at single trees for determination of tree stand biomass was tested in two localities. The main deviation in total biomass depends on the method used for calculation. The precondition of existence of an error in the measurement of trees with large crowns

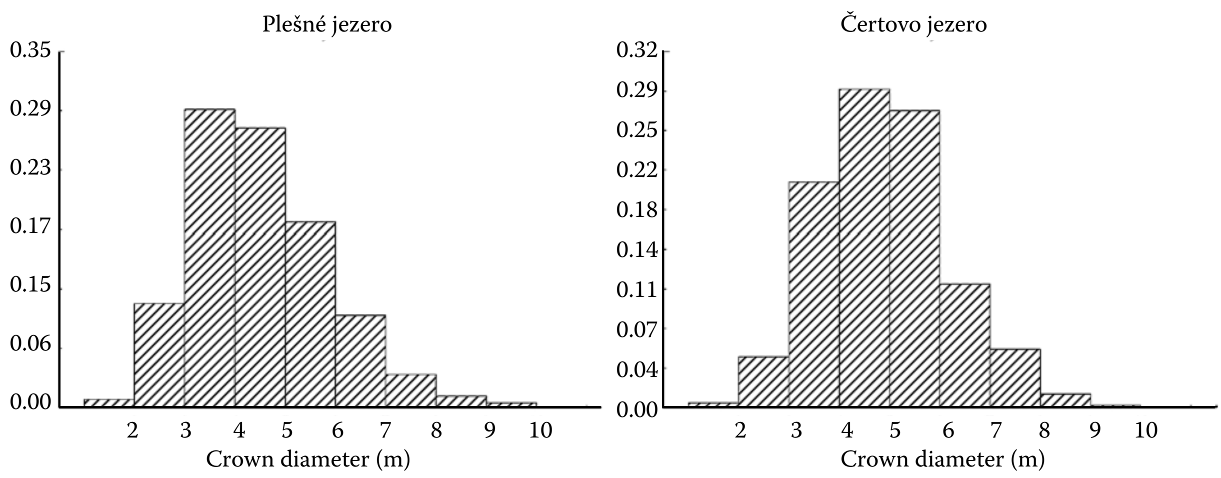


Fig. 9. The frequency of trees in the sample squares according to crown diameter

Table 1. Average size/biomass parameters of single tree (*Picea abies* L.) in the Plešné jezero Lake catchment according to trees in the set of sample squares. *N* – number of trees in sample squares, dbh – estimated average tree diameter at breast height, *H* – estimated average tree height

Altitudinal zone	*N*	dbh (cm)	*H* (m)	Stem wood	Stem bark	Foliage	Branch	Root
						(kg)		
0 (< 1,100 m)	139	54.5	30.2	965.3	54.8	79.8	175.1	206.9
1 (1,100–1,150 m)	463	53.9	28.9	917.5	52.2	75.7	163.0	196.1
2 (1,150–1,200 m)	274	54.3	27.4	887.7	50.5	73.2	155.3	189.3
3 (1,200–1,250 m)	196	54.5	25.4	841.5	47.9	69.2	144.1	178.9
4 (1,250–1,300 m)	128	52.6	23.3	742.2	42.3	60.8	120.3	156.6
5 (1,300–1,350 m)	318	53.2	21.6	710.0	40.5	58.1	113.0	149.5
6 (> 1,350 m)	197	51.5	19.6	626.9	35.8	51.1	94.5	131.1

Table 2. Stand biomass in the Plešné jezero Lake catchment

Altitudinal zone	Total area (ha)	Tree density (ha)	Stem wood	Stem bark	Foliage	Branch	Root	Total
					(t/ha)			
0 (< 1,100 m)	4.781	209.0	201.8	11.46	16.67	36.61	43.25	309.8
1 (1,100–1,150 m)	13.927	162.7	149.3	8.49	12.32	26.52	31.90	228.5
2 (1,150–1,200 m)	10.232	134.9	119.8	6.81	9.87	20.95	25.54	182.9
3 (1,200–1250 m)	9.077	125.6	105.7	6.01	8.69	18.10	22.47	160.9
4 (1,250–1,300 m)	5.379	134.7	100.0	5.70	8.19	16.20	21.10	151.2
5 (1,300–1,350 m)	8.583	162.4	115.3	6.57	9.43	18.35	24.27	173.9
6 (> 1,350 m)	4.505	192.7	120.8	6.90	9.84	18.21	25.26	181.0
Whole catchment	56.484		129.2	7.35	10.63	22.13	27.47	196.8

Table 3. Average size/biomass parameters of single Norway spruce (*Picea abies* L.) tree in the Čertovo jezero Lake catchment according to trees in the set of sample squares. *N* – number of trees in sample squares, dbh – estimated average tree diameter at breast height, *H* – estimated average tree height

Altitudinal zone	*N*	dbh (cm)	*H* (m)	Stem wood	Stem bark	Foliage	Branch	Root
						(kg)		
0 (< 1,050 m)	577	38.2	20.9	560.8	32.0	45.9	89.7	118.1
1 (1,050–1,100 m)	410	45.7	24.4	707.7	40.3	58.1	118.5	150.0
2 (1,100–1,150 m)	495	42.7	22.8	632.9	36.1	51.8	102.7	133.6
3 (1,150–1,200 m)	678	46.2	24.6	664.3	37.9	54.3	105.2	139.7
4 (1,200–1,250 m)	355	45.7	24.3	638.0	36.4	52.1	98.8	133.8
5 (1,250–1,300 m)	203	48.2	25.1	700.8	39.9	57.4	112.6	147.7
6 (> 1,300 m)	291	46.5	24.4	636.6	36.3	51.9	97.4	133.3

leads to a procedure based on sorting trees into size classes, where the size of the biggest trees can be limited (Svoboda et al. 2006a). The resulting value represents the lower approximation of tree biomass stock – 134 t/ha in the Plešné jezero Lake catchment. It accounts for 68% of biomass assessed according to

Table 4. Stand biomass of Norway spruce (*Picea abies* L. only) in the Čertovo jezero Lake catchment

Altitudinal zone	Total area (ha)	Tree density (ha)	Stem wood	Stem bark	Foliage	Branch	Root	Total
			(t/ha)					
0 (< 1,050 m)	10.173	152.2	85.4	4.86	6.98	13.65	17.98	128.8
1 (1,050–1,100 m)	15.005	147.0	104.1	5.92	8.54	17.42	22.05	158.0
2 (1,100–1,150 m)	14.294	147.4	93.3	5.32	7.64	15.14	19.69	141.1
3 (1,150–1,200 m)	14.601	153.3	101.8	5.80	8.32	16.12	21.42	153.5
4 (1,200–1,250 m)	10.320	164.6	105.0	5.99	8.57	16.27	22.03	157.9
5 (1,250–1,300 m)	6.370	181.5	127.2	7.25	10.41	20.44	26.81	192.1
6 (> 1,300 m)	5.449	203.8	129.8	7.40	10.58	19.86	27.18	194.8
Whole catchment	76.212		103.0	5.87	8.43	16.51	21.71	155.5

the method based on individual trees in the selected sample squares. It is not possible to decide between both approaches because field measurements are missing.

Russ and Cienciala (2007) carried out the field inventory of tree biomass in the area of Plešné jezero Lake with a boundary line somewhat different from the catchment border. Their results are similar to the present values: total trunk biomass 143.4 t/ha (+5.0% comparing data in Table 1), branches 42.9 t/ha (+94%), foliage 11.1 t/ha (+4.7%), and roots 39.5 t/ha (+44%). The values for trunk biomass are very close. A large difference is in branches.

CONCLUSIONS

This paper brings a description of the method for assessment of tree stand biomass based on the combination of georeferenced colour aerial photos and limited field measurement of individual trees. The used method of tree measurement on the basis of aerial photos is based on the same principle as some other approaches – for instance automated detection of trees (tree tops) described by Šumbera and Židek (2002). The technique was carried out in two localities of Norway spruce forests – small catchments of natural lakes in the Bohemian Forest (56 and 76 ha in size, respectively).

Table 5. Stand biomass of European beech (*Fagus sylvatica* L.) estimated according to Svoboda et al. (2009)

Altitudinal zone	Tree density (ha)	Total biomass (t/ha)
0 (< 1,050 m)	86.4	35.1
1 (1,050–1,100 m)	68.5	27.8
2 (1,100–1,150 m)	50.6	20.5
3 (1,150–1,200 m)	32.7	13.3
4 (1,200–1,250 m)	14.8	6.0
5 (1,250–1,300 m)	0	0
6 (> 1,300 m)	0	0
Whole catchment		17.4

The catchment of Plešné jezero Lake represents a typical Norway spruce stand of the region. The phenomenon of an anemo-orographical system (Jeník 1961) is visible there demonstrated in the differentiation of environmental conditions of sites at separate places according to altitude and/or inclination.

The catchment of Čertovo jezero Lake lies approximately 50 m lower. The structure of the stand was changed during the last two centuries. The cutting was performed there resulting in an increase in Norway spruce and a decrease in both the tree average age and the size. Total stand biomass is decreased by 12% compared to the Plešné jezero Lake catchment.

There are some features common to both catchments: (a) Regular to random tree pattern prevails. Tree clumping is typical of the most extreme stands. (b) Minimum tree density occurs in the zone of altitudes 1,200–1,250 m a.s.l. (c) The crown diameter per dbh ratio is independent of altitude. (d) Tree height decreases linearly with altitude. (e) Distribution of trees according to crown diameter is skewed to higher values.

Presented data describes the situation at the date of photography (in 2000). The current situation is quite different. Serious dying of the tree layer around the Plešné jezero Lake was caused by the bark beetle (*Ips typographus*) gradation. Some parts of the Čertovo jezero Lake catchment were affected by last winds.

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Odhad stromové biomasy pomocí leteckých snímků v povodí dvou jezer na Šumavě

ABSTRAKT: Pro určení porostní biomasy lesů s převahou smrku bylo použito kombinace barevných leteckých snímků zpracovaných do podoby ortofotomap a měření vybraných jednotlivých stromů v terénu. Tato technika byla využita na dvou lokalitách – v malých povodích glaciálních jezer na Šumavě (Plešné jezero, plocha povodí 56 ha, a Čertovo jezero s odpovídající plochou povodí 76 ha). Tato metoda není tak pracovně náročná jako odhady založené na měření celých zkusných ploch, zvláště pak v podmínkách náročného horského terénu. Metoda je založena na poloautomatickém odhadu velikosti korun jednotlivých stromů z ortofotomap pomocí vlastního programového vybavení. Povodí Plešného jezera může být popsáno následujícími parametry: smrk je silně dominantním druhem dřeviny, zastoupení ostatních druhů ve stromovém patře je z hlediska odhadu porostní biomasy zanedbatelné, střední průměr korun stromů 4,5 ± 1,35 m, rozpětí průměrné výšky stromů 19,6 až 30,2 m v závislosti na nadmořské výšce (průměr a směrodatná odchylka pro jednotlivé stromy jsou 25,5 ± 3,9 m), počet stromů na plochu 154 ± 67,7 ha a průměrná biomasa porostu 197 t/ha. Povodí Čertova jezera vykazuje podobné hodnoty: smrk je doprovázen jedlí (jejíž odhad biomasy byl počítán jako biomasa smrku, protože na základě zpracovávaných leteckých snímků není odlišitelná od smrku) a bukem, střední průměr korun stromů (smrk) 4,9 ± 1,35 m, průměrná výška stromů se pohybuje mezi 20,9 a 25,1 m (průměr a směrodatná odchylka pro jednotlivé stromy jsou 25,6 ± 2,0 m), přičemž závislost na nadmořské výšce je slabší oproti prvému povodí, hustota stromů je 200 ± 65,7 ha (všechny tyto údaje jsou pouze pro smrk); porostní biomasa byla odhadnuta ve výši 156 t/ha (smrk) + 17 t/ha (buk). Některé parametry jsou společné pro obě povodí: převažuje pravidelné až náhodné rozmístění stromů v porostu. Shlukovitost rozmístění stromů je typická pro extrémní polohy (například v okolí stěny karu). Minimální hustota stromů se vyskytuje okolo nadmořské výšky 1 200 až 1 250 m. Poměr průměru koruny a dbh je nezávislý na nadmořské výšce. Výška stromů klesá lineárně s nadmořskou výškou. Rozdělení frekvence stromů podle průměru koruny je zešikmeno k vyšším hodnotám.

Klíčová slova: alometrie; výškový gradient; Šumava; průměr koruny; povodí; ortofoto; *Picea abies* L.

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