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INFLUENCE OF NUMBER OF CONTROL SAMPLE PLOTS ON THE ACCURACY OF STATISTICAL-MATHEMATICAL SYSTEM OF INVENTORY

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Abstract. The influence of the number of sample plots on quantity of an average error of a stand volume, number of trees and increment in uneven-aged stands is presented in the study. The research was carried out in 43 stands in which 739 control sample plots were established. It was stated that at least 8 sample plots should be established for the accuracy of stand inventory at the level of 20%.

Key words: average error, accuracy of inventory, uneven-aged forest

INTRODUCTION

Statistical – mathematical system of inventory with an utilization of control sample plots delivers a lot of essential information concerning an uneven-aged forest. This kind of inventory demands however considerable outlays of work, especially at the stage of establishing and measuring the sample plots. From among many of such factors as: type and accessibility of terrain, sampling schemes and size of sample plots, the greatest influence on the labour-consuming inventory is exerted by the number of sample plots. To take decision how many of sample plots should be established is one of the basic tasks of preparatory works and to a high degree decides about the costs of the inventory. Obtaining the results concerning the acceptable accuracy will demand receiving a proper number of sample plots for every computational units. If a basic units is stand and the object of the inventory are numerous stands then the required outlays can considerably surpass the financial possibilities and thus render the inventory impossible. It should be assumed that results for single stands can be estimated with considerable average error [Rutkowski 1981], however they have to be reliable and situated in a specified range.

The aim of the presented research is investigation of influence of sample plots number on the value of an average error of the number of the trees, volume and increment in uneven-aged stands.

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MATERIAL AND METHODS

Investigations were conducted in two groups of stands. The first one is created by hardwood forests of the Municipal Park and Zoological Garden in Cracow fulfilling functions of protective forests around the city. The forests are prevailigly multi-species stands consisting mostly of oak, beech and birch growing on fertile sites of upland forest and mixed upland forest. The other group includes uneven-aged mountain forests situated in the Forest Experimental Station in Krynica. These forests are managed mostly under shelter wood cutting system with Swiss irregular method. In fertile sites of mountain forest and mountain mixed forest occurr monospecies of fir forests and spruce forests as well as multispecies forests with domination of fir, beech or spruce.

Research material determines the results of measurements on 739 control sample plots of the Department of Forest Management of Agricultural University of Cracow. A detailed description of these plots is found in the work [Banaś 2004]. The measurements on the sample plots were periodically repeated, length of control period in the research objects varied from 7 to 12 years. Only the stands in which at least 12 sample plots were established, were selected for the investigations. General characterisation of stands as well as description of control periods in each research objects are found in Table 1.

Table 1. Characterisation of stands and sample plots chosen for study
Tabela 1. Zestawienie wybranych do badań drzewostanów i powierzchni próbnych

Group of stands Grupa drzewostanów	Research object Obiekt badawczy	Control period Okres kontrolny	Phase of development Faza rozwoju	Number of stands Liczba drzewostanów	Number of sample plots Liczba powierzchni próbnych
Multispecies decidues stands around cites Wielogatunkowe lasy liściaste wokół miast	Las Wolski	1989-1998	$O_{st.}$	10	147
			T	3	51
Uneven aged stands in mountain Różnowiekowe lasy górskie	Czarny Potok	1987-1999	$O_{st.}$	2	36
			T	9	141
	Szczawiczne	1994-2001	$O_{st.}$	2	37
			T	3	89
	Wojkowa	1992-2002	$O_{mł.}$	2	47
			$O_{st.}$	5	63
			T	8	128

$O_{mł.}$ – young optimal phase of development.
$O_{st.}$ – older optimal phase of development.
T – terminal phase of development.
$O_{mł.}$ – faza rozwoju optymalna młodsza.
$O_{st.}$ – faza rozwoju optymalna starsza.
T – terminalna faza rozwoju.

Precision of inventory results was analysed on the basis of quantity of relative average error of: volume, number of tree and current increment of volume. Errors of calculation of mean volume and mean number of trees per 1 hectare were calculated for every stand both at the beginning as well as the end of control period. Influence of number of sample plots on quantity of error was investigated in range from 3 to 12 sample plots on the basis of the following schema of sampling. From sample plots established in stand (at least 12 sample plots), sampling of 3 plots with five times replacement was made. Following series of sampling from every stand were made similarly for four, five, up to twelve sample plots. The collected samples during every sampling were treated separately and for each of them the following were calculated: volume of stand, mean number of trees and increment with appropriate error expressed in percentage of this feature. In total for 43 stands sampling five times from 3 to 12 sample plots 2150 quantity of investigated features were calculated and analysed together with appropriate errors. The value of average errors was calculated using the following formula [Tadeusiewicz et al. 1993]:

$$\Delta x = \frac{\alpha_{t\ n-1} \cdot \frac{s}{\bar{x}}}{\sqrt{n}} 100$$

where: s – standard deviation from sample,
$\bar{x}$ – average value of feature,

n – number of sample plots,

α_t – critical value of t-distribution for n-1 of degrees of freedom.

Stands were grouped in following sections formed according to sizes of an average error: up to 10%; 11-20%; 21-30% and above 30%. Such combinations were made separately for errors of volume, numbers of trees and increment of volume.

RESULTS

The obtained results of the investigations pointed to a large variability of the inventoried features both in multispecies hardwood forests in region of Cracow and in uneven-aged forests in the Forest Experimental Station in Krynica. As a result of five times sampling the same number of plots for each sampling different values of given features were obtained. The higher number of plots was sampled the smaller were the differences. For example in Table 2 results of qualification of average volume in stand 71 T in LZD Krynica were introduced. From among 15 sample plots in this stand from 3 to 12 plots were sampled in successive five series. For samples consisting of 3 plots differences of volume calculating are very large: from 301 (±196) $m^3 \cdot ha^{-1}$ in the second sampling to 512 (±102) $m^3 \cdot ha^{-1}$ in the fifth sampling.

Together with an increase of sample plots the differences in qualification of volume among following series are smaller. At 12 sample plots average the volume was qualified from 381(±53) $m^3 \cdot ha^{-1}$ in the first series of sampling to 427(±51) $m^3 \cdot ha^{-1}$ in the fifth series.

Table 2. Results of calculation of volume and mean error for variable number of sample plots in stand 71 T in LZD Krynica
Tabela 2. Wyniki określenia zasobności wraz z błędem średnim przy zmiennej liczbie powierzchni próbnych w drzewostanie 71 T LZD w Krynicy

Number of sample plots Liczba powierzchni próbnych	Number of drowing series – Numer serii losowania				
	1	2	3	4	5
	volume (mean error), $m^3 \cdot ha^{-1}$ zasobność (błąd średni), $m^3 \cdot ha^{-1}$				
3	380 (±169)	301 (±196)	503 (±211)	478 (±100)	512 (±102)
4	418 (±130)	418 (±130)	397 (±119)	318 (±83)	364 (±124)
5	448 (±108)	473 (±109)	473 (±109)	301 (±84)	360 (±94)
6	396 (±83)	384 (±73)	444 (±75)	390 (±90)	416 (±92)
7	404 (±93)	416 (±83)	434 (±82)	390 (±66)	395 (±67)
8	359 (±65)	386 (±69)	368 (±66)	388 (±78)	356 (±61)
9	434 (±65)	456 (±55)	447 (±45)	418 (±63)	415 (±62)
10	407 (±61)	363 (±58)	419 (±54)	407 (±65)	417 (±63)
11	414 (±58)	400 (±56)	433 (±61)	405 (±57)	407 (±57)
12	381 (±53)	418 (±54)	385 (±54)	409 (±53)	427 (±51)

Value of average error marks section, in which with given probability (in this work P = 0.8) the real value inventoried feature is situated. Figure 1 shows values obtained during the first series of sampling (Table 1) and explains the influence of the number of sample plots on width of confidence interval of volume qualification. This interval for 3 plots is very wide and varies from 211 to 549 $m^3 \cdot ha^{-1}$. Double enlargement of sample to 6 plots influences the narrowing of the examined confidence interval by half and for 12 plots it varied from 328 to 434 $m^3 \cdot ha^{-1}$.

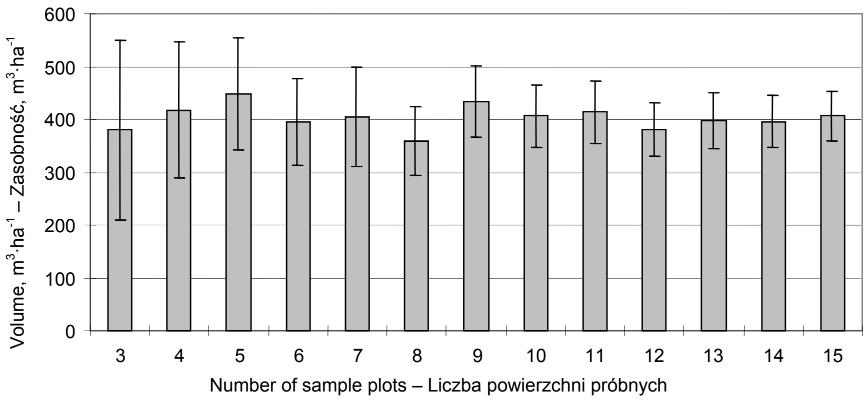

Fig. 1. Qualification of volume and confidence intervals with respect to number of sample plots in stand 71 T in LZD Krynica
Rys. 1. Określenie zasobności oraz przedziałów ufności w zależności od liczby powierzchni próbnych na podstawie 1 serii losowania w drzewostanie 71 T LZD w Krynicy

All values of average errors of volume in 30 selected stands in the Forest Experimental Station in Krynica are shown in Table 3. With the numbers of samples frequency at 3 plots per stand, the error of volume in 60% of events exceeded 30%, in extreme events reached 129%. Along with an increase of the number of sample plots an average error decreases, however for 6 sample plots still prevail the stands in which the error has values above 20%. For 8 sample plots the error of volume qualification is at an average level of 20%. With a greater number of sample plots significantly increases the participation of stands, in which volume was qualified with error from 11 to 20%. In the analysed range of the number of sample plots (from 3 do12) a significant participation of stands, for which the volume would qualify with error up to 10% was not reached.

Table 3. Quantity of relative error of volume with respect to number of sample plots in chosen stands in LZD Krynica
Tabela 3. Wielkość błędu względnego zasobności, w zależności od liczby powierzchni próbnych w wybranych drzewostanach w LZD Krynica

Number of sample plots Liczba powierzchni próbnych	Mean error of volume – Błąd średni zasobności					
	< 10%	11-20%	21-30%	> 30%	Max. value Wartość maksymalna %	Mean value Wartość średnia %
	schare of stands, % udział drzewostanów, %					
3	3	14	23	60	129	41
4	4	23	31	42	81	29
5	2	24	39	35	62	27
6	3	35	46	15	48	23
7	4	46	40	9	47	21
8	5	53	38	5	45	20
9	8	62	28	2	41	18
10	7	71	22	1	33	17
11	9	76	15	-	33	17
12	13	76	10	1	31	16

In hardwood forests in regions of Cracow an average error of volume took a little lower values (Table 4) than in the analysed above stands of the Forest Experimental Station in Krynica. Qualification of volume in this type of forests with error up to 20% is possible for 6-7 sample plots.

The value of error of increment and error of average number of trees is approaching the error of qualification of volume (Fig. 2 and 3). In uneven-aged mountainous stands in the Forest Experimental Station in Krynica the volume is qualified in general with a little greater error than the number of trees or increment of volume. Instead in multispecies hardwood stands in regions of Cracow at the same number of plots an average error of volume is a little smaller than the error of increment or error of number of trees.

Table 4. Quantity of relative error of volume with respect to number of sample plots in chosen stands in Las Wolski
Tabela 4. Wielkość błędu względnego zasobności, w zależności od liczby powierzchni próbnych w wybranych drzewostanach w Lesie Wolskim

Number of sample plots Liczba powierzchni próbnych	Mean error of volume – Błąd średni zasobności					
	< 10%	11-20%	21-30%	> 30%	Max. value Wartość maksymalna %	Mean value Wartość średnia %
	schare of stands, % udział drzewostanów, %					
3	2	11	19	68	97	37
4	8	33	35	23	53	24
5	8	38	35	18	49	23
6	8	43	38	11	41	21
7	12	54	29	5	35	18
8	12	68	17	3	34	17
9	18	68	14	–	28	15
10	14	68	18	–	27	15
11	24	66	10	–	23	14
12	26	67	7	–	24	14

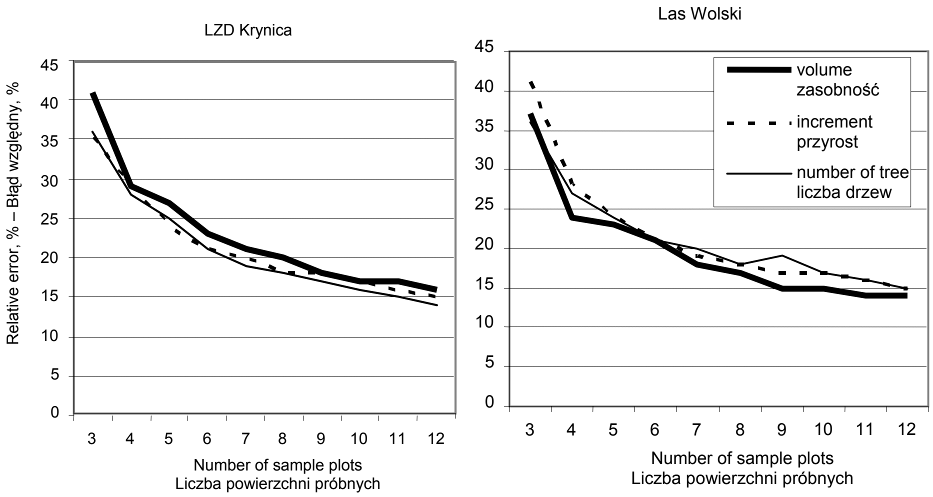

Fig. 2. Value of mean error of volume, increment and number of tree with respect to number of sample plots in chosen stands of Las Wolski and LZD Krynica
Rys. 2. Wartości średnie błędów określenia zasobności, przyrostu i liczby drzew w zależności od liczby powierzchni próbnych w wybranych drzewostanach Lasu Wolskiego i LZD w Krynicy

DISCUSSION

Investigations over the accuracy of statistical- mathematical system of inventory with the application of control sample plots have been carried out in the Department of Forest Management from over 30 years. The obtained results were compared with the results of Rutkowski research relating both to the forests in Krynica as well as stands from Las Wolski. Values of an average error of volume qualification of single stands in Wojkowa object were calculated at the level of 15% at average number 11 sample plots [Rutkowski 1981]. The distribution of an average error was as follows: in 15% of the stands an average error did not exceed 10%, in most of stands (70%) volume was qualified with error from 11 to 20%, in 5% events error included in section from 21 to 30% and in 10% of stands error was greater than 30%. In the presented work similar results were obtained: for 11 sample plots error was on the average 17%. Distribution of an average error is also similar: smaller (9%) is participation of stands with average error up to 10%, however bigger is (76%) participation of stands, in which volume was qualified with error from 11 to 20% and participation of stands (15%) with average error from 21 to 30%.

Results of Rutkowski's works pointed that error of qualification of increment on control sample plots is in general at the same level as error of volume or only a little higher [Rutkowski 1989, Rutkowski et al. 1986]. In this work it was stated that it is not unambiguous relationship between value of errors of volume and of increment. In multispecies hardwood forests volume was qualified in general more precisely than increment however in mountain uneven-aged stands increment was qualified with smaller error than volume. Relationship between quantity of errors are analogous as between quantity of variability coefficients of: volume, increment and number of trees in investigated stands [Banaś 2004].

For practices of forest management important is qualification of value of average error of inventoried features for single stand possible to accepting. According to Rutkowski [1989] in uneven-aged stands in Forest Experimental Station in Krynica qualification of volume increment with precision up to 10% will demand to establish from 19 to 23 sample plots with sizes of 0.04 hectare in stand with optimum phase of development and from 24 to 36 sample plots with size of 0.05 hectare in stand with terminal phase. Analysis of average error distribution in presented work indicated that precision of inventoried features for single stand on level of 10% will demand to established in general 20 or more sample plots. When object of inventory are many stands such solution from economic point of view is difficult to acceptable. It seems that on level of single stand possible acceptable would be average error up to 20%. Increase of precision of inventory may be obtained on the grouping of stands with similar features and creation stratum of stands.

CONCLUSIONS

1. Qualification of number of sample plots in each computational unit is one of basic assignments for solutions on stage of preparatory works. Costs of inventory realisation depend mostly on number of sample plots.

2. Results of inventory with statistical-mathematical system are always charged to average error of sample. For single stands such error can be considerable however should not be higher that specific interval.

3. Older stands, especially embraced in schedule of final cuts that is in terminal phases of development, should be inventoried with greater precision than younger stands.

4. In stands being in terminal phase of development one should establish at least 8 sample plots, so that quantity of average error did not exceeded 20% of volume. In younger stands (in optimum – phase of development) is possible to diminish number of sample plots to 5 however it will influence on diminution of precision up to 25%.

5. Accuracy of inventory results increase by joining of stands about similar species composition and in the same phase of development in stand layers. The higher level of computation units aggregate the more precision are results of inventory.

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WPŁYW LICZBY KONTROLNYCH POWIERZCHNI PRÓBNYCH NA DOKŁADNOŚCI WYNIKÓW INWENTARYZACJI SYSTEMEM STATYSTYCZNO-MATEMATYCZNYM

Streszczenie. W pracy analizowano wpływ liczby powierzchni próbnych na wielkość błędu średniego określenia: liczby drzew, zasobności oraz przyrostu miąższości w drzewostanach różnowiekowych. Badania przeprowadzono w 43 drzewostanach, w których założono 739 kontrolnych powierzchni próbnych. Stwierdzono, że aby uzyskać dokładność wyników inwentaryzacji dla drzewostanu na poziomie 20%, należy założyć co najmniej 8 powierzchni próbnych.

Słowa kluczowe: błąd średni, las różnowiekowy, dokładność inwentaryzacji

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