Local variability of stand structural features in beech dominated natural forests of Central Europe: implications for sampling

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Objectives:

The objective of this study was to identify the within-site variability of major stand structural features: i.e. density (N_{live}), basal area (BA_{live}) and volume (V_{live}) of living trees, volume of coarse woody debris (V_{CWD}), total volume (V_{total}) and proportion of CWD from total volume (R_{CWD}) in beech-dominated natural stands of Central Europe. In addition, this within-site structural variability is tested as it is directly reflected by different simulated sampling schemes. As a result, two main questions are answered:

1. How do major stand structural characteristics vary at local scales in dependence on the size of sample plots?

2. How many and what size sample plots are needed to estimate particular stand characteristics with acceptable accuracy?

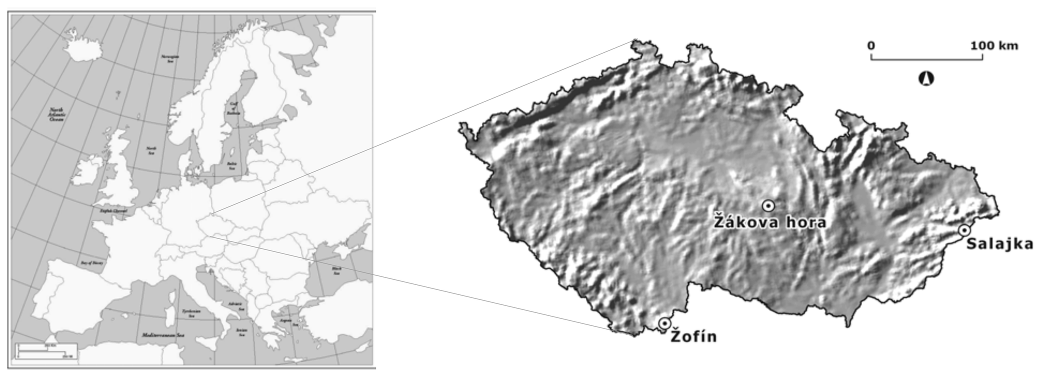

Fig. 1. Location of study sites.

Plot size	Square
0.01ha	10x10m
0.04ha	20x20m
0.09ha	30x30m
0.25ha	50x50m
0.49ha	70x70m
1ha	100x100m
2ha	140x140m
4ha	200x200m

Table 1 Size of sample plots used.

Methods:

The study makes use of stem-position datasets from three different beech-dominated natural forests in the Czech Republic – Zofin, Salajka and Zakova hora (Fig. 1). All standing and downed trees of DBH ≥ 10 cm within the core areas of the three localities have previously been mapped and the DBH recorded. The resulting stem position maps (Fig. 2) with linked databases provided detailed data about stand structure to be used in these analyses (in total about 29 000 trees on 107ha).

The stem position maps were used for a computer-simulated placement of different sized plots using a moving window method (Zenner, 2005; Kral *et al.*, 2010). The focal filter scanned the input stem position map, shifting at each step by one meter and calculating the number, basal area and volume of trees inside the window. In this manner all three study sites were examined using square sample plots of the following sizes: 10x10m; 20x20m; 30x30m; 50x50m; 70x70m; 100x100m; 140x140m and 200x200m (Table 1). Reference mean values for particular characteristics and study sites were calculated from total site datasets excluding a 50m buffer around the site border.

Basic statistics (mean, standard deviation, minimum and maximum) were calculated for all sampling distributions for every plot size and each of the six major stand characteristics produced by focal filtering as described above (Table 2). Variabilities of derived characteristics were compared for different plot sizes using coefficients of variation. The change in coefficients of variation with increasing plot size was evaluated by regression modeling (power functions were used; Table 3, Fig. 3).

The number of plots n needed to estimate the mean of appropriate characteristics within an error d at an error rate α was calculated by an iterative solution of (Zar, 1996):

$$n = \frac{s^2 \cdot t^2_{\alpha(2),n-1}}{d^2}$$

where t is the Student's *t*-statistic and s^2 the population variance estimate. Total sampling area (sample size) was calculated for each plot size and suggested number of plots (Table 4).

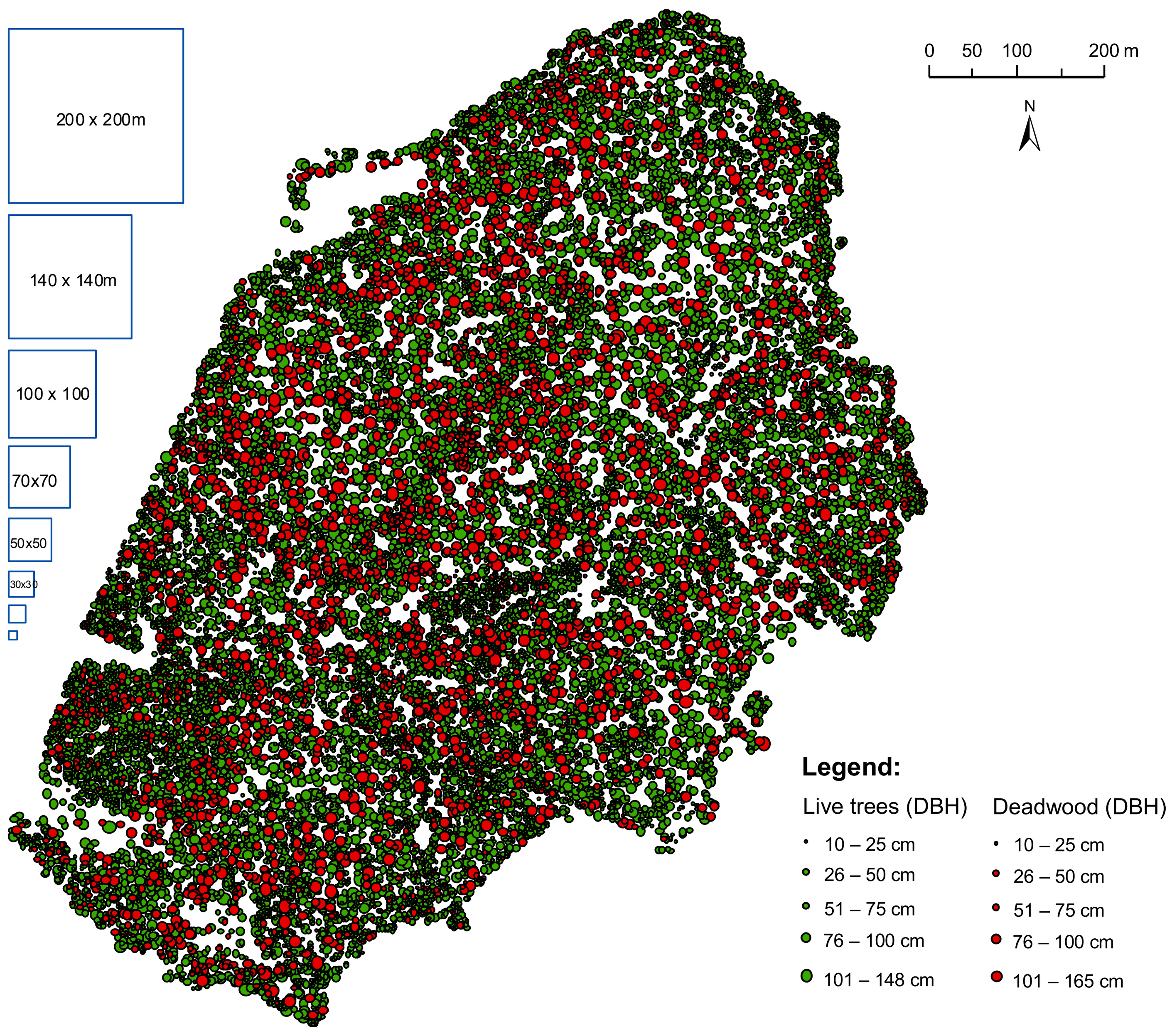

Fig. 2. Stem-position map of the Zofin study site with indicated size of used sample plots.

Results:

As expected, the within-site relative variability of major stand structural features decreased with increasing plot size. For particular stand features, the observed trend was expressed by significant regression models ($y = a \cdot x^b$) with high coefficients of determination across all study sites (Table 3, Fig. 3). According to the Chow (1960) test, the regression models appear to be specific for particular stand characteristics or pairs of related characteristics. Comparable trends in variation with increasing plot size can be observed between BA_{live} and V_{live} and between V_{CWD} and R_{CWD}, both of which can be expressed by a common regression model for the pair (Fig. 4, summarized in Table 3). The variability of V_{total} has a similar trend as BA_{live} and V_{live} , but is generally slightly lower (Fig. 4). The variability trend of N_{live}, however, is different – the curve is generally more flat and relative variability is slightly higher (except for the smallest plot sizes). The deadwood variables (i.e. V_{CWD} and R_{CWD}) have significantly distinct variability trends, with relative variability generally almost twofold that of living trees (e.g. BA_{live} and V_{live}).

The results further show that even hectare by hectare values are still highly variable; e.g., the volume stock of living trees can range from 474 to 1049 m3/ha within one study site (Table 2). Hence, single samples of one hectare can be poorly representative for a site.

We also calculated the minimal number of plots and total sampled area required for estimations of major stand features to within 20% (± 10%) of the mean with 95% confidence for particular plot sizes (Table 4). We emphasize that the recommended plot numbers and sizes given here apply only to estimates of the stand structural variables studied.

Feature	10x10m				100x100m				200x200m			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
N_{live}	205.1	169.7	0.0	1800.0	206.1	61.2	76.0	426.0	203.4	49.2	124.0	325.8
BA_{live}	40.6	39.4	0.0	291.2	40.9	5.5	28.0	69.6	40.5	2.9	34.4	53.3
V_{live}	692.1	705.7	0.0	6136.0	694.5	76.8	473.9	1048.6	689.8	38.0	578.0	843.0
V_{total}	894.1	783.3	0.0	6136.0	896.7	97.9	605.0	1285.2	897.6	55.5	730.9	1055.5
V_{CWD}	202.0	422.7	0.0	5066.0	201.6	59.7	49.0	401.8	207.8	35.7	102.2	310.4
R_{CWD}	21.1	34.3	0.0	100.0	22.3	5.4	5.5	41.2	23.1	3.1	13.2	31.0

Table 2 Statistics for major stand structural features at Zofin, derived from sample plots of different sizes; SD signify standard deviation.

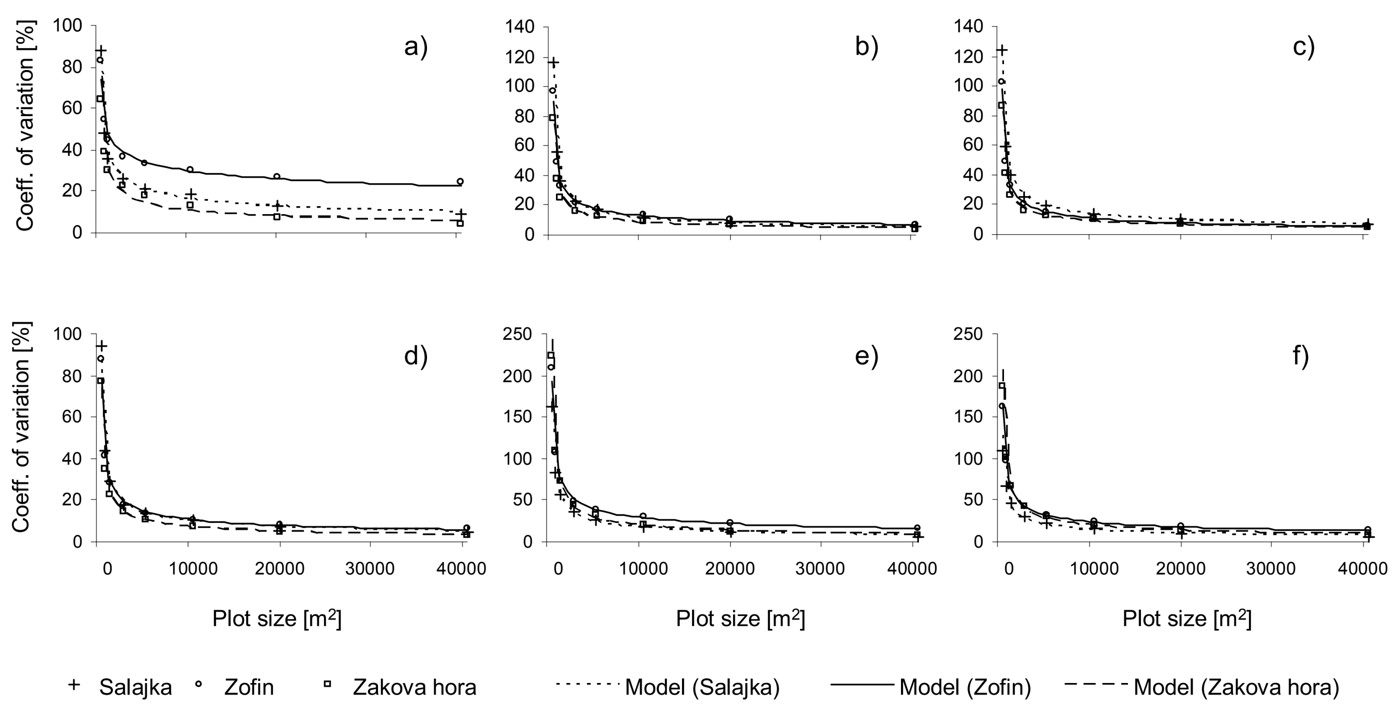

Fig. 3. Coefficient of variation [%] of density (a), basal area (b) and volume (c) of living trees; total volume (d), volume of CWD (e) and proportion of CWD from total volume (f) in relation to plot size [m²] in the three study sites, fitted by the regression models $y = a \cdot x^b$.

Feature	a	b	R^2	p
N_{live}	349.004	-0.327	0.735	< 0.001
BA_{live} [a]	799.265	-0.470	0.960	< 0.001
V_{live} [a]	892.338	-0.479	0.965	< 0.001
V_{total}	714.838	-0.475	0.965	< 0.001
V_{CWD} [b]	1920.234	-0.490	0.945	< 0.001
R_{CWD} [b]	1446.883	-0.472	0.941	< 0.001
BA, V_{live} (a)	*844.520*	*-0.474*	*0.962*	*< 0.001*
V, R_{CWD} (b)	*1666.840*	*-0.481*	*0.938*	*< 0.001*

Table 3 Specifications of the regression models ($y = a \cdot x^b$) of CV [%] in relation to plot size [m²] based on data from all three study sites. The models labeled with the same letter are, according to the Chow test, better fitted by a single (common) regression model (introduced at the bottom of the table).

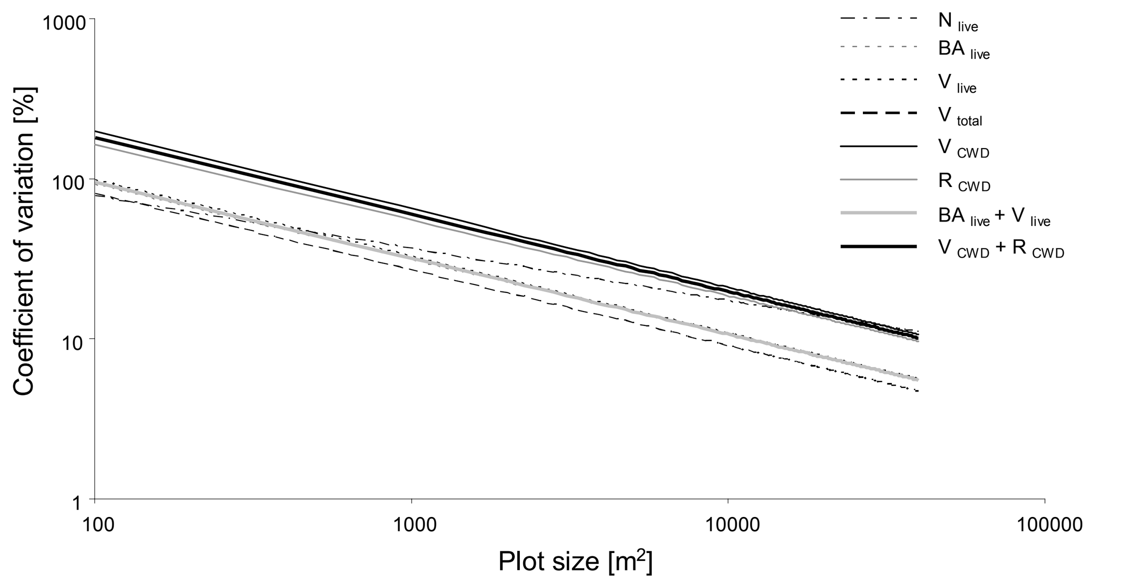

Fig. 4. Regression models ($y = a \cdot x^b$) of the coefficients of variation [%] in relation to plot size [m²]; all three study sites together. The axes of the graph are in logarithmic scale.

Feature	Plot size [m]	10x10	20x20	30x30	50x50	70x70	100x100	140x140	200x200
	Plot area [ha]	0.01	0.04	0.09	0.25	0.49	1.00	1.96	4.00
N_{live}	No. of plots	234	96	58	31	21	14	10	7
	Total sampling area [ha]	*2.34*	*3.84*	*5.22*	*7.75*	*10.29*	*14.00*	*19.60*	*28.00*
V_{total}	No. of plots	251	69	34	15	9	6	4	3
	Total sampling area [ha]	*2.51*	*2.76*	*3.06*	*3.75*	*4.41*	*6.00*	*7.84*	*12.00*
BA_{live}, V_{live}	No. of plots	350	96	46	19	12	7	5	4
	Total sampling area [ha]	*3.50*	*3.84*	*4.14*	*4.75*	*5.88*	*7.00*	*9.80*	*16.00*
V_{CWD}, R_{CWD}	No. of plots	1272	337	156	60	33	18	11	7
	Total sampling area [ha]	*12.72*	*13.48*	*14.04*	*15.00*	*16.17*	*18.00*	*21.56*	*28.00*

Table 4 The minimal number of plots and total sampling area required for estimations of main stand characteristics to within 20% (± 10%) of the mean with 95% confidence for various plot sizes according to Zar (1996).

Conclusions:

Observed trends in variability of estimates along increasing plot sizes appear to closely follow the power function $y = a \cdot x^b$. It appears that plot sizes between 0.01 and 0.09ha would be the most efficient for sampling the above-mentioned variables in European beech-dominated natural forests. Considering our results (Table 4), one can conclude that a range of historical and recent studies have been based on insufficient and/or biased datasets, especially when research plots were placed subjectively.

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The paper: "Král et al.: Local variability of stand structural features in beech dominated natural forests of Central Europe: implications for sampling" is currently under review in the journal of Forest Ecology and Management ©.