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A comparison of two growing stock assessments by stratified sampling– how does accuracy of inventory affect our interpretation of the results

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Abstract. Since 1967, when the Polish State Forests were first inventoried, a continuous increase in the volume of growing stock has been recorded. This increase in timber resources is mainly the result of sustainable forest management. However, during this time period inventory methods have been changed a few times and this may have affected the estimates of of wood resources.

Since 2011 new instructions have been in place for forest management plans in the Polish State Forests. Despite this, the method of taking forest inventories remained consistent with the previous guidelines. This should allow us to consider changes in the volume of growing stock in relation to inventory methods and their accuracy.

In this paper, the results of growing stock estimations based on two assessments made using stratified random sampling are compared. After five years of inventories made for forest management plans, 422 sample plots in two forest districts were measured within 15 strata. Predicted age classes structure at the beginning of successive management plans was used to determine new strata. Data from two inventories were compared on the basis of age class. In addition, data from the State Forests Information System i.e. updated stand level inventory data (on felling and tree growth) were analyzed.

Comparing data from the two inventories, in three of seven age classes there was a decrease in the volume of growing stock after a five year period. We found no rational explanation for this. The extent of felling in the analyzed stand was very low, as confirmed by data from State Forests database. However, the largest decrease in volume was 1.5%, whereas the accuracy of growing stock assessment of discussed age class was estimated at some 9% in 2006 and 8% in 2011. Hence, from statistical viewpoint there was no differences between the results of both inventories.

However, the differences between volume of growing stock of examined age classes, updated in the Information System of the State Forests and results of assessments by stratified sampling are less than 95% confidence intervals for means of samples. Because of that, updated information could be used in the long term management planning. The results clearly suggest that changes of growing stock, estimated as a difference between two assessments, should be interpreted in conjunction with the accuracy of these inventories. The accuracy of sampling should be also taken into account when creating management plans.

Key words: changes of growing stock, stratified sampling, accuracy of inventory

1. Introduction

Since the end of the sixties of the 20th century, a steady increase in the volume of timber resources has been recorded in the State Forests National Forest Holding (PGLLP). This increase is primarily a result of forest management in accordance with the principle of sustainability of forests. It should be noted, however, that the use of more accurate inventory methods is also mentioned as one of the reasons for the increase of resources (Raport 2011).

Inventory of growing stock in the State Forests runs in a 10-year cycle, in the preparation of management plans for the forest districts. Forest inventory results are then updated each year. In the last few decades inventory methods underwent significant changes.

Within the so-called definite management planning, the volume of forest stand was estimated on the basis of selective sample plots (Instrukcja 1957). Consecutive Forest Management Plan (FMP thereinafter) Manual (1970), as a complementary method of inventory, introduced variable-radius sample plots (angle count sampling) also established at representative area in stands. In the next revision of the forest management planning, the basic inventory system was formed by randomly chosen variable-radius sample plots or alternatively circle plots (Instrukcja 1980). Subsequent method assumed random sample plots in different stands or stratified sampling, depending on the variant of the method adopted (Instrukcja 1994). Both the Manual of 1994, as well as the two previous ones, assumed that in the stands below the age of 40 years no random sampling was expected and the volume of growing stock was estimated instead, using the appropriate tables or selective plots.

The stratified random sampling method of measuring the growing stock of a forest division, introduced in the FMP Manual in 2003, finally draws the line at the tree stand as the basic unit of inventory. Based on the age and dominant species of the stands there are created layers, in which random circle plots are established. Only tree stands over the age of 20 years and with a height of dominant species over 7 m, or those which meet the relevant site index criteria, qualify for measuring (Instrukcja 2003). The process of preparing a forest management plan (early signing contracts) makes the new instructions come into practice usually with a delay. Less than half of the districts having forest management plans as of January 1, 2005 were surveyed using the stratified random sampling. In most districts, in accordance with the agreements previously signed, inventories were performed using the earlier method.

In 2011 the new FMP Manual was introduced for use in PGLLP (Instrukcja 2012). What is particularly important, determining the growing stock of the forest division according to the mentioned Manual is to be done using the same method of survey. Only the algorithm for determining the number of sample plots for the division has changed. Therefore, for the forest districts managed according to the Manual of 2003 and 2012, the changes of timber resources in the subsequent cycles of forest management planning will not be affected by the differences in the inventory methods used.

As noted by Bruchwald (2004), between the volume of the forest unit at the beginning and at the end of the period there may be one of the following relationships: the volume of the end of the period is equal to, greater than or less than the volume at the beginning of the period, which means that the volume increment is respectively equal to, greater than or less than the loss in trees (in current management). For these, relationships should be noted on the inventory data accuracy issue. In the case of a stratified random sampling method it can be expected that the estimation error of the forest divisions growing stock does not exceed 4-5% at the 95% confidence interval for the mean from the sample, while for the age class usually is at the level of 5-10%, and in rare cases can exceed 20% (Jabłoński 2011). The difference in the volumes of divisions in subsequent cycles of forest management planning (at the beginning and end of the 10-year period) will largely depend on the representativeness of the sample.

The purpose of this study is to present the changes in the volume of growing stock in subsequent cycles of forest management planning when a stratified random sampling with temporary plots is used.

2. Study areas and methods

Since none of the districts used a stratified random sampling method of inventory twice so far, it is assumed that a comparison of data from inventory in selected units with the results of remeasurements performed at these units five years later will provide the information about the changes of timber resources.

Inventory measurements were conducted in selected age classes in Szczytno Division of Szczytno Forest District on August and September 2009. This district has an FMP dated January 1, 2005 (forest inventory was done in 2004). The measurements made in 2009 characterize the state of timber resources dated January 1, 2010. Szczytno Division was chosen as an object of research due to, among others, the fact of having forest management inventory data (in the form of the Taksator programme) obtained for the earlier studies. What is important, the sample size for Szczytno Division was determined during forest management works based on new forest survey specification (stand description). Therefore, in this forest unit there was no problem with the reallocation of the sample and its consequent mismatch with the species and age structure of the division in contrast to a situation where updated information from previous FMP are used for stratification (Jabłoński 2010).

Additional inventory of growing stock was conducted in August and November 2010 in three age classes of Jedlnia Division, Radom Forest District. This district

has a forest management plan dated January 1, 2006 (forest inventory was done in 2005). Measurements made in 2010 characterize the state of timber resources of analyzed age classes dated January 1, 2011.

To determine the sample size for each layer to be measured in inventory, procedures of Taksator application, version 5.2.3 were used. Age layers were based on the age of stands predicted in a consecutive forest management plan (on January 1, 2015 for Szczytno Forest District and January 1, 2016 for Radom Forest District). Adoption of real age of stands (dated January 1, 2010 and 2011) and creating the table of age classes (subclasses) on this basis would mean that each age class after 5 years would consist of different stands than at the time of the development of a forest management plan, which would undoubtedly affect the results obtained and the possibility of their interpretation. The applied solution in turn allows us to compare the same groups of stands and reflects the actual shift to higher age subclasses in the following revision of forest management. Therefore, the age of the species listed in the composition of forest stands (in the table f_storey_species of Taksator application database) of analyzed forest divisions has been increased by 10 years. For mature stands, in addition, the changes in structure resulting from felling had to be taken into consideration. Because in the last five years of forest management plans being performed, felling was conducted only in a part of the stands, for the purpose of determining the number of sample plots for the division and their allocation to the various layers during the re-inventory, an assumption was taken that felling would be performed in all stands provided for in the plan. Modification of forest survey specification for mature stands is important, because their total area determines the number of sample plots planned also in other layers of inventory. The modification of above-mentioned specification in Taksator application databases included the following changes:

– in the table f_storey_species the age was changed to 5 years for the stands planned to be clear-cut;

– in the table f_subarea the area of forest subcompartments was reduced by the area of stands planned to be partly clear-cut (on manipulation plots);

– in the table f_subarea the description of the structure of forest stands was changed from even-aged to uneven-aged for the stands, which were scheduled to start more complex fellings;

– in the table f_subarea the description of stand structure was changed from uneven-aged to even-aged and in the table f_storey the age was changed to 10 years (providing exact age is not necessary) for the stands where overstorey removal was planned;

– in the table f_subarea two fields describing forest subcompartments and their area were created in the case of stands, where more complex felling was planned on manipulation plots; in one of the subcompartments the stand structure was changed from even-aged to uneven-aged.

The structure of selected age-species strata within Szczytno Division, both as on January 1, 2005 and the one forecasted in the next revision of forest management are shown in table 1. Inventory measurements covered stands representing IIb, IIIa, Va, and VI age classes according to age layers forecasted for 2015. Limiting the scope of research to four age classes resulted from the high workload of field work. In these layers, 300 circular sample plots were established.

The characteristics of the layers within the inventory of Jedlnia Division are contained in table 2. Measurements included stands that belonged to IIb, IIIa, and Vb age classes, where a total of 122 sample plots were set up.

Location of sample plots in the stands was also performed using the procedure in Taksator application, i.e. using geometric data of districts (subcompartments unit layers). Then the offset (azimuth and distance) between sample plot and the datum points – rendered on the map – was determined. As reference points were recognized: the intersections of compartment lines, roads, power lines, etc. Offset to the center of the plot was derived using a measuring tape and compass. The idea of using GPS receivers instead was intentionally discarded because of its accuracy, and therefore high probability of subjective choice of the plot center.

Measurements were performed following the methodology adopted in the FMP Manual in 2003.

Table 1. Characteristics of analyzed age-species strata in the Szczytno forest division

After forest management plan in 2005				Forecast of forest management plan in 2015			
age class*	dominant species**	area [ha]	number of sample plots	age class	dominant species	area [ha]	number of sample plots
				…	…	…	…
IIa	Św	39,57	4	IIb	Św	39,57	4
IIa	So	283,93	14	IIb	So	283,93	18
IIa	Brz	67,89	5	IIb	Brz	67,89	6
IIb	So	614,66	38	IIIa	So	614,66	46
IIb	Ol	34,32	4	IIIa	Ol	34,32	4
IIb	Brz	54,04	5	IIIa	Brz	54,04	6
…	…	…	…	…	…	…	…
IVb	So	441,39	56	Va	So	429,16	60
…	…	…	…	…	…	…	…
VI	So	609,79	115	VI	So	789,30	140
Vb	Db	42,46	6				
VI	Db	55,34	12	VI	Db	82,24	16
Forest division		6829,44	778	Forest division		6613,32	789

* Age classes of stands are: IIa – 21-30 years, IIb – 31-40, IIIa – 41-50, IIIb – 51-60, IVb – 71-80, Va – 81-90, Vb – 91-100, VI – 101-120.
** Św – Norway spruce, So – Scots pine, Brz – birch, Ol – black alder, Db – oak

Table 2. Characteristics of analyzed age-species strata in the Jedlnia forest division

After forest management plan in 2005				Forecast of forest management plan in 2016			
age class*	dominant species**	area [ha]	number of sample plots	age class	dominant species	area [ha]	number of sample plots
				…	…	…	…
IIa	Ol	60,23	6	IIb	Ol	60,23	7
IIa	So	184,41	15	IIb	So	191,06	19
IIb	Jd	34,86	7	IIIa	Jd	46,78	7
IIb	Ol	51,69	6	IIIa	Ol	51,69	8
IIb	So	218,07	18	IIIa	So	218,07	27
…	…	…	…	…	…	…	…
Va	So	223,61	49	Vb	So	218,77	54
…	…	…	…	…	…	…	…
Forest division		4271,07	778	Forest division		4260,63	858

* As in Table 1
** Ol – black alder, So – Scots pine, Jd – silver fir

By deploying the Taksator application the data from sample plots were introduced to the database and then the growing stock volume of the trees on the plots as well as of inventory layers were calculated. The next step was to determine the accuracy of the estimation, with a 95% confidence interval, of the growing stock of each age-species layer [p_h- formula 1] and the whole age classes [$p_{kl.w.}$ - formula 2]:

$$p_h = k_h \cdot \frac{v_h}{\sqrt{n_h}}$$ [1]

where:

k_h – the critical value of $z_{a/2}$ - a normal distribution for the layers of at least 30 samples, or $t_{a/2}$ (Student's distribution) in layers of less than 30 samples,

v_h – the coefficient of variation of the growing stock volume of plots in h-layer,

n_h – the number of sample plots in h-layer.

$$p_{kl.w.} = \sqrt{\sum_h W_h^2 \frac{k_h^2 \cdot v_h^2}{n_h}} = \sqrt{\sum_h W_h^2 \cdot p_h^2}$$ [2]

where:

W_h – the share area of the selected species-age layer within the total area of the age class.

Furthermore the accuracy of the growing stock estimation for all analyzed layers of the divisions was fixed together. Parameter W_h in this case was defined as a ratio between the area of selected age-species layer and the total area of all measured layers.

Since only the standard error is estimated during the FMP, the formulas [1] and [2] were used to determine the accuracy of growing stock estimation of the age layers analyzed within the forest management works.

Changes in the growing stock of the layers analyzed in inventory, defined as the difference between measurements made in 2009-2010 and forest inventory data,

were also compared with the changes resulting from the growing stock updating in the Information System of the State Forest (thereinafter SILP). SILP data for Szczytno District dated January 1, 2010, and for Radom District dated January 1, 2011 was obtained in the form of selected tables (f_arodes, f_arod_storey, f_storey_species, f_subarea). Because within this study the inventory was carried out in age classes accordant with the state at the end of the period of validity of forest management plans (January 1, 2015 or January 2, 2016), the age of the trees in the table f_storey_species was increased by 5 years. Taking into consideration that the area of analyzed age classes, according to the assumptions made in the study, may differ from SILP data, when comparing the results the average volume of growing stock was used for analyzed age classes.

3. Results

Average growing stock per hectare of analyzed age classes in Szczytno Division, resulting from growing stock inventory via stratified random sampling method taken in two points in time, and the volume of growing stock updated in SILP, are shown in figure 1.

Average growing stock per hectare of re-inventory was higher than the results of measurements of 2005 only for class IIb, while in the case of IIIa, Va, and VI age classes it was found that after 5 years of inventory the average growing stock volume of these classes was lower by 2-3 m³/ha. It should be noted, however, that these differences fit into the confidence interval evaluated for the mean from the samples. For example, the error of growing stock estimation for Va age class in 2005 was ± 30 m³/ha and in 2010 ± 27 m³/ha, hence ten times more than the difference in average growing stock per hectare between the measurements (tab. 3). The greatest error of the growing stock estimation, which was af-
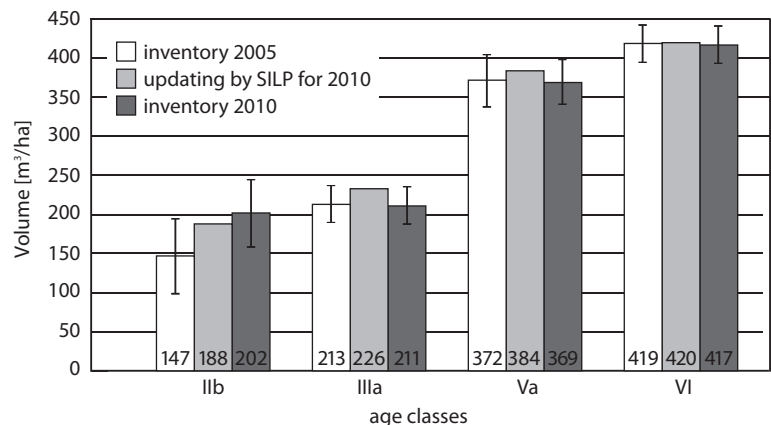
Figure 1. The average volume of growing stock and confidence intervals for the mean of analyzed age classes in the Szczytno forest division: updating for 2010 was made using the Information System of the State Forests.

Table 3. The accuracy of growing stock estimation of analyzed age classes in the Szczytno forest division (with 95% confidence interval)

Age class	01.01.2005			01.01.2010		
	number of sample plots	error		number of sample plots	error	
		%	m³/ha		%	m³/ha
IIb	23	± 28,4	±42	28	± 19,0	±38
IIIa	47	± 9,3	±20	56	± 9,2	±20
Va	56	± 8,2	±30	60	± 7,4	±27
VI	133	± 5,1	±21	156	± 5,2	±22
Total		± 6,3	±19		± 4,7	±15

Table 4. The accuracy of growing stock estimation of analyzed age classes in the Jedlnia forest division (with 95% confidence interval)

Age class	1.01.2006			1.01.2011		
	number of sample plots	error		number of sample plots	error	
		%	m³/ha		%	m³/ha
Iib	21	± 25,8	± 32	26	± 21,2	± 39
IIIa	31	± 15,0	± 26	42	± 14,2	± 29
Vb	49	± 9,1	± 30	54	± 8,1	± 26
Total		±10,2	± 20		± 8,9	± 21

fected by establishing only 23 sample plots in 2005 and 28 in 2010, was found for age class IIb.

In the case of IIIa, Va, and VI age classes the volume of growing stock of forest stands in 2010, determined on the basis of inventory measurements, was lower than the growing stock updated for stands by SILP made on January 1, 2010. According to the SILP the growing stock per hectare of IIIa age class dated January 1, 2010 was 226 m³/ha, while the average growing stock per hectare of this age class estimated on the basis of the measurements was 211 m³/ha. Similar pattern was observed in the case of Va age class. Its value of growing stock volume according to SILP updates amounted to 384 m³/ha, while the average of 60 sample plots established in the framework of the audit works was 369 m³/ha (15 m³/ha less), (fig. 1). These differences, however, fit the confidence intervals specified for the samples.

With respect to stands of VI age class, it should be noted that the obtained results were affected by the assumption that they were planned to undergo the felling. In 2010, the stands of VI age class, in fact, occupied a much larger area than it was forecasted for the end of the forest management plan. The volume of growing stock updated in SILP for the same stands of VI age

class, which were included in the inventory measurements, averaged 415 m³/ha, was therefore 2 m³/ha less than the result of inventory measurement in 2010.

The increase in the growing stock per hectare obtained in the update process in SILP clearly indicates that the extent of felling in the stands of analyzed age classes was lower than the increase in growing stock (by tables). Therefore the possibly high level of felling cannot be considered responsible for the decrease in the volume of growing stock in IIIa and Va age classes between 2005 and 2010.

The results of measurements carried out in Jedlnia Division are shown in figure 2 and table 4. The growing stock per hectare of stands of IIb age class, determined from measurements on 26 plots dated 01.01.2011, amounted to 182 m³/ha and was by 17% (27 m³/ha) higher than the results of the SILP updates. In the case of IIIa age class the difference between the measurements and the updated data amounted to about 7% (14 m³/ha).

When it comes to the stands of Vb age class, it was found that their volume of growing stock dated 01.01.2011, determined from measurements of 54 sample plots, was 15 m³/ha less than the one resulting from the updates in SILP. The growing stock per hectare de-
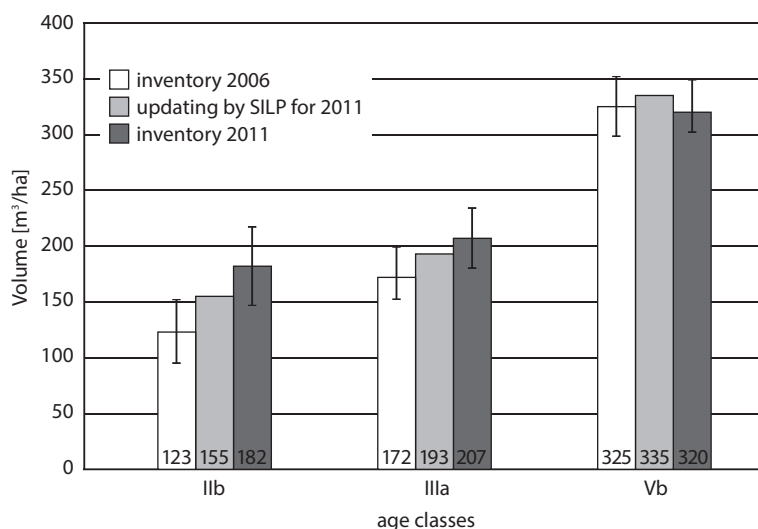
Figure 2. The average volume of growing stock and confidence intervals for the mean from the sample of analyzed age classes in the Szczytno forest division: updating for 2010 was made using the Information System of the State Forests

termined for 2011 is at once lower by 5 m³/ha than the results of the inventory in 2006. The volume of growing stock for stands of this particular age class, among all analyzed age classes in Jedlnia Division, was estimated with the greatest accuracy. The percentage error determined by formulas [1] and [2] equals 4.2% for the inventory in 2011, which corresponds to 26 m³/ha.

4. Discussion

The use of a random distribution of sample plots not only excludes an element of subjectivity, but also allows us to determine the theoretical accuracy of the parameter estimates (Rosa 1972). Evolution of the growing stock inventory methods applied in forests meant that the issue of the accuracy of the results of the inventory was given no special attention. Applying the same method of inventory in two successive management plans permits, or even forces, us to take into account the element of accuracy in the analysis of changes in the volume of timber resources of districts. The results of research presented here show in a meaningful way the need for interpretation of data from forest inventories in the light of the statistical assumptions of the method used, i.e. treating them as a random variable (Zasępa 1972).

The projection of the results from the sample plots on the general population (e.g., forest division) requires giving an error of such a generalization. Repeat sampling and measurement of the same number of sample plots (at the same time) each time will provide a slightly different result, but fitting with a certain probability the confidence interval specified for the mean from the sample (Banaś 2005).

In the face of presented results identifying the measurements on the sample plots as the actual growing stock of a stand would mean that after five years it reduced, for example, in stands of Vb age class in Jedlnia Division from 325 m³/ha in 2006 to 320 m³/ha in 2011. The only reason for such a change could be the felling after accessing the rate of stock growth of these stands, which was not confirmed by the results of the growing stock updates in SILP. The difference of 1.5% between the growing stock of the age class mentioned in 2011 and 2006 is invalid in the situation when the results of both measurements were characterized by 8-9% estimation error. Until the confidence intervals for the mean from the sample are part of a joint, you cannot talk about the differences from a statistical point of view. Establishing 49 sample plots in the age class Vb in Jedlnia Division allows us to conclude that the actual growing stock of this age layer in 2006, with a 95% probability, is somewhere between 295 and 355 m³/ha. We could speak of a statistically lower value of growing stock in the situation of obtaining the result of 270 m³/ha (assuming 8% error of estimate) in the second measurement (2011).

The study adopted the assumptions regarding the number of sample plots from the Forest Management Guideline of 2003. The algorithm to determine the number of sample plots for the division proposed in the current Guideline (Instrukcja 2012), makes it more dependent on the division area. According to the current instructions about 20% less sample plots should be set within Jedlnia Division, which means that the accuracy of the growing stock estimation for the division and for the individual layers would have additionally declined.

Due to the highly labor-consuming inventory works this research deals only with a few selected age classes.

At the division or higher forest unit level, the results are expected to average. It is as much likely a possibility that in the other age classes after ten years the average growing stock per hectare will be far too high according to the knowledge about increase of timber resources in stands. It is important, however, to understand the limitations of the method applied whenever a situation like in IIIa and Va age classes in Szczytno Division or in Vb age class in Jedlnia Division occurs.

The use of temporary sample plots is an effective way of assessing the forest at any given moment in time. Comparison of the survey results of the two moments in time also allows us to determine the changes in the volume of wood resources (Scott 1998). This method, however, is not effective (Schreuder et al. 1993). It is not possible to determine the components of the growth, and its variance is equal to the sum of the variances of the growing stock volume of the two measurements.

Obtaining reliable information about changes in timber resources, including the relationship between the processes of tree growth, loss and increment, is possible through the use of permanent sample plots (continuous forest inventory). The solution is propagated in Poland since the late 70s of the last century (Rutkowski et al. 1972; Banaś 2005). As a result of the occurrence of a positive covariance between the results of the measurements on permanent plots, the increase is determined with a smaller error than in the case of independent temporary sample plots (Scott 1998).

In situations where the subject of the research is both the size of the resources at any given time as well as their changes, it is reasonable to also apply the method using both space and time constants (sampling with partial replacement), (Scott 1984). This system is especially reasonable in the case of stratified random sampling and if there are changes in the structure of the layers between the measurements (Scott, Köhl 1994; Saborowski et al. 2010). As noticed by Köhl et al. (1995), where the measurements are carried out in more than two points in time, due to the simplicity, the method of permanent sample plots is more appropriate for the assessment of the changes in wood resources

5. Conclusions

The study results tend to formulate the following conclusions:

(1) Assessment of the growing stock volume of age classes in the successive revisions of forest management without information on the accuracy of estimating this volume, but only from the point of view of the mean from the sample, may lead to inappropriate generalizations.

(2) Possibly lower average volume of growing stock of the inventory layer or age class in the consecutive revision of forest management doesn't denote the decrease in volume, and may be the result of a random sample.

(3) Average annual changes in the volume of growing stock of the age layer between consecutive cycles of forest management at the level of 2-3 m^3/ha can arise solely from the method used in survey.

(4) When considering forest divisions it can be expected that the errors of the growing stock estimation of the individual inventory layers and age classes will average, as demonstrated by both the results of this paper and the literature data. In order to avoid bias, do not question the results indicating decrease of growing stock volume of stands even if it looks unreasonable in the light of the knowledge about tree growth.

(5) The results obtained in this work indicate that it is necessary to take into account the element of statistical accuracy of the stratified random sampling method (especially at the age classes level) in the course of analytical works performed in accordance with § 76-77 of forest management guideline (Instrukcja 2012), namely:

– the analysis of forest management for the duration of the current FMP and the formulation of proposals for the future,

– the analysis of timber resources and determining the desired level of stocks at the end of the planned economic period.

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