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COMPARATIVE ANALYSIS OF RESULTS OBTAINED FROM DIFFERENT SHAPES OF SAMPLE PLOTS IN PARTIAL INVENTORY OF HIGH BEECH FORESTS IN MONTENEGRO

SUMMARY

The paper presents the results of a comparative analysis of the number of trees, stand volume and the position of the height curve within the height overdiameter curves, obtained through a partial survey of high beech forests on different shapes of sample plots: concentric circles used in Montenegro (CC CG), concentric circles used in Serbia (CC RS) and angle count sampling (WZP RS) applied in the Serbian forest inventory. Data processing was conducted in Osnova software and within a GIS environment. Height curves were modelled using the Näslund function, while spatial interpolation of results was performed using the Spline with Barriers method. Regarding the average number of trees and average volume, although the CC CG method produced the lowest values, it is difficult to determine which plot shape is superior. The reason lies in the differing elements of partial survey designs among the tested plot types (number, size, sampling intensity, number of detailed subplots, etc.). However, since the studied stand belongs to selection forests, which represent extremely heterogeneous structural forms, we consider that priority should be given to angle count sampling (WZP RS). This method is based on unequal probabilities of tree selection for measurement, specifically the likelihood of a tree being selected is proportional to its diameter which undoubtedly contributes to a more reliable determination of stand volume under the given conditions. Furthermore, we consider that the method of selecting trees for height measurement in the forest inventory of Montenegro does not ensure a representative sample for accurate modelling of the height curve. As a result, poorer height classes are determined, leading to lower stand volume values. Spatial visualization through raster analysis facilitates planning and decision-making in forest management planning, as it provides a more realistic insight into internal stand variations that are often overlooked in conventional tabular presentations. In this context, GIS software and raster analyses represent

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efficient tools for the assessment, comparison and visualization of field data results, enabling better decision-making and improvement of forest resource management.

Keywords: partial inventory, concentric circles, angle count sampling, comparative analysis of results, raster analysis, spatial interpolation

INTRODUCTION

The numerous and complex objectives of contemporary forest management planning necessitate the development of a planning system that at all levels, from operational to strategic, has an integrated character (Medarević, 2006; Golubović, 2024). Over time, the goals of forest management have evolved from the aim of ensuring continuous production, yield and revenue in wood (a monofunctional approach) toward the objective of multifunctional utilization of the overall forest potential within forest areas, as encompassed in the globally accepted definition of sustainable forest management. Therefore, every decision-maker in forestry must take into account a variety of criteria that influence the selection of management strategies and methods (Medarević *et al*., 2006; Pantić *et al*., 2015; Golubović, 2024). The fundamental assumption for developing realistic forest management plans is the availability of a wide range of highly reliable information about the forest resources. Such information is provided by forest inventory – a discipline that establishes the informational foundation of forestry (Banković *et al*., 2002). Forest inventory involves the collection, processing, evaluation and presentation of information about forest resources, their spatial distribution, structural composition, temporal (dynamic) development, degree of utilization and other relevant characteristics (Banković and Pantić, 2006; Pantić *et al.,* 2013a). In parallel with the overall development of forestry, particularly with the advancement of forest management planning, forest inventory has also necessarily evolved. This development has progressed from terrestrial methods of data collection using simple measuring instruments and manual data processing, through the introduction of modern measuring equipment and specially designed software packages for data processing, to the application of aerial photogrammetry and remote sensing (Borota, 2018). Furthermore, Geographic Information Systems (GIS) have become an indispensable component of the forest management planning process. Since most activities in forest management planning involve working with spatial data, the need for their efficient storage, processing and analysis has become increasingly pronounced. In this context, GIS represents a set of functions that enable advanced management of spatially referenced data, as well as their visualization and interpretation (Pantić *et al.,* 2013b). Raster analysis constitutes an essential component of modern data analysis in forestry, as it allows for the visualization and assessment of the spatial distribution of various data types, both attribute and numerical. Understanding the spatial heterogeneity of these values is of great importance for assessing the condition and potential of forest resources, as well as for making timely and sound decisions in forest management planning. Given the importance of forest inventory from the perspective of forestry as a whole and the sophisticated techniques it employs for data collection, processing and database development at various levels of forest spatial division, the objective of this research was defined accordingly. It lies in determining the most suitable shape of sample plots used for partial inventory in high beech forests of Montenegro, based on a comparative analysis of the number of trees, stand volume and the position of the height curve within the height overdiameter curves (height class determination). The study also takes into account the fundamental elements of measurement on different plot types, such as sample size, measurement intensity and the number of measured tree heights. Pure and mixed beech forests account for 21.4% of the total forest area of Montenegro, 33.9% of the total growing stock and 28.5% of the volume increment, with relatively high values of these elements expressed per hectare (Dees *et al.,* 2013). In studies conducted in Biogradska Gora, Čurović *et al.* (2011) reported high productivity within different subassociations of beech forests, ranging from 365 to 775 m³/ha. Regarding biodiversity, even 58 vascular plant species were recorded on a relatively small area within these forests (Čurović *et al.,* 2020). These findings point to the exceptional multifunctional importance of Montenegrin beech forests, not only at the local but also at the regional level. Therefore, the reliability of inventory data is a necessary prerequisite for preserving the ecological and structural stability, biological diversity and high productivity of these forests, which was the main motivation for the present research.

MATERIAL AND METHODS

Montenegro ranks among the most forested countries in Europe. In order to ensure the rational use and preservation of this natural resource for future generations, it is necessary to establish a planning and decision-making system that meets the numerous demands of modern society toward forests, while maintaining the functional permanence and stability of forest ecosystems. One of the prerequisites for rational and realistic planning is the existence of a wide range of highly reliable information about forests, provided through forest inventories.

Data collection

Data for this research were collected in stand 12/b of the management unit "Kaludarsko–Dapsićke šume," located in the municipality of Berane, in the northeastern part of Montenegro. Forest management in this area is carried out by the regional unit Berane within Administration for Forest and Hunting Management. According to its characteristics, the stand belongs to high beech forests. Data were collected through a partial inventory (Table 1), in accordance with the methodology applied in:

A. In Montenegro, the concentric circles method is applied for stands larger than 10 ha, arranged in a 100x100 m grid. On every second plot, for each tree species and diameter class of 26–65 cm, the heights of two trees per diameter class are measured.

B. In Serbia, until mid-2024, experts considered the previously applied methodology far superior to the one prescribed by the new Regulation (2024). It allowed for the selection of sample plot shapes, sample size and number of detailed subplots in accordance with the variability of the population (the stand), expressed through a certain degree of homogeneity.

Table 1. Basic elements of partial inventory according to methodologies A and B

Shape of sample plots	Stand area [ha]	Number of sample plots - n [no.]	Number of detailed sample plots - n_d [no.]	Plot size [are/counting factor]	Sampling intensity - Pp [%]	Distance - S [m]
CC CG	12,45	10	4	1, 2, 5, 10	8,0	100,0
CC RS	12,45	28	6	1, 2, 5, 10	22,5	66,7
WZP RS	12,45	28	6	2	37,8	66,7

Note: CC CG – concentric circles Montenegro; CC RS – concentric circles Serbia; WZP RS – angle count sampling plots Serbia.

It is important to note that the centers of the concentric circles and the circular angle count sampling plots used in Serbia were identical, which enabled a more accurate comparison of the results obtained from these two types of sample plots. Using GIS tools, the sample plots were systematically distributed across the stand area (a simple systematic sampling design). For the center of each sample plot, precise coordinates were determined and subsequently transferred to the field using handheld GPS devices during fieldwork activities.

Data processing

Data processing was carried out using classical dendrometric and statistical methods integrated into the “Osnova” software. To ensure a more consistent comparison of the obtained results and the derivation of relevant conclusions, the same version of the software was used for processing data collected from CC CG, as well as from CC RS and WZP RS. In addition to the measured tree diameters (d, cm) and heights (h, m), the input elements in the data processing procedure also included the stand area and the data describing site and stand characteristics. Numerous output parameters were generated through the data processing procedure, with this research focusing primarily on the number of trees, stand volume, their distributions and the height curve.

Depending on the shape of the sample plot, correction factors were applied to convert each tree within a given diameter class to a per-hectare basis and by summing these values N/ha was obtained for each sample plot within the stand. The arithmetic mean of N/ha across all sample plots represented the final N/ha value for the sample. This value, together with the standard error of the estimate, defines the range within which the number of trees in the population (the stand) varies.

The best statistical parameters in modeling the relationship h= f(d) (height curve) were obtained using the Näslund function:

$$h = 1{,}30 + \frac{d^2}{(a + b \cdot d)^2}$$

The application of the Näslund function for modeling the relationship between tree height and diameter is widely used in European forestry practice and has been confirmed in contemporary studies (Mehtätalo *et al.,* 2015; Sharma and Breidenbach, 2015; Liziniewicz *et al.,* 2016; Holmström *et al.,* 2018; Lidman *et* *al.,* 2021; Mensah *et al.,* 2022; Persson *et al*., 2022; Ogana *et al.,* 2023; Siipilehto *et al.,* 2023). The resulting height curves were used to determine the height class, since the stand volume was calculated using the tariff method:

$$V = \sum_{i=1}^{n} n_i \cdot v_i$$

v_i – volume of the mean tree in the diameter class,
n_i – number of trees in the diameter class expressed per hectare.

The procedure for calculating V/ha at the level of each sample plot, the calculation of the average volume of the sample and the estimation of the total stand volume based on the sample volume and the standard error of the estimate is identical to the procedure used for calculating the number of trees per hectare.

For the spatial analysis of the data obtained from field measurements, the Spline with Barriers method was applied within the ArcMap 10.8 software. The main objective of the interpolation was to display the spatial distribution of the number of trees and volume per hectare, based on the sample plots established within the stand. The input values used in the interpolation consisted of the number of trees and volume values positioned at the centers of all sample plots. Each sample plot represented a location where the number of trees was measured and the volume calculated, both converted to a per-hectare basis (Table 2). The Spline with Barriers method enables the generation of a continuous surface without abrupt transitions between sample plots, while treating stand boundaries as barriers that prevent the calculation of values beyond the actual limits of the analyzed area. This method is widely used in spatial analyses, as it provides a realistic representation of variability and prevents interpolation across physical barriers, as demonstrated by its applications in ecological and geomorphological studies (Hogg *et al*., 2016; Hogg *et al.,* 2021; Brophy *et al*., 2019; Wardell and Huvenne, 2022; Brenko *et al.,* 2024; Wang *et al.,* 2024; Bosso *et al*., 2025). This approach enabled the visualization of spatial variability of the analyzed parameters (number of trees and volume) within the specific forest complex. After creating individual rasters for each of the applied sample plot types used in the partial inventory (CC CG, CC RS and WZP RS), a comparison of results was performed to assess the level of agreement and deviation among the different approaches. For this purpose, the Raster Calculator function was used, allowing arithmetic operations on rasters within the GIS environment. By combining the corresponding rasters of tree numbers and volumes, formulas were applied to calculate the percentage differences per pixel. The calculation of these differences resulted in new rasters that visually and numerically represent the deviations per spatial unit, or per pixel.

The following formulas were used to calculate the differences in the number of trees and volume per hectare between the sample plot rasters:

$$R_1 = \frac{CC\ CG - CC\ RS}{CC\ RS} \cdot 100\%$$

$$R_2 = \frac{CC\ CG - WZP\ RS}{WZP\ RS} \cdot 100\%$$

$$R_3 = \frac{CC\ RS - WZP\ RS}{WZP\ RS} \cdot 100\%$$

RESULTS AND DISCUSSION

Number of trees, volume, distributions

The lowest number of trees and the lowest sample volume were obtained through the partial inventory using CC CG, amounting to 529 trees/ha and 338.2 m^3/ha (Table 2). For CC RS, these values were 614 trees/ha and 502.9 m^3/ha, while for WZP plots the number of trees was 679 trees/ha and the volume 461.4 m^3/ha. The standard error of the estimate for the number of trees ranged from 19.3% for CC RS to as high as 38.6% for CC CG. In terms of volume, this error ranged between 10.3% for WZP RS and 18.8% for CC CG. Considering the structural composition of the stand, if the values obtained from WZP sample plots are assumed to be the most relevant, the deviations (R_2) amount to -22.1% for the number of trees and -26.7% for the volume, while deviations (R_3) are -9.6% and 9.0%. The differences (R_1) are -13.8% for the number of trees and as much as -32.8% for stand volume (Table 3). Similar relationships between numerical elements obtained from concentric circles and WZP plots were reported in previous studies (Matérn, 1972; Bitterlich, 1984; Schreuder *et al.*, 1987; Scott and Alegria, 1989; Packard and Radtke, 2007; Piqué *et al.*, 2011; Leiter and Hasenauer, 2023).

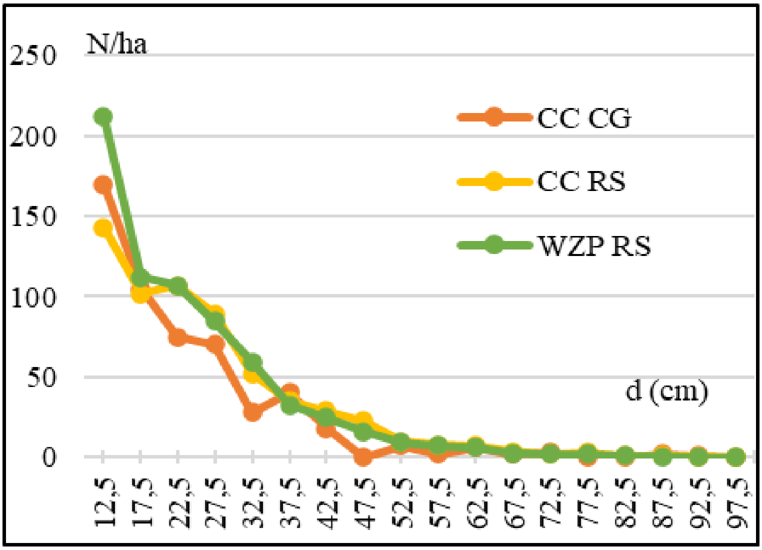
From the distribution of the number of trees by diameter classes (Figure 1), it can be seen that the stand structure is very close to a typical selection structure, even though in forest management plans it is defined as an uneven-aged stand with a long regeneration period, which implies age diversity.

The distributions of the number of trees and volume obtained through partial inventory on the tested shapes of sample plots show significant differences (Graphs 1 and 2, Table 3), confirming the findings of other authors who compared fixed (CC) and variable sample plots (WZP) (Lowell, 1997; Fallah *et al.,* 2000; Rios *et al.*, 2000; Motz *et al.*, 2010; Piqué *et al.,* 2011; Alijanpour *et al.,* 2018). The variation ranges of the distributions are pronounced (12.5–92.5/97.5 cm), as a consequence of the presence of trees of different dimensions, confirming that the stand is indeed of a selection type.

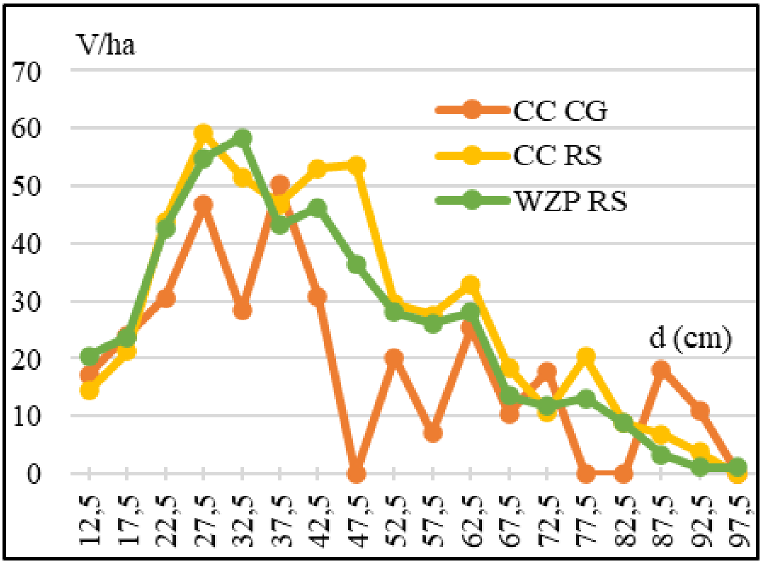
Table 2. Number of trees and volume per hectare obtained from the tested shapes of sample plots

Number of sample plot	CC CG		CC RS		WZP RS	
	N	V	N	V	N	V
	no./ha	m^3/ha	no./ha	m^3/ha	no./ha	m^3/ha
1	100	371,8	450	687,2	378	556,0
2	490	269,1	220	677,5	211	441,1
3	560	368,1	330	902,1	268	667,6
4	110	204,5	30	82,2	58	106,4
5	610	237,9	500	632,8	404	516,0
6	680	545,4	490	371,0	468	337,7
7	960	255,2	770	513,1	779	454,3
8	960	353,5	950	596,8	1174	598,2
9	140	427,7	410	448,0	505	537,3
10	680	362,7	930	420,1	1562	495,9
11	-	-	210	470,2	223	417,9
12	-	-	650	465,8	763	456,1
13	-	-	660	363,0	763	315,0
14	-	-	700	364,1	917	402,5
15	-	-	350	395,3	363	351,7
16	-	-	700	406,5	800	382,0
17	-	-	480	443,8	485	450,7
18	-	-	890	766,0	712	641,8
19	-	-	490	633,6	502	599,8
20	-	-	530	538,3	594	442,9
21	-	-	1070	675,2	1219	663,1
22	-	-	360	381,3	434	411,4
23	-	-	420	343,1	564	257,6
24	-	-	1330	618,4	1209	578,2
25	-	-	970	447,9	1288	382,5
26	-	-	500	528,9	445	457,5
27	-	-	560	473,5	580	507,1
28	-	-	1250	436,0	1354	495,0
$\bar{N}, \bar{V}$ *(ha)*	529	338,2	614	502,9	679	461,4
sN, sV (%)	38,6	18,8	19,3	12,1	21,6	10,3

Note: $\bar{N}, \bar{V}$ (ha) - average number of trees and volume per hectare in the sample; sN% – standard error of the estimate for the number of trees; sV% – standard error of the estimate for volume.



Graph 1. Distribution of the number of trees by diameter classes



Graph 2. Distribution of volume by diameter classes

Differences in the number of trees by diameter classes are significant and fall within the intervals: R_1=(–73.3)–185.7%, R_2=(–72.2)–900.0% and R_3=(–32.7)–300.0%. Differences in volume by diameter classes are also large, amounting to R_1=(–74.3)–189.5%, R_2=(–72.9)–900.0% and R_3=(–29.3)–245.5% (Table 3). It should be noted that in Table 3, a value of –100% represents the absence of trees or volume in the respective diameter class.

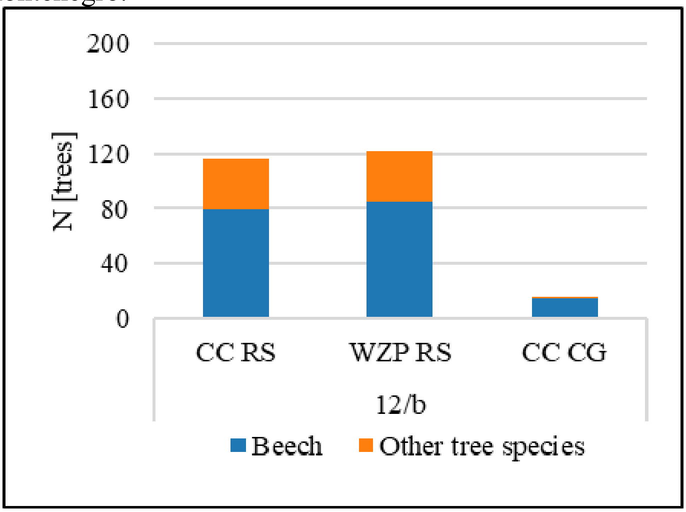
Table 3. Differences in the distributions of the number of trees and volume obtained from the tested shapes of sample plots

d (cm)	R_1=(CC CG–CC RS)/CC RS*100		R_2=(CC CG–WZP RS)/ WZP RS*100		R_3=(CC RS–WZP RS)/WZP RS*100	
	N/ha R_1 (%)	V/ha R_1 (%)	N/ha R_2 (%)	V/ha R_2 (%)	N/ha R_3 (%)	V/ha R_3 (%)
12,5	19,0	18,6	-20,0	-16,1	-32,7	-29,3
17,5	3,1	9,0	-6,3	1,3	-9,2	-7,1
22,5	-30,0	-30,5	-29,8	-28,6	0,2	2,8
27,5	-21,6	-21,0	-17,2	-14,8	5,7	7,8
32,5	-46,3	-45,0	-53,0	-51,3	-12,6	-11,5
37,5	14,3	7,5	23,1	16,4	7,7	8,3
42,5	-37,1	-41,7	-27,7	-33,3	14,9	14,5
47,5	-100,0	-100,0	-100,0	-100,0	44,0	47,1
52,5	-27,1	-31,8	-23,9	-28,1	4,3	5,3
57,5	-73,3	-74,3	-72,2	-72,9	4,2	5,3
62,5	-15,5	-22,8	-3,2	-9,6	14,5	17,1
67,5	-44,4	-43,8	-23,1	-23,5	38,5	36,0
72,5	66,7	67,3	57,9	51,7	-5,3	-9,3
77,5	-100,0	-100,0	-100,0	-100,0	61,1	55,0
82,5	-100,0	-100,0	-100,0	-100,0	-15,4	4,8
87,5	185,7	162,3	400,0	432,4	75,0	102,9
92,5	150,0	189,5	900,0	900,0	300,0	245,5
97,5	-	-	-100,0	-100,0	-100,0	-100,0
Difference at stand level	-13,8	-32,8	-22,1	-26,7	-9,6	9,0

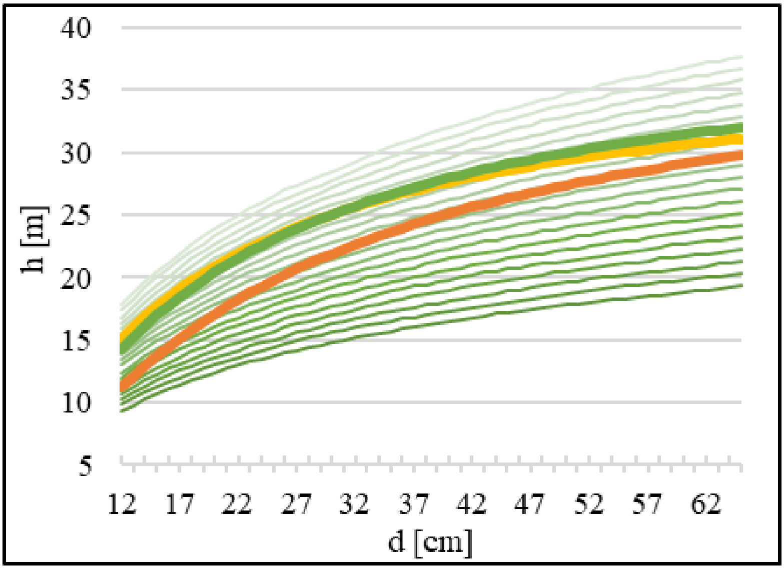
The analysis of differences in the average number of trees and volume per hectare in the sample, as well as differences in their distributions by diameter classes, does not allow for a definitive determination of the sample plot shape that provides the most accurate results under the given conditions. The reasons, among others, lie in the significantly lower sampling intensity of CC CG, which is 8%, compared to 22.5% for CC RS and 37.8% for WZP, as well as in the fact that the CC CG plots, due to their 100 m spacing, were located in different parts of the stand compared to CC RS and WZP RS plots, whose centers were positioned at the same locations, 67 m apart. The non-coincidence of the centers of the tested sample plots certainly affects the quality of the analyses and the conclusions drawn. Since the stand in question is of the selection type, representing an extremely heterogeneous structure, a complete inventory would yield the most accurate results. However, the Montenegrin Regulation (2016) does not recognize this measurement method, while the Serbian Regulation (2024) allows its optional application. Therefore, under the given conditions, preference should be given to angle count sampling. The reason lies in the fact that this type of partial inventory is based on unequal selection probability that is, the probability of a tree being selected for measurement is proportional to its importance for the final result. The selection structure is characterized by a large proportion of thin trees, hence, during measurement, priority must be given to trees that represent the main volume carriers large-diameter trees which is precisely the principle of unequal selection probability on which WZP is based.

Height curve, height classes

Based on the measured heights from the detailed sample plots, the relationship h=f(d) was modeled, resulting in height curves that were used to determine the stand's belonging to a specific height class (tariff series). The number of detailed sample plots for CC RS and WZP RS was 6 each (Table 1), with tree heights measured for every tree above the inventory threshold, resulting in 79 and 85 measured beech heights, respectively, as the dominant tree species on these plot types. For CC CG, 4 detailed plots were established; however, due to the measurement method applied (two heights per tree species within diameter classes of 26–65 cm), only 14 beech heights were obtained, which is considerably lower than the realistically possible and required number (Graph 3). Since the quality of the height curve directly depends on the number and accuracy of the measured tree heights (Sharma, Parton, 2007; Nowak *et al.,* 2008; Pretzsch, 2009; Alijanpour *et al*., 2018; Leiter, Hasenauer, 2023; Ogana *et al*., 2023; Siipilehto *et al.,* 2023), it is evident that the quality of the curve for CC CG is lower compared to the curves obtained from the other tested sample plot types. The position of the CC CG curve within the height bundle is significantly lower than that of the other two curves (Graph 4), which directly affected the determination of the tariff series and, consequently, the stand volume. These findings indicate the need to re-examine the validity of the height measurement methodology applied in the partial inventory of forests in Montenegro.



Graph 3. Number of measured tree heights



Graph 4. Position of height curves within the height overdiameter curves

Raster analysis

Raster analysis provided additional insight into the spatial distribution of the number of trees and volume within the studied stand, obtained through partial inventory using the tested shapes of sample plots. It also enabled a visual examination of the influence of plot shape, measurement intensity (sample size) and the scope of input data on interpolation results and the spatial structure of the forest resources. Essentially, this analysis served as a logical continuation of the previous comparisons, aimed at a more detailed examination of the differences in results that arose from the application of different sample plot shapes in the partial inventory.

The spatial distribution of the number of trees obtained from CC CG (Figure 1 – left) shows a relatively uniform pattern, with fewer transition zones between distribution groups. This pattern is a consequence of the smaller number of sample plots, which limits interpolation possibilities and reduces spatial resolution. One large zone of high density (over 1,200 trees/ha) stands out, though without pronounced internal heterogeneity. The inventories based on CC RS (Figure 1 – center) and WZP RS (Figure 1 – right) display a much more complex spatial structure. A larger sample and more even stand coverage resulted in a higher degree of data variability and the occurrence of local extremes. In the case of CC RS, areas of higher density are noticeable in the western and eastern parts of the stand, while WZP RS, although following the same layout, shows slightly higher values in the central and southeastern zones. These shapes more accurately reflect the actual heterogeneity of the stand.

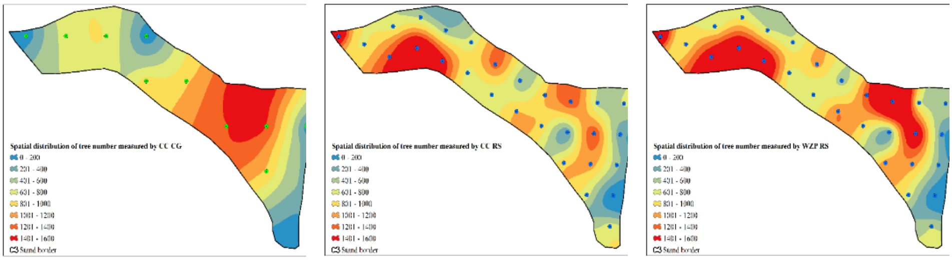


Figure 1. Spatial distribution of the number of trees (left – CC CG; center – CC RS; right – WZP RS)

The percentage differences in the number of trees obtained from the tested shapes of sample plots are shown in Figure 2.

•CC CG:CC RS (Figure 2 – left): The differences reach extreme values, exceeding 4,000% in zones where CC CG data are absent or minimal. Such large deviations indicate insufficient representativeness of the CC CG sample for a stand structure similar to a typical selection structure. Most areas are displayed in blue-green tones (differences up to 500%), but in the outer zones, CC CG plots can be observed where the number of trees is underestimated compared to the reference CC RS.

•CC CG:WZP RS (Figure 2 – center): Spatially, the deviations occur in zones that are poorly covered by CC CG plots, which once again indicates the limited reliability of this plot type in terms of interpolation accuracy.

•CC RS:WZP RS (Figure 2 – right): When comparing the number of trees obtained from these two sample plot types, the smallest mutual deviations were recorded, with most differences around ±30%. This outcome is expected, as both plot types use the same grid layout (distribution across the stand area), meaning that the differences arise solely from the distinct sampling methods, specifically, the way trees are selected for measurement. The sample size and the number of measured trees directly influence the results, making them more reliable compared to those obtained from CC CG.

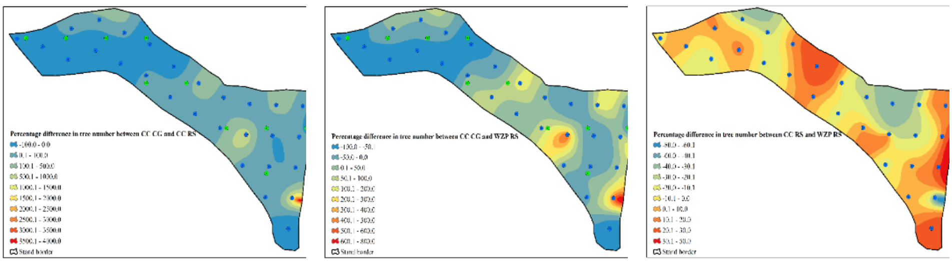


Figure 2. Percentage differences between N/ha obtained from the tested shapes of sample plots (left – CC CG:CC RS; center – CC CG:WZP RS; right – CC RS:WZP RS)

These results clearly demonstrate that the methodological approach and the scope of collected data have a decisive impact on the spatial interpretation of results. Due to the small number of sample plots and the limited amount of input data, CC CG produces results that are not sufficiently stable, particularly in the boundary zones of the stand. In contrast, CC RS and WZP RS, owing to a considerably larger sample and greater volume of input data in the processing stage, provide not only statistically more reliable values but also a spatial representation that more accurately reflects the actual field conditions. Furthermore, such spatial analysis enables the identification of local zones and differences that would otherwise remain hidden in aggregated tabular presentations. It is important to note that in certain zones, the WZP RS raster detects a higher number of trees than CC RS, which suggests that angle count sampling more effectively captures larger trees, even at greater distances. This reflects the fundamental principle of unequal selection probability and represents a necessary condition for obtaining reliable results in structurally heterogeneous situations such as uneven-aged and selection forests.

As in the case of the number of trees, methodological differences among the tested sample plot types led to distinct spatial distributions of volume, with this variability being more pronounced than in the case of tree numbers (Figure 3).

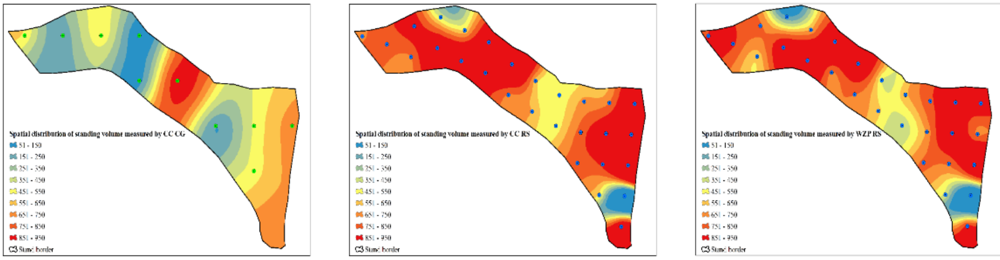


Figure 3. Spatial distribution of volume (left – CC CG; center – CC RS; right – WZP RS)

The CC CG plots (Figure 3 – left) show a very uniform and simplified spatial distribution of volume. The values of this parameter are mainly concentrated in the central and eastern parts of the stand, but without clearly defined zones of high concentration. This uniformity results from the smaller number of input data and insufficient spatial coverage to capture all internal variations within the stand. The absence of higher volume values in certain zones indicates that this plot type did not include larger trees (volume carriers), which is consistent with the tabular data (Table 2) showing the lowest average sample volume of 338.2 m^3/ha. On the other hand, CC RS (Figure 3 – center) and WZP RS (Figure 3 – right) display a more complex and differentiated volume structure. Both plot types show several zones with high volume values (over 750 and even 950 m^3/ha), mostly distributed in the western and southeastern parts of the stand. The fact that these zones do not always coincide with the areas of the highest number of trees indicates that the increased volume results from a greater number of measured large-diameter trees, which represents the main advantage of angle count sampling plots in structurally heterogeneous stands. Thus, these spatial patterns align with the characteristics of a stand with a structure close to the selection type, where volume is not distributed proportionally to the number of trees but largely depends on the inclusion of individual large trees.

The percentage differences in volume obtained from the tested shapes of sample plots are shown in Figure 4.

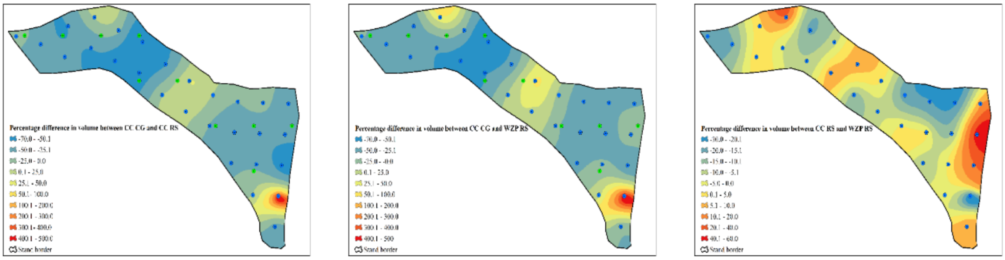


Figure 4. Percentage differences between V/ha obtained from the tested shapes of sample plots (left – CC CG:CC RS; center – CC CG:WZP RS; right – CC RS:WZP RS)

•CC CG:CC RS (Figure 4 – left): The differences are significant across a large portion of the stand, most commonly ranging from 50% to over 300%, while in a smaller part of the stand they reached values exceeding 500%. These differences are a direct consequence of the CC CG inventory insufficiently capturing large-diameter trees, which resulted in a systematic underestimation of the stand volume.

•CC CG:WZP RS (Figure 4 – center): The distribution pattern is similar to the previous comparison (CC CG:CC RS). In most parts of the stand, the differences range between 100% and 300%, which is a consequence of the fact that angle count sampling plots more effectively capture large-diameter trees that contribute significantly to the total volume. One zone with an extremely high difference is also noticeable here, further indicating the limitations of using CC CG with a relatively low sampling intensity under structurally heterogeneous stand conditions.

•CC RS:WZP RS (Figure 4 – right): The differences are much smaller, mostly around ±10%, with local exceptions reaching up to ±20%. These values confirm the previous conclusions regarding the reliability of inventories conducted on these two sample plot types. Since CC RS and WZP RS plots have the same number and spatial arrangement, the observed differences result from the distinct methods of tree selection for measurement. In certain zones, WZP RS shows higher volume values than CC RS, which is likely due to the inclusion and measurement of larger trees captured within the selected counting angle but not encompassed by the CC radius.

Volume has proven to be a parameter more sensitive than the number of trees to the shape and spatial arrangement of sample plots, the range of tree diameters and the number of measured trees in higher diameter classes. This indicates that a partial inventory with a denser and more systematic grid of sample plots, which also includes a greater number of trees, particularly those of larger dimensions, provides a more accurate representation of the spatial distribution of numerical stand attributes. The CC CG method shows clear limitations in interpolation, producing a simplified spatial representation that may lead to misinterpretation in forest management planning, silvicultural decisions and related applications.

CONCLUSIONS

By synthesizing the research results, the following conclusions can be drawn regarding the selection of the most suitable plot shape for partial inventory under the given conditions:

1. Partial inventory conducted on different plot shapes, even when applied within the same stand, may produce significantly different values of numerical elements and their distributions. Consequently, these differences arise from variations in sample size and sample type, the intensity of the inventory, the number of detailed sample plots and the number of trees whose heights are measured.

2. In the present case, it is difficult to determine which of the tested plot shapes is superior, due to the differing elements used in partial inventory. Considering the structural characteristics of the stand and in the absence of a complete (total) inventory, priority should nevertheless be given to angle count sampling, because this method is based on selection with unequal probability, the probability of selecting a tree is proportional to the importance of that element for the final result.

3. The method of height selection applied in the partial inventory of Montenegro generally does not provide a sufficient amount of data for constructing a reliable height curve. As a result, the curve tends to be positioned lower within the height overdiameter curve (producing a tariff series inferior to the actual one), which consequently leads to underestimated volume, volume increment and the feasible allowable cut in production forests. In light of these findings, it is recommended that the height-measurement methodology used in the forest inventory of Montenegro be reassessed and revised where necessary.

4. By applying raster analysis in a GIS environment, a more detailed insight was obtained into the spatial distribution of the number of trees and volume per hectare for the tested plot shapes, as well as into the percentage differences of these elements. The spatial distribution of tree numbers and volume enables more precise planning, improves the organization of field activities, and contributes to the optimization of silvicultural measures implemented within the stand. Spatial visualization facilitates decision-making regarding regeneration, tending operations, stand utilization, and similar activities, as it provides a realistic understanding of internal stand variability, which is often overlooked in traditional tabular presentations of stand conditions.

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