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Variation Between Voivodships in Terms of Forest Area and Silviculture Activities in Polish Forests in 2015-2019

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Abstract: The objective of the study reported here was to compare voivodships in terms of forest area, forest regeneration area, afforested area, thinned forest area and natural forest regeneration area Main Statistical Office data for Polish voivodships was analysed. It included forest area, natural forest regeneration and silviculture activities (forest regeneration, afforestations and thinning) in all forests, state-owned forests and privately-owned forests. Voivodships were compared using the arithmetic mean, the indicator of structure, the average rate of change, principal component analysis and cluster analysis. Principal Component Analysis, revealed that state-owned forest area, forest regeneration in state forests, total forest regeneration, and thinning in state-owned forests had the greatest share in the multivariate variation among voivodships analysed in terms of forestry. Cluster analysis yielded two groups of voivodships. The voivodships in the first group had a higher average total forest area, area of state-owned forests, total area of forest regeneration and forest regeneration in state-owned forests, area of natural forest regeneration and thinning in state-owned forests. On average, forests of voivodships which formed group 2 included less privately-owned forests in which fewer forest regeneration and afforestation activities had been conducted. Opolskie and Śląskie Voivodships as well as Łódzkie and Świętokrzyskie Voivodships were the most similar in terms of all the analysed characteristics.

Keywords: forest area, forest regeneration, afforestation, thinning, voivodship

1. Introduction

The forest area in Poland in 2019 was 9,258.8 th ha (Rocznik… 2020). Increasing forest cover is a permanent element of spatial, ecological and economic policy of the country. The forested area in Poland has constantly been growing since World War II (Sobczak 1996). Forest cover increased from 20.6% in 1946 to 29.6% in 2019 (Broda 2000, Polna 2017, Leśnictwo… 2017, Rocznik… 2020). The State Forests National Forest Holding manages 76.9% total forest area, privately-owned forests cover 19.3% and the remaining 3.8% is made up of e.g.: forests in National Parks and community-owned forests. In the European Union, Poland is at+ the forefront of countries with the greatest forest area. Of all the forests in Poland, lowland forests cover 7.8 million ha (85% forest area), highland forests – 600 thousand ha, and mountain forests – 795 thousand ha (Jagodziński 2019).

Despite the leading position of Poland in Europe, all the neighbouring countries (excluding Ukraine – 16.7%) have a higher percentage of forests in the land area (Poland – 30.8%) which is 32.8% in Germany, 34.5% in the Czech Republic, 36.4% in Lithuania, 40.4% in Slovakia, and 44.5% in Belarus (Leśnictwo… 2017).

Afforestation is defined as an initiation of the forest establishment process and regeneration (restoration of community structure and function due to internal forces) of the forest ecosystem in the place where, for a variety of reasons and at a different time, the forest was replaced with other land use forms. Both forests and forested areas should be attended to, that is subjected to various practices and actions to control tree stand development. Thinning, being one of such practices, conditions structural diversity, dynamics of development and productivity of tree stands (Brzeziecki 2005, Lockow 2003). In forestry, thinning is defined as the selective removal of trees which is mainly conducted in order to improve the growth rate or take care of the health of the remaining trees. Forest areas developing in this way play many important environmental and economic roles which include: nature and landscape protection, strengthening and expanding the forest functions contributing to water and air protection, reduction of the 'greenhouse effect' and counteracting global climate change, enhancing the aesthetic and recreational advantages of the environment, rehabilitation of contaminated and degraded land, implementation of spatial management policy, land use rationalisation, management of regional development and rural area development in an economic sphere (Gorzelak 1999, Falencka-Jabłońska 2012, Wysocka-Fijorek 2020).

Research indicates that from the point of view of land use structure and environment management in Poland and the present stage of civilisation development, rational forest cover should be 33-34% (Kwiecień et al. 2002). Afforestations are conducted based on the 'The National Programme of Increasing

Forest Cover' (1995). It assumes the proper conditions will be created to increase Poland's forest cover to 30% in 2020 and to 33% in 2050. The programme outlines an optimum distribution of afforestation, establishes ecological and economic priorities and instruments necessary to achieve them. Particular stress is placed on strengthening environmental functions (water and soil conservation, nature protection). Based on the established criteria, afforestations carried out in Wielkopolskie and Kujawsko-pomorskie Voivodships are most preferred, and those in Opolskie, Dolnośląskie and Śląskie Voivodships – the least preferred (Krajowy… 2003, Kaliszewski et al. 2016).

Forests, like other ecosystems, are largely shaped by human activity (Vitousek et al. 1997, Bomanowska, Kiedrzyński 2011). The worldwide concern for the state of forests, the need for their protection and sustainable management of forest resources manifest themselves in international conventions pertaining to forests and environmental protection (Paschalis 1992, Paschalis-Jakubowicz 2011). Sustainable management of forests requires suitable tools which make it possible to implement the overall rules adopted in strategic documents (Rykowski 2006, Wijewardana 2008). It is necessary to adjust forest management and use concepts to new conditions (Gil et al. 2002, Golos 2008).

One of basic tasks of modern forestry is to sustainably meet the needs of the society by permanent maintaining and rational utilisation of forest resources. In order to achieve these tasks, constant control of the effects of human interference with forests ecosystems (Stępień 1995), particularly when there is growing demand for information about forests (Vidal et al. 2008, Talarczyk 2015) and changing expectations of the society as to the functions forests fulfil (Paschalis-Jakubowicz 2011). A proper assessment of the forest's condition requires a clearly defined system of indicators matching the spatial scale of undertaken activities (McElhinny et al. 2005, Motz et al. 2010, Jabłoński et al. 2017).

The Ministerial Conference on the Protection of Forests in Europe (MCPFE), at present referred to as Forest Europe, is indicated as the major initiative of European countries in terms of improving and assessing the permanently sustainable forest management (Paschalis-Jakubowicz 2010). Thus, there is a need for an assessment of forests and forest management. Forest area and its temporal changes are one of basic indicators referred to by authors (State… 2011, Baycheva et al. 2013, Jabłoński 2015). The forest area in Poland undergoes an annual assessment within the programmes of examining public statistics (Rozporządzenie … 2014, Jabłoński 2015), and the results are presented in Statistics Poland (SPL) Yearbooks (Leśnictwo… 2017; Ochrona… 2013).

2. Materials and methods

Data for the years 2015-2019 published in SPL Yearbooks was analysed (GUS 2016, 2017, 2018, 2019).

The first step of the analysis involved calculation of arithmetic means and indicators of structure for all the examined characteristics. In order to study temporal changes in phenomena, an average rate of change (tz) was calculated according to the formula (Sobczyk 2007):

$$tz = \left(\bar{y}_g - 1\right) \tag{1}$$

where: tz – average rate of change; $\bar{y}_g$ – geometrical mean of chain indices for 2015-2019 calculated as follows:

$$I = \frac{y_n}{y_{n-1}} \tag{2}$$

where: I –index of dynamics, y_1 – value of the phenomenon in the study period, y_0 – value of the phenomenon in the base period.

In order to determine the multivariate variation of objects (voivodships) in terms of 11 characteristics, principal component analysis (PCA) was employed. The following variables were selected: X_1 – total forest area, X_2 – state-owned forest area, X_3 – privately-owned forest area; X_4 – total forest regeneration; X_5 – forest regeneration in state-owned forests; X_6 – forest regeneration in privately-owned forests; X_7 – total afforestation; X_8 – afforestation in state-owned forests; X_9 – afforestation in privately-owned forests; X_{10} – natural forest regeneration in state-owned forests; X_{11} – thinning in state-owned forests.

The principal components whose eigenvalues were greater than 1 (according to Kaiser criterion (1958) were interpreted. Next, in order to divide voivodships into groups with similar parameters reflecting silvicultural activities undertaken in forests, cluster analysis was carried out by means of Ward's method, the Euclidean distance being chosen as a measure of multivariate dissimilarity of objects.

To obtain clusters, the dendrogram was divided following Mojena rule according to which the cut-off level is the length of the bond for which the following is true (Milligan and Cooper 1985):

$$d_{i+1} > \bar{d} + ks_d; \tag{3}$$

where: $\bar{d}$ and s_d are, respectively, mean and standard deviation of d_i and k is a constant ranging from 2.75 to 3.50 (Mojena 1977). Following Milligan and Cooper (1985), the value k = 1.25.

3. Results and discussion

Analysis of values presented in Table 1 revealed that the highest total forest area was in Zachodniopomorskie Voivodship (indicator of structure – almost 9%), followed by Mazowieckie (almost 9%), Warmińsko-mazurskie and Wielkopolskie Voivodships (8.4% for both).

By contrast, the lowest area was found for Opolskie Voivodship (indicator of structure – less than 3%). The total forest area remained unchanged throughout the study period as reflected in the value of average rate of change (0.0%). The same situation was found for state-owned forests. The greatest total forest area was in Zachodniopomorskie Voivodship (indicator of structure – almost 11%) followed by Lubuskie (9.4%) and Pomorskie Voivodship (more than 8%). The smallest area of state forests was found in the Małopolskie Voivodship (indicator of structure – below 3%. The average rate of change in voivodships was 0.0%, too. For privately-owned forests, they covered largest area was in Mazowieckie followed by Lubelskie and Podlaskie Voivodship (21%, more than 13%, and more than 11%, respectively). The lowest value was for Lubuskie and Opolskie Voivodships (less than 1%). The average rate of change in the area of privately-owned forests was the greatest (1.2%) in Zachodniopomorskie and Warmińsko-mazurskie Voivodship. The rate indicates that the average yearly increase in the area of privately-owned forests was 1.2%. Moreover, in 10 voivodships, the average increase was 1%.

Table 1. Arithmetic mean (thousand ha), index of structure (Ws %) and average rate of change (tz %) for total forest area, privately-owned forest area and state-owned forest area in individual voivodships in 2015-2019

Voivodship	Total			State-owned			Privately-owned		
	$\bar{x}$	Ws	tz	$\bar{x}$	Ws	tz	$\bar{x}$	Ws	tz
Dolnośląskie	580.3	6.5	0.0	552.2	7.8	0.0	21.0	1.2	1.1
Kujawsko-Pomorskie	420.5	4.7	0.0	367.5	5.2	0.0	49.4	2.8	1.0
Lubelskie	570.4	6.4	0.0	328.8	4.6	0.0	240.3	13.5	1.0
Lubuskie	682.6	7.6	0.0	667.7	9.4	0.0	12.8	0.7	1.1
Łódzkie	384.8	4.3	0.0	246.7	3.5	0.0	134.8	7.6	1.1
Małopolskie	400.5	4.5	0.0	199.0	2.8	0.0	189.8	10.7	1.0
Mazowieckie	795.3	8.9	0.0	419.6	5.9	0.0	373.3	21.0	1.0
Opolskie	247.0	2.8	0.0	232.7	3.3	0.0	12.8	0.7	1.1
Podkarpackie	638.3	7.1	0.0	488.6	6.9	0.0	121.4	6.8	1.0
Podlaskie	586.7	6.5	0.0	380.9	5.4	0.0	204.3	11.5	1.0
Pomorskie	653.2	7.3	0.0	572.7	8.1	0.0	77.2	4.3	1.0

Table 1. cont.

Voivodship	Total			State-owned			Privately-		
	$\bar{x}$	Ws	tz	$\bar{x}$	Ws	tz	$\bar{x}$	Ws	tz
Śląskie	388.0	4.3	0.0	305.3	4.3	0.0	79.0	4.4	1.0
Świętokrzyskie	321.6	3.6	0.0	225.0	3.2	0.0	95.5	5.4	1.0
Warmińsko-Mazurskie	753.9	8.4	0.0	688.8	9.7	0.0	61.8	3.5	1.2
Wielkopolskie	752.5	8.4	0.0	662.3	9.3	0.0	84.5	4.8	1.0
Zachodniopomorskie	797.5	8.9	0.0	771.7	10.9	0.0	21.3	1.2	1.2

Source: Own compilation based on SPL data.

The largest area of total forest regeneration (Table 2) was observed in Wielkopolskie Voivodship (share in the structure – more than 10%), it being slightly lower in Zachodniopomorskie and Lubuskie Voivodships (respectively, almost 10% and more than 9%). The lowest area of forest regeneration was found in Małopolskie Voivodship (share in the structure – 2.1%).

Table 2. Arithmetic mean (ha), indicator of structure (Ws %) and the average rate of change (tz %) for total forest regeneration in state- and privately-owned forests by voivodships, in 2015-2019

Voivodship	Total			State-owned			Privately-owned		
	$\bar{x}$	Ws	tz	$\bar{x}$	Ws	tz	$\bar{x}$	Ws	tz
Dolnośląskie	4401	7.7	-1.0	4349.6	8.0	-1.0	13.4	0.7	-45.9
Kujawsko-Pomorskie	3337	5.8	16.4	3233.2	5.9	16.0	93.5	5.0	31.1
Lubelskie	2554	4.5	1.1	2462.2	4.5	1.6	89.7	4.8	-11.9
Lubuskie	5258	9.2	4.0	5244.8	9.6	4.0	10.0	0.5	4.1
Łódzkie	2166	3.8	4.5	2070.6	3.8	4.1	69.0	3.7	11.4
Małopolskie	1541	2.7	-10.2	1120.4	2.1	-12.2	245.3	13.1	-9.9
Mazowieckie	3738	6.5	1.3	3492.6	6.4	1.7	237.1	12.6	-4.2
Opolskie	2182	3.8	-3.0	1770.4	3.2	-2.9	18.6	1.0	-15.1
Podkarpackie	3275	5.7	-7.4	2988.8	5.5	-7.9	183.2	9.8	-5.1
Podlaskie	2441	4.3	1.9	2284.4	4.2	1.3	149.7	8.0	11.3
Pomorskie	5103	8.9	16.9	4835.4	8.9	14.9	264.2	14.1	59.1
Śląskie	2947	5.1	-0.2	2793.2	5.1	0.3	144.8	7.7	-10.5
Świętokrzyskie	1778	3.1	-2.6	1615.4	3.0	-3.2	162.2	8.6	3.9
Warmińsko-	5016	8.7	1.5	4947.8	9.1	1.7	51.6	2.8	-15.2
Wielkopolskie	5925	10.3	2.0	5749.1	10.5	1.9	92.8	4.9	-7.9
Zachodniopomorskie	5673	9.9	1.6	5616.2	10.3	1.7	52.1	2.8	-17.3

Source: Own compilation based on SPL data.

The highest rate of change in the value of this characteristic was obtained for Pomorskie and Kujawsko-pomorskie Voivodships (respectively, almost 17% and over 16% per year, on average, the highest drop in the value of this characteristic (-10.2%) being observed for Małopolskie Voivodship. In state-owned forests, the greatest area of forest regeneration was confirmed in Wielkopolskie and Zachodniopomorskie Voivodships (respectively, 10.5 and 10.3%). The lowest area planted to forest regeneration was found in Małopolskie Voivodship (share in the structure – 2.1%). The greatest rate of change was associated with Kujawsko-pomorskie Voivodship (16% increase per year, on average) and Pomorskie Voivodship (almost 15%). The greatest drops in the area of forest regeneration were determined in Małopolskie Voivodship (more than -12% per year, on average).

Table 3. Arithmetic mean (ha), indicator of structure (Ws %) and the average rate of change (tz %) for total afforestations in state- and privately-owned forests by voivodships, in 2015-2019

Voivodship	Total			State-owned			Privately-owned		
	$\bar{x}$	Ws	tz(%)	$\bar{x}$	Ws	tz(%)	$\bar{x}$	Ws	tz(%)
Dolnośląskie	4401	7.7	-1.0	77.7	4.6	-13.2	13.4	0.7	-45.9
Kujawsko-Pomorskie	3337	5.8	16.4	83.8	5.0	-20.4	93.5	5.0	31.1
Lubelskie	2554	4.5	1.1	154.9	9.2	-9.5	89.7	4.8	-11.9
Lubuskie	5258	9.2	4.0	75.8	4.5	40.0	10.0	0.5	4.1
Łódzkie	2166	3.8	4.5	105.6	6.3	-9.3	69.0	3.7	11.4
Małopolskie	1541	2.7	-10.2	31.1	1.8	27.7	245.3	13.1	-9.9
Mazowieckie	3738	6.5	1.3	161.0	9.6	-22.8	237.1	12.6	-4.2
Opolskie	2182	3.8	-3.0	23.5	1.4	-16.4	18.6	1.0	-15.1
Podkarpackie	3275	5.7	-7.4	127.8	7.6	-40.6	183.2	9.8	-5.1
Podlaskie	2441	4.3	1.9	125.8	7.5	-20.8	149.7	8.0	11.3
Pomorskie	5103	8.9	16.9	121.5	7.2	2.7	264.2	14.1	59.1
Śląskie	2947	5.1	-0.2	11.6	0.7	12.8	144.8	7.7	-10.5
Świętokrzyskie	1778	3.1	-2.6	93.6	5.6	-5.2	162.2	8.6	3.9
Warmińsko-Mazurskie	5016	8.7	1.5	197.3	11.8	-17.0	51.6	2.8	-15.2
Wielkopolskie	5925	10.3	2.0	71.3	4.2	-14.0	92.8	4.9	-7.9
Zachodniopomorskie	5673	9.9	1.6	216.5	12.9	-33.5	52.1	2.8	-17.3

Source: Own compilation based on SPL data.

Values for afforestation presented in Table 3 are concurrent with data for forest regeneration. As far as total afforestations are concerned, the superior

region was Wielkopolskie Voivodship whose share in the structure exceeded 10%. Slightly lower values for afforestation were obtained for Zachodniopomorskie and Lubuskie Voivodships (respectively, almost 10% and more than 9%), them being the lowest in Małopolskie and Świętokrzyskie Voivodships (almost 3% for both). The rate of change in afforestation was the greatest in Pomorskie and Kujawsko-pomorskie Voivodships whose respective shares in the structure were 17 and more than 16%. The greatest decline in the value of this characteristic was observed for Małopolskie Voivodship (less than -10%). In state-owned forests, the afforested area was the greatest in Zachodniopomorskie and Warmińsko-mazurskie Voivodships (almost 12 and 13%, respectively. By contrast, the lowest value of this characteristic was determined in Śląskie Voivodship (0.7% share in the structure). The highest rate of change in afforestation was found in Lubuskie Voivodship (40%), it being the lowest (-40%) in Podkarpackie Voivodship. In privately-owned forests, afforestations were the greatest in Pomorskie Voivodship (over 14% share in the structure), and Małopolskie and Mazowieckie Voivodships (almost 13%). The lowest value of this characteristic were found for forests in Lubuskie and Dolnośląskie Voivodships (0.5 and 0.7%, respectively). In Pomorskie Voivodship, the afforested area increased at the greatest pace (59% per year, on average) whereas the decline in the value of this characteristic was the highest in Dolnośląskie Voivodship (46% per year, on average).

The final analysis pertained to natural forest regeneration and thinning in state-owned forests.

The greatest area of natural forest regeneration was found in Dolnośląskie, Warmińsko-mazurskie and Podkarpackie Voivodships (the respective shares in the structure: more than 15%, almost 12% and 10%). The lowest value of this characteristic was obtained for Kujawsko-pomorskie Voivodship (0.2%). In Podlaskie Voivodship, the rate of change in the values of this characteristic was the greatest (more than 16% per year, on average) whereas the greatest decline in natural forest regeneration was found in Kujawsko-pomorskie (-26% per year, on average). The greatest thinning area was in Zachodniopomorskie, Warmińsko-mazurskie and Lubuskie Voivodships (respectively, 10, 9 and 9% share in the structure). By contrast, the lowest value of this characteristic was found for Opolskie Voivodship (more than 2%). The greatest annual rate of change in thinning area, 4%, on average, was in Łódzkie Voivodship, the greatest drop in the thinning area being observed in Kujawsko-pomorskie Voivodship (almost -9% per year, on average).

Principal component analysis revealed that the examined characteristics in voivodships were affected by traits connected with the first three principal components (as indicated by eigenvalues of these components which were

greater than 1). The components accounted for 84.55% of overall variance, that is total multivariate variation of the characteristics describing forests (Table 5).

The first principal component was strongly positively correlated with the area of state-owned forests (r = -0.978), forest regeneration in state-owned forests (r = -0,937), total forest regeneration (r = -0.936) and thinning in state-owned forests (r = -0.889). These variables had the greatest share in multivariate variation of voivodships in terms of the analysed characteristics.

Afforestation in privately-owned forests, area of privately-owned forests and total afforestation were the most strongly associated with the second principal component (PC2) (respectively, r = -0.902, r = 0.869 and r = 0.698), and caused less variation between voivodships in terms of the examined characteristics (PC2 accounted for 24.26% variation). The third principal components explained about 10% variation between voivodships and was associated with forest regeneration in privately-owned forests (r = 0.638) and natural forest regeneration in state-owned forests (r = 0.485).

Table 4. Arithmetic mean (ha), indicator of structure (Ws %) and the average rate of change (tz %) for natural forest regeneration and thinning in state-owned forests by voivodships, in 2015-2019

Voivodship	Natural forest regeneration			Thinning		
	$\bar{x}$	Ws	tz	$\bar{x}$	Ws	tz
Dolnośląskie	1260	15.4	-0.8	24525.0	4.9	-6.3
Kujawsko-Pomorskie	16	0.2	-26.2	25719.0	5.2	-8.6
Lubelskie	411	5.0	1.2	42694.8	8.6	-2.9
Lubuskie	431	5.3	12.4	44055.2	8.9	-3.1
Łódzkie	226	2.8	4.3	20478.8	4.1	4.1
Małopolskie	667	8.2	-16.6	17218.6	3.5	0.7
Mazowieckie	645	7.9	-1.1	36739.4	7.4	-2.4
Opolskie	193	2.4	-4.0	11677.6	2.4	-8.4
Podkarpackie	822	10.1	-22.1	35338.6	7.1	-5.7
Podlaskie	147	1.8	16.3	25889.4	5.2	1.2
Pomorskie	498	6.1	13.4	37472.6	7.5	-6.1
Śląskie	606	7.4	4.6	16151.2	3.3	-4.1
Świętokrzyskie	269	3.3	1.7	20246.8	4.1	-1.1
Warmińsko-Mazurskie	965	11.8	9.2	45046.8	9.1	-2.6
Wielkopolskie	573	7.0	-5.4	43582.0	8.8	-1.8
Zachodniopomorskie	429	5.3	-4.6	50075.4	10.1	-0.2

Source: Own compilation based on SPL data.

The distribution of voivodships in the system of the first two principal components is presented in Figure 1. The distance between voivodships approximately reflects the multivariate similarity between them in terms of the examined characteristics. Objects (voivodships) which are widely distanced differ in terms of many characteristics. Voivodships whose values of the first principal component were close to zero (Podkarpackie and Lubelskie) had average values of characteristics which were strongly correlated with this components (state-owned forests, total forest regeneration, forest regeneration in state-owned forests and thinning in state-owned forests). The largest negative values of the first principal component were obtained for Zachodniopomorskie Voivodship, which indicates that this region had the highest values of characteristics associated with PC1. The greatest PC1 values were obtained for Małopolskie and Opolskie Voivodships, which is indicative of the fact that in those voivodships values of traits associated with PC1 were the lowest. The relationships result from a negative correlation of these traits with PC1. Zachodniopomorskie and Świętokrzyskie Voivodships varied the most in terms of the examined characteristics whereas Pomorskie and Małopolskie Voivodships had average values of characteristic associated with the second principal component, that is privately-owned forests, total afforestation and afforestation in privately-owned forests.

Table 5. Eigenvalues, share of principal components in the overall variation and correlation coefficients between these components and the examined characteristics

Item	Principal components		
	PC1	PC2	PC3
X_1 – Total forest area	-0.866	-0.359	0.244
X_2 – Area of state-owned forests	-0.978	0.138	0.054
X_3 – Area of privately-owned forests	0.245	-0.869	0.261
X_4 – Total forest regeneration	-0.936	0.207	0.130
X_5 – Forest regeneration in state-owned forests	-0.937	0.226	0.080
X_6 – Forest regeneration in privately-owned forests	0.178	-0.456	0.638
X_7 – Total afforestations	-0.549	-0.698	-0.393
X_8 – Afforestations in state-owned forests	-0.813	0.200	-0.207
X_9 – Afforestations in privately-owned forests	0.018	-0.902	-0.308
X_{10} – Natural afforestations in state-owned forests	-0.465	-0.018	0.485
X_{11} – Thinning in state-owned forests	-0.889	-0.350	-0.147
Eigenvalue	5.52	2.67	1.11
Cumulative variance (%)	50.20	74.46	84.45

Source: Own compilation based on SPL data.

Variation between voivodships in terms of the examined characteristics was confirmed by cluster analysis which produced two groups. One group was formed by the following voivodships: Zachodniopomorskie, Warmińsko-mazurskie, Pomorskie, Wielkopolskie, Lubuskie and Dolnośląskie. The other cluster consisted of Mazowieckie, Lubelskie, Śląskie, Opolskie, Małopolskie, Podlaskie, Podkarpackie, Świętokrzyskie, Łódzkie and Kujawsko-pomorskie Voivodships. The following voivodships were the most similar in terms of the analysed characteristics: Lubuskie and Wielkopolskie, and Łódzkie and Świętokrzyskie; they formed a cluster at the first and second step of agglomeration (Table 6, Figure 2). The voivodships in the first group had a higher average total forest area, area of state-owned forests, total area of forest regeneration and forest regeneration in state-owned forests, area of natural forest regeneration and thinning in state-owned forests.

On average, forests of voivodships which formed group 2 included less privately-owned forests where less forest regeneration and afforestation had been conducted (Table 7).

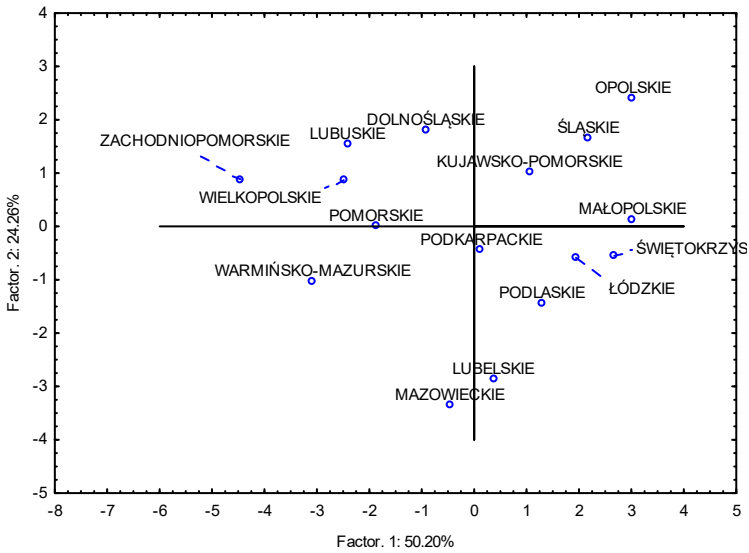

Fig. 1. Division of voivodships, in terms of the examined characteristics, in the system of the first two principal components

Source: Own compilation based on SPL data.

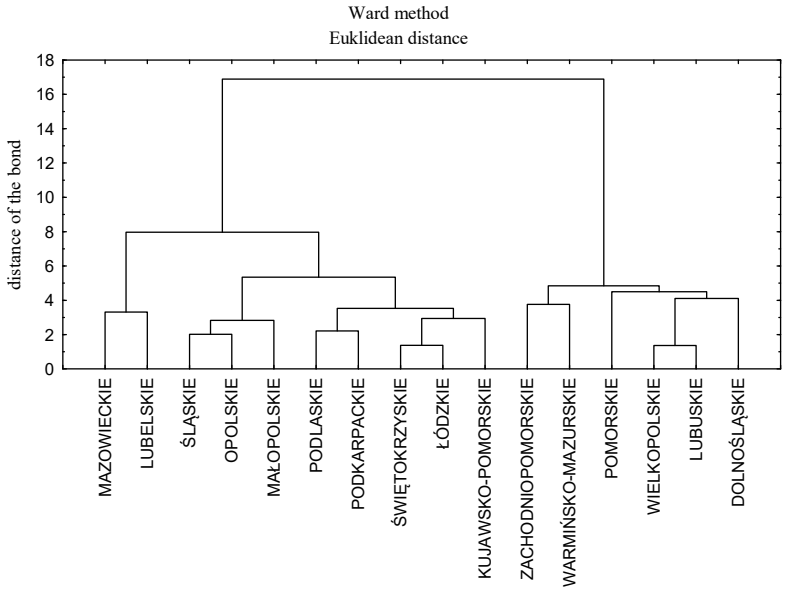

Fig. 2. Clusters of voivodships formed using cluster analysis
Source: Own compilation based on SPL data.

Table 6. Agglomeration course

Step	clusters															
1	LB	WP														
2	Ł	Ś														
3	O	ŚL														
4	PD	PDL														
5	MP	O	ŚL													
6	KP	Ł	Ś													
7	LL	M														
8	KP	Ł	Ś	PD	PDL											
9	WM	ZP														
10	DS	LB	WP													
11	DS	LB	WP	PM												
12	DS	LB	WP	PM	WM	ZP										
13	KP	Ł	Ś	PD	PDL	MP	O	ŚL								
14	KP	Ł	Ś	PD	PDL	MP	O	ŚL	LL	M						
15	KP	Ł	Ś	PD	PDL	MP	O	ŚL	LL	M	KP	Ł	Ś	PD	PDL	MP

LB – lubuskie, WP – wielkopolskie, Ł – łódzkie, Ś – świętokrzyskie, ŚL – Śląskie, PD – podkarpackie, PDL – podlaskie, MP – małopolskie, O – opolskie, KP – kujawsko-

pomorskie, LL – lubelskie, M – mazowieckie, WM – warmińsko-mazurskie, ZP – zachodniopomorskie, DS – dolnośląskie, PM – pomorskie

Source: Own compilation based on SPL data.

Table 7. Average values of characteristics describing forests in groups formed using cluster analysis

Characteristics	group 1	group 2
X_1 – Total forest area	716726	495171
X_2 – Area of state-owned forests	653063	319593
X_3 – Area of privately-owned forests	46850	150475
X_4 – Total forest regeneration	5354	259
X_5 – Forest regeneration in state-owned forests	5239	2420
X_6 – Forest regeneration in privately-owned forests	88.4	134.8
X_7 – Total afforestation	99.3	77.5
X_8 – Afforestation in state-owned forests	54.3	8.10
X_9 – Afforestation in privately-owned forests	42.4	67.1
X_{10} – Natural forest regeneration in state-owned forests	702.1	368.8
X_{11} – Thinning in state-owned forests	39150	24540

Source: Own compilation based on SPL data

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