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Constructions of logical expressions in analysis of vegetation transformations

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Abstract. The paper reports on the effects and range of anthropogenic pressure exerted on forest communities of the Knyszyńska Forest. A comparison between the potential natural vegetation and real vegetation gives an idea on the degree of damage to forest communities, which has been classified in ecological modelling. Logical expressions have been applied in ecological modelling for spatial analyses of vegetation changes carried out by the program ArcView GIS. The logical expressions applied to the GIS spatial database have permitted finding correlations of occurrence of particular types of the present-day real vegetation (in particular the post-clear-cutting communities, young tree communities and secondary forest communities) relative to the present-day potential natural vegetation. The data obtained in this way have been used in analysis of the scale and range of changes in the forest communities of the Knyszyńska Forest caused by forest management measures.
Results of the study have shown that in the Knyszyńska Forest, the secondary communities occupy as much as 88.3% (919.56 km^2), while the oldest tree-stands representing natural communities (of 100 – 120 years of age) occupy only 11.7% (122.28 km^2). Among the secondary communities the greatest area is occupied by the secondary forest communities representing the stickstand and old-growth phases (66.9%) aged from 30 to about 100 years. The contribution of young tree stands – aged from 10 to 30 years is smaller – 16.6%, and that of post-clear-cutting and forest crops forming directly after clear cutting and aged up to 10 years is still smaller – of 4.8%. In the young-tree stands (16.6%) and forest secondary communities (66.9%) the largest is the contribution of those with domination of pine trees (*Pinus sylvestris*) from artificial reforestation, making 11.2 and 55%, respectively, while the contribution of other secondary communities is much lower.

Key words: N-E Poland, Knyszyńska Forest, GIS spatial database, potential natural vegetation, real vegetation, secondary communities, range of anthropogenic changes.

1. Introduction

Mathematical modelling in ecology mainly depends on the strategy and aim of research. Conceptually, the model constitutes a generic framework for testing and sorting out hypotheses on functioning processes involved in plants development (Berec 2002; Drouet & Pagès 2003, 2007) or populations (Reed & Levine 2005; Sakanoue 2007), communities (Reineking et al. 2006), ecosystems (Dambacher et al. 2003a, b) and landscapes (Lischke et al. 2006).

Ecological mathematical models, diverse in purpose and structure, are increasingly used to simplify the representations of reality. Early models were simple theoretical ones designed to produce general predictions unconstrained by the details of a particular time or place. These systems can be easily analytically described and solved (Fath 2004; Ulanowicz 2004; Fath et al. 2007). The growth of public interest in solving environmental problems has since provided a new impetus for the development of complex ecological models employing different methods such as numerical, artificial neural network (ANNs) and new software for ecological modelling, simulation and analysis (MVSP, Syntax, Statistica, EcoNet, ArcGis) (Jørgensen & Bendoricchio 2001; Liu et al. 2003; Corne et al. 2004; Kazanci 2007; Scrinzi et al. 2007). The complex ecological models increased the range of problems of ecological research by the risk assessment of species (Li et al. 2000; Gevrey et al. 2006), biological conservation (Wintle et al. 2003), the quality of local and global change predictions (Jager & King 2004), impact of climate changes (Fuentes et al. 2006), habitat sustainability and forest management (Van der Lee et al. 2006), biotic, abiotic and anthropogenic disturbances (Lundquist & Sommerfeld 2002; Sturtevant et al. 2004a, b; Laughlin & Grace 2006; Edgar & Burk 2007; Laughlin & Abella 2007; Tichit et al. 2007). For analysis of more complex correlations between different disturbing factors, in particular anthropogenic ones, the spatial modelling with the use of GIS procedures have been successfully applied (Nienartowicz & Kunz 2001; McNeil et al. 2006).

This paper reports on the modelling made with the help of constructions of logical expressions to be used for analyses of spatial processes in vegetation in the program ArcView GIS (Esri 1993). The GIS method, which has been developing since 1960s, used for automatic mapping and modelling ecological systems, is extremely useful nowadays for transforming data and defining relationships between them (Gough & Rushton 2000; Łaska & Hildebrand 2001; Łaska 2006a). For many years different algorithms that could be used for identifying features such as structure of landscape, change of vegetation, characteristics of urban, degradation of soil, degeneration of forest, condition of forest etc., have been discussed. The aim of the study is to give an idea of the scale and range of changes in the forest communities of the Knyszyńska Forest performed on the basis of determination of correlations between the occurrence of particular types of the real vegetation with respect to the types of the potential natural vegetation, performed with the use of the logical expressions applied to the spatial GIS database. It is interesting to find why the pine tree stands dominate in the vertical structure of the majority of the forest communities despite a considerable presence of the potentially fertile oak-hornbeam habitats. The question is what are the reasons for the inconsistencies between the species composition and the types of habitats.

2. The area and methods of study

The idea of the study was prompted by the earlier field observations of changes in plant communities performed over 15 years (1987 – 2001) whose outcome was, among others, preparation of digital GIS databases for the forest communities in the Knyszynska Forest and their graphic presentation on 3 maps. The digital maps were prepared within the research project (KBN – nr 6P04G02812) realised in the years 1997 – 1999 (Łaska 1999a, b, c, d, 2006b).

The study area was determined by the main forest complex mapped onto 12 sheets of the "Review Maps of State Forest Divisions" on the scale 1:25000, covering 12 forest districts included into 7 State Forest Divisions (Fig. 1). From the total area of the Knyszyńska Forest – 1267.02 km^2 (GUS 1999), only the State Forests area of 1094.634 km^2, which makes 86.4% of the total area of the Knyszyńska Forest, was subjected to GIS analysis. The area is delimited between 52°55'47" and 53°42'10" of the north latitude and 22°52'20" and 23°54'22" east longitude. It was defined in the coordinates of the state reference system "Coordinate System 42".

2.1. Processing and presentation of the information on the natural environment

The processing of the environmental information was performed with the use of two digital spatial databases on the vegetation of the Knyszynska Forest, i.e. the present-day potential natural vegetation and the present-day real vegetation. The basic field units of the spatial database were defined as the spatial resultant of aggregation of forest subunits. The fundamental area unit of the spatial database was defined as spatial resultant of aggregation of forest subdistricts (forest taxation) belonging to the assumed categories of the potential and real vegetation. The exclusions were generalised to the level of the 1:25000 scale map detail.

In the informative datalayer each area was assigned with the system attributes of the surface database (PAT – polygon attribute table) area, circumference, unique system number and user number. Besides the surface attribute table, each area was characterised by descriptive attributes specifying the type of the present-day potential natural vegetation (Rosp) and the present-day real vegetation (Rosr) to enable their processing in the computer system GIS. The descriptive but not spatial attributes were specified with the help of a coding system of vegetation units. In total, 9 categories of the present-day potential natural vegetation (Code Rosp) (Tab. 1) and 19 categories of the present-day real vegetation (Code Rosr) (Tab. 2) were distinguished.

2.2. Computer system of GIS analysis

The construction of logical expression was performed using the software GIS – ArcView version 3.0 (Esri 1993). The construction of a logical expression is used to formulate an exact logical question addressed to the database concerning the problem of interest. The logical inquiry to the database of vegetation attributes can comprise a number of attributes, operators and mathematical functions, and its construction should permit an effective and precise selection of the objects desired. The syntax is made most often with the chain type fields with the operators "and", "or" and "not". The operator "and" means that both logical expressions are true, "or" that at least one of them is true,

Forest divisions and forest districts in the Knyszyńska Forest

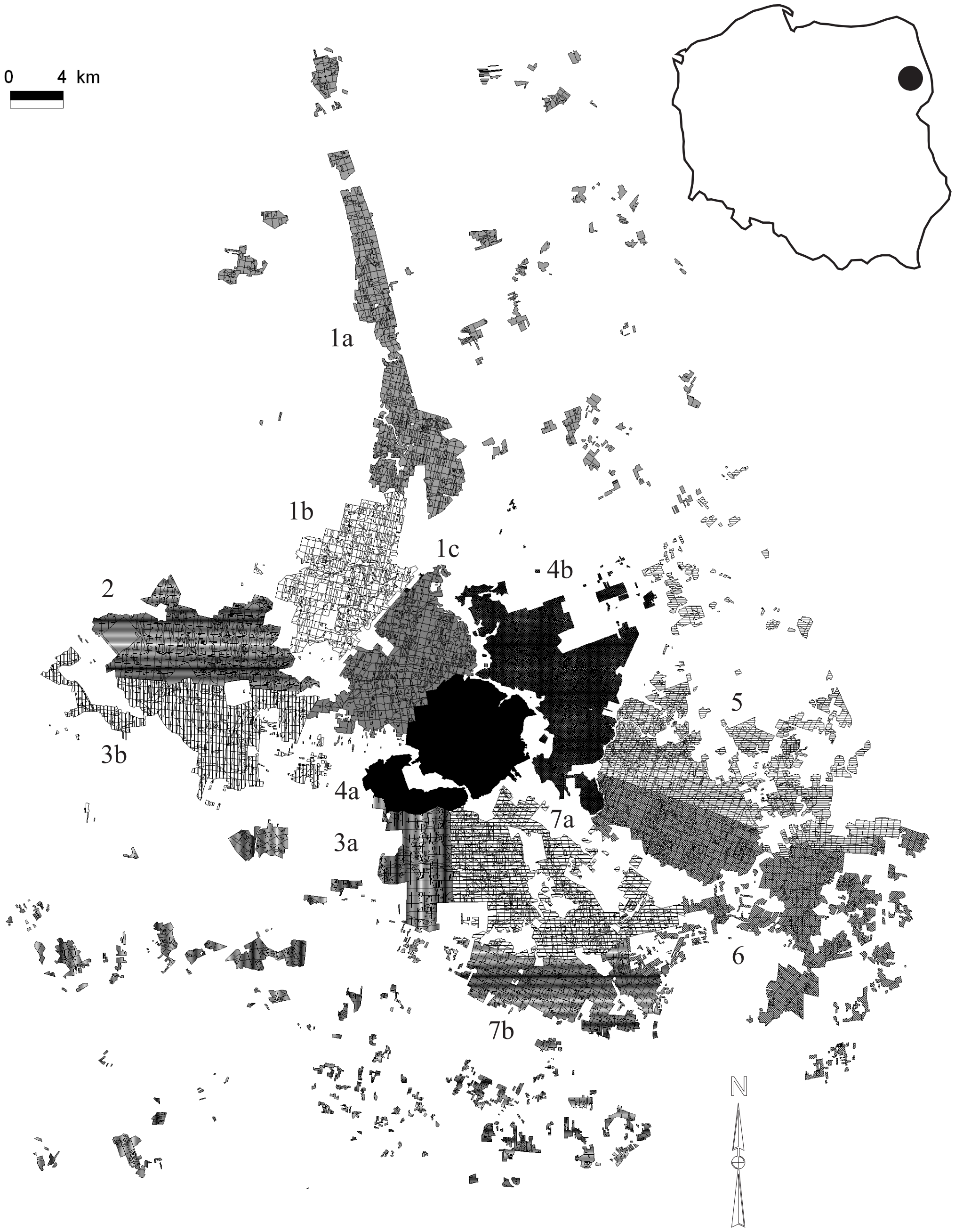

Figure 1. Localization and borders of the forest divisions and forest districts in the Knyszyńska Forest: 1 – Forest Division Czarna Białostocka, 1a – Forest District Kumiałka, 1b – Forest District Czarna Białostocka, 1c – Forest District Złota Wieś; 2 – Forest Division and Forest District Knyszyn; 3 – Forest Division Dojlidy, 3a – Forest District Dojlidy, 3b – Forest District Katrynka; 4 – Forest Division Supraśl, 4a – Forest District Supraśl, 4b – Forest District Sokółka; 5 – Forest Division and Forest District Krynki; 6 – Forest Division and Forest District Waliły; 7 – Forest Division Żednia, 7a – Forest District Zajma, 7b – Forest District Żednia

Table 1. Manner of coding of descriptive attributes of 9 categories of the present-day potential natural vegetation

I Attribute – The present-day potential natural vegetation (Rosp)		
Code	The name of distinguished vegetation units	The syntaxonomic names of communities
1	Subcontinental East-European pine forest subboreal vicariant with spruce	*Peucedano-Pinetum*
2	High coniferous forest	*Carici digitatae-Piceetum*
3	Fresh mixed coniferous forest	*Serratulo-Piceetum*
4	Thermophilous oak-hornbeam forest	*Melitti-Carpinetum*
5	Subcontinentale lowland linden-oak-hornbeam forest; subboreal vicariant with spruce	*Tilio-Carpinetum* (together with *Acer platanoides-Tilia cordata*)
6	Wet mixed coniferous forest	*Querco-Piceetum* (together with *Myceli-Piceetum*)
7	Flood plain forests, bog forests, bog-spruce and bog-pine forests	*Fraxino-Alnetum*, *Piceo-Alnetum*, *Ficario-Ulmetum*, *Carici elongatae--Alnetum, Thelypteri-Betuletum*, *Sphagno-Piceetum*, *Carici chordorrhizae--Pinetum*, *Vaccinio uliginosi-Pinetum*, *Ledo-Shagnetum*
8	Village areas within the Knyszyńska Forest	
11	Forests in the areas outside the compact complex of the Knyszyńska Forest	

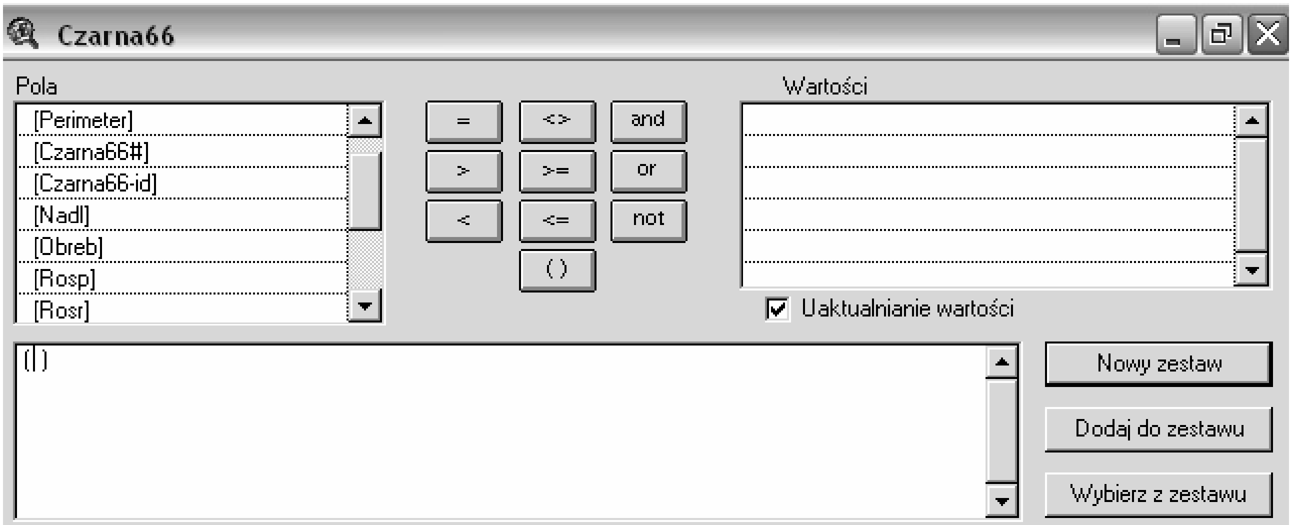

Figure 2. Constructor of logical expressions for determination of the correlation of occurrence of the present-day real vegetation (Rosr) against the units of the present-day potential natural vegetation (Rosp)

while “not” permits construction of mutually exclusive logical expressions (Fig. 2).

The syntax of the logical expression used in ArcView permitted a determination of the number of spatial objects satisfying the conditions of the logical expression x = code Rosr and y = code Rosp (Fig. 2). Thanks to this procedure of mapping the present-day real vegetation on the background of the present-day potential natural vegetation it was possible to get the information on the main cause of vegetation changes in the Knyszyńska Forest.

The method enabled statistical analyses of the presence and distribution of particular attributes distinguished in different datalayers. The results permitted calculation of the total and partial areas with the selected categories of the present-day potential natural and real vegetations over the whole area of the Knyszyńska Forest and in individual

Table 2. Manner of coding of descriptive attributes of 19 categories of the real vegetation

II Attribute – The real vegetation (Rosr)	
Code	The name of distinguished vegetation units
1	The post-clear-cutting and forest crops communities used of clear cutting
2	The post-clear-cutting and forest crops communities used of partial cutting
3	The natural forest communities
The young tree communities, including:	
4	The young tree communities with domination of birch tree (*Betula pendula*)
5	The young tree communities with domination of pine tree (*Pinus sylvestris*)
6	The young tree communities with domination of spruce (*Picea abies*)
7	The young tree communities with domination of oak (*Quercus robur*)
15	The young tree communities with domination of alder (*Alnus glutinosa*)
The secondary forest communities, including:	
8	The secondary forest communities with domination of pine tree (*Pinus sylvestris*)
9	The secondary forest communities with domination of spruce (*Picea abies*)
10	The secondary forest communities with domination of birch tree (*Betula pendula*)
11	The secondary forest communities with domination of oak (*Quercus robur*)
12	The secondary forest communities with domination of hornbeam (*Carpinus betulus*)
13	The secondary forest communities with domination of aspen (*Populus tremula*)
16	The secondary forest communities with domination of alder (*Alnus glutinosa*)
17	The secondary forest communities with domination of ash tree (*Fraxinus excelsior*)
19	The secondary forest communities with domination of linden (*Tilia cordata*)
14	The seminatural (meadows, pastures) and synanthropic (ruderals) communities
18	Village areas within the Knyszyńska Forest

forest sections within its area. At the next step, a detail statistical analysis of the selected categories of vegetation of different types in the system of combination of their co-occurrence was performed. The database records satisfying the imposed logical expression were exported in the form of the Dbase files (*.dbf) to the calculation sheet in Microsoft Excel 2003 in which they were subjected to further statistical analysis (Tab. 3).

3. Results

3.1. Present-day potential natural vegetation

The results of the GIS analysis of 12 source maps have shown that the State Forest takes an area of 1094.63 km^2, which makes 86.4% of the area of the Knyszyńska Forest. Of this area 24.4% (267.30 km^2) is taken by peripheral forests outside the compact complex of the Knyszyńska Forest, 3.57% (38.91 km^2) is taken by villages and 72.03% (788.42 km^2) is occupied by the distinguished types of the present-day potential natural vegetation. According to the syntaxonomic approach assumed after Czerwiński (1995) and Matuszkiewicz (2001), the following syntaxons have been identified (Tab. 4):

Association: *Peucedano-Pinetum* W. Mat. (1962) 1973
Association: *Carici digitatae-Piceetum* Czerw. 1978
Association: *Serratulo-Piceetum* Sokoł. 1968
Association: *Melitti-Carpinetum* Sokoł. 1971 em Czerw. 1978
Association: *Tilio cordatae-Carpinetum betuli* Tracz. 1962 (together with *Acer platanoides-Tilia cordata* Jutrz.-Trzeb. 1993)
Association: *Querco-Piceetum* (W. Mat. 1952) W. Mat. et Pol. 1955 (together with *Myceli-Piceetum* Czerw. 1978)

Flood plain forests, bog forests, bog-spruce and bog-pine forests (*Fraxino-Alnetum* W. Mat. 1952, *Piceo-Alne-*

Table 3. Exemplary data exported from the ArcView program to the calculation sheet of Microsoft Excel, obtained taking into regard the logical expressions for the Forest Division Supraśl and Forest Districts Supraśl and Sokółka

Logical expressions	Forest Division Supraśl							
	Forest District Sokółka				Forest District Supraśl			
	AREA	PER.	SOK66_	SOK66_ID	AREA	PER.	SUP66_	SUP66_ID
1 Rosr – 1 Rosp					0.03786	0.93637	1455	1448
					0.0347	0.97421	1464	1456
					0.00553	0.29891	1702	1701
SUM TOTAL					**0.07809**			
1 Rosr – 2 Rosp	0.00437	0.27511	258	257	0.05332	1.0466	38	40
	0.01892	0.61836	281	282	0.0032	0.27819	46	47
	0.01241	0.53973	288	289	0.00865	0.43505	106	110
	0.01829	0.55616	322	327	0.01762	0.7981	121	120
	0.01085	0.44387	356	365	0.02262	0.66912	130	134
	0.06594	1.27687	368	378	0.0274	1.08031	137	148
	0.02352	0.74942	385	393	0.02443	0.68575	188	193
	0.00395	0.25458	401	407	0.01008	0.53232	193	197
	0.01101	0.41731	523	535	0.01817	0.80637	318	325
	0.00672	0.33069	556	552	0.01451	0.50344	440	446
	0.00579	0.31533	566	560	0.0373	0.87639	569	577
	0.03193	0.78033	575	583	0.00192	0.18059	1136	1123
	0.00646	0.31855	580	593	0.06209	1.3182	1148	1147
	0.0464	1.22549	585	591	0.01083	0.46199	1179	1167
	0.01575	0.55604	628	621	0.01476	0.56831	1257	1259
	0.04282	1.22062	629	634	0.05491	1.84115	1278	1267
	0.00808	0.37103	675	679	0.04324	1.15565	1306	1312
	0.03693	1.15236	709	708	0.01932	0.59845	1404	1406
	0.01057	0.38978	727	715	0.01421	0.51659	1420	1405
	0.02897	1.02261	742	755	0.01451	0.48985	1426	1412
	0.02622	0.88074	743	721	0.00087	0.1213	1447	1450
	0.00343	0.23822	747	752	0.0155	0.49545	1506	1501
	0.04218	1.14799	754	732	0.01898	0.96015	1596	1593
	0.04527	1.07666	767	772	0.00638	0.3413	1606	1605
	0.00863	0.34279	777	780	0.01922	1.54356	1668	1669
	0.0139	0.63823	811	803	0.04633	1.0949	1694	1693
	0.05056	1.249	890	910				
	0.02264	1.06197	906	921				
	0.00883	0.3672	909	935				
	0.04526	1.07288	932	951				
	0.03782	1.28448	951	973				
	0.03296	1.14232	959	978				
	0.01418	0.6155	986	1003				
	0.02019	0.65717	994	1012				
	0.00634	0.32745	996	1017				
	0.00802	0.34599	1241	1267				
	0.04291	1.56043	1249	1275				
	0.09194	1.28479	1264	1291				
	0.07435	1.55894	1265	1292				
	0.08767	1.61837	1282	1309				
SUM TOTAL	**1.0930**				**0.58037**			

Logical expressions	Forest Division Supraśl							
	Forest District Sokółka				Forest District Supraśl			
	AREA	PER.	SOK66_	SOK66_ID	AREA	PER.	SUP66_	SUP66_ID
1 Rosr – 3 Rosp	0.0081	0.46065	31	31	0.00398	0.28743	207	209
	0.0115	0.49522	137	117	0.03197	0.87623	213	219
	0.03007	0.80356	225	229	0.00923	0.47419	284	293
	0.01868	0.78271	342	342	0.03812	1.03344	293	289
	0.0036	0.2625	538	582	0.02238	0.61707	310	310
	0.02326	0.59686	548	570	0.02878	0.74821	366	379
					0.04017	1.09975	396	402
					0.02426	0.61712	522	526
					0.01015	0.42761	547	551
					0.05501	1.05944	652	645
					0.01707	0.83748	670	670
					0.00741	0.40822	1023	1015
					0.00695	0.34832	1034	1047
					0.00955	0.38611	1044	1059
					0.00512	0.36912	1095	1097
					0.03986	1.12243	1108	1116
					0.00307	0.219	1137	1124
					0.03644	1.35584	1159	1155
					0.01026	0.46783	1203	1204
					0.02519	0.89586	1303	1297
					0.02892	0.78215	1346	1343
					0.02096	0.60634	1384	1389
					0.01709	0.537	1400	1410
					0.04514	1.0878	1471	1463
					0.00731	0.46496	1555	1555
					0.00553	0.28887	1633	1634
SUM TOTAL	**0.09521**				**0.54992**			
							and continued….	

Legend:
Rosr – Present-day real vegetation
Rosp – Present-day potential natural vegetation
AREA – The forest area of polygon in km^2
PER. – Perimeter of polygon
SOK66_, SUP66_ – System number
SOK66_ID, SUP66_ID – User number

tum Sokoł. 1980, *Ficario-Ulmetum minoris* Knapp 1942 em. J. Mat. 1976, *Carici elongate-Alnetum* Koch 1926, *Thelypteri-Betuletum* Czerw. 1972, *Carici chordorrhizae-Pinetum* Pałcz. 1975, *Sphagno girgensohnii-Piceetum* Polak. 1962, *Vaccinio uliginosi-Pinetum* Kleist 1929).

The first six units represent the forest communities on the mineral soil taking 88.8% of the Forest area of which 58.9% are the forest communities in the coniferous forests habitats and 29.9% are the forest communities in the oak-hornbeam habitats (Tab. 4). The last seventh unit represents the forest communities on hydrogenic soil, taking 11.2% of the Forest area, comprising flood plain forests, bog forests, bog-spruce and bog-pine forests, treated as one unit.

3.2. Present-day real vegetation

The term the present-day real vegetation refers to the actual vegetation in a given area whose state and composition reflect the current state of habitats and subjected to the impact of forest management. According to the spatial GIS analyses of the area of State Forests 1094.63 km^2 the real vegetation occupies 1041.84 km^2 (Tab. 5). The oldest tree-stands in the Knyszyńska Forest representing the natural and close to natural communities, of 100 – 120 years of age, make only 11.7% (122.28 km^2). The total area taken by the secondary communities including post-clear-cutting and forest crop communities, young tree communities and secondary forest communities is 919.56 km^2, which makes 88.3% of the Knyszyńska Forest area (Tab. 5). Among the

Table 4. The forest area (km²) and percent contribution of the types of the present-day potential natural vegetation in the Knyszyńska Forest, in the area controlled by forest divisions and forest districts

The area under state control, in this: – 1094.6340 km²
– the area taken by forest but outside the compact Knyszyńska Forest complex – 267.3033 km² (24.4%)
– the area of villages – 38.9095 km² (3.57%)
– types of the present-day potential natural vegetation – 788.4212 km² (72.03%)

Code	Present-day potential natural vegetation	Knyszyńska Forest	
		The forest area [km²]*	Percent contribution [%]**
	a) Forest communities on mineral soils	**700.0035**	**88.8**
1	Subcontinental East-European pine forest *Peucedano-Pinetum*	93.9788	11.9
2	High coniferous forest *Carici digitatate-Piceetum*	206.3705	26.2
3	Fresh mixed coniferous forest *Serratulo-Piceetum*	112.5128	14.3
4	Thermophilous oak-hornbeam forest *Melitti-Carpinetum*	77.3294	9.8
5	Subcontinentale lowland linden-oak-hornbeam forest *Tilio-Carpinetum* (together with *Acer platanoides-Tilia cordata*)	158.4779	20.1
6	Wet mixed coniferous forest *Querco-Piceetum* (together with *Myceli-Piceetum*)	51.3341	6.5
7	**b) Forest communities on hydrogenic soils** *Fraxino-Alnetum*, *Piceo-Alnetum*, *Ficario-Ulmetum*, *Carici elongatae-Alnetum*, *Thelypteri-Betuletum*, *Sphagno-Piceetum*, *Carici chordorrhizae-Pinetum*, *Vaccinio uliginosi-Pinetum*, *Ledo-Sphagnetum*	**88.4177**	**11.2**
TOTAL		**788.4212**	**100**

* The area of the compact Knyszyńska Forest complex, without the area taken by forest but outside the compact Knyszyńska Forest complex.

** Percent contribution in the area of the compact forest complex Area of forest units in km² to the fourth place after comma, given for easy change of units to ha units.

secondary communities the greatest area is occupied by the secondary forest communities representing the stickstand and old-growth phases (66.9%) in the age from 30 to about 100 years. The contribution of young tree stands – aged from 10 to 30 years is smaller – 16.6%, and that of post-clear-cutting and forest crops forming directly after clear cutting and aged up to 10 years is still smaller – of 4.8%.

3.3. Analyses of vegetation changes in terms of the spatial GIS data

In the area of the Knyszyńska Forest, the secondary forest communities making 66.9% are mostly represented by those with dominant pine (*Pinus sylvestris*) (55%) in the stickstand phase (Tab. 5). They have developed mainly from the young tree communities with artificially planted pine trees taken from plantations. The contribution of the secondary forest communities with domination of other species is very low. For example, the secondary forest communities with domination of oak (*Quercus robur*) make only 4.2%, with domination of spruce (*Picea abies*) – 3.5%, with domination of birch tree (*Betula pendula*) – 2.8% and with domination of alder (*Alnus glutinosa*) – 1.2% (Tab. 5).

In the young-tree stands (16.6%) the largest is the contribution of those with domination of pine trees (*Pinus sylvestris*) from artificial reforestation, making 11.2%, while the contribution of other young-tree communities is much

Table 5. The forest area (km²) and percent contribution of the types of real vegetation in the Knyszyńska Forest in the area controlled by forest divisions and forest districts

The total area of the Knyszyńska Forest – 1267.02 km² (126 702 ha)
The area under state control, in this: – 1094. 634 km²
– seminatural communities (meadows, pastures) – 8.6081 km² (0.8%)
– synanthropic communities (segetal, ruderal) – 20.9422 km² (1.9%)
– areas devoid of vegetation or unidentified – 23.2450 km² (2.1%)
Total – 52.7953 km² (4.8%)
Types of present-day real vegetation – 1041.8386 km² (95.2%)

Code	Present-day real vegetation	The forest area [km²] *	Percent contribution [%] **
3	**The natural forest communities**	**122.2834**	**11.7**
	Non-forest and forest secondary communities:	**919.5552**	**88.3**
1	**The post-clear-cutting and forest crops communities used of clear cutting**	**34.0176**	**3.3**
2	**The post-clear-cutting and forest crops communities used of partial cutting**	**15.8066**	**1.5**
	The young tree communities, including:	**172.9709**	**16.6**
4	– the young tree communities with domination of birch tree (*Betula pendula*)	9.7908	1.0
5	– the young tree communities with domination of pine tree (*Pinus sylvestris*)	117.0835	11.2
6	– the young tree communities with domination of spruce (*Picea abies*)	24.2628	2.3
7	– the young tree communities with domination of oak (*Quercus robur*)	18.9362	1.8
15	– the young tree communities with domination of alder (*Alnus glutinosa*)	2.8976	0.3
	The secondary forest communities, including:	**696.7601**	**66.9**
8	– the secondary forest communities with domination of pine tree (*Pinus sylvestris*)	572.3313	55.0
9	– the secondary forest communities with domination of spruce (*Picea abies*)	36.1124	3.5
10	– the secondary forest communities with domination of birch tree (*Betula pendula*)	29.0520	2.8
11	– the secondary forest communities with domination of oak (*Quercus robur*)	43.9932	4.2
12	– the secondary forest communities with domination of hornbeam (*Carpinus betulus*)	1.6982	0.2
13	– the secondary forest communities with domination of aspen (*Populus tremula*)	0.3044	0.03
16	– the secondary forest communities with domination of alder (*Alnus glutinosa*)	12.7935	1.2
17	– the secondary forest communities with domination of ash tree (*Fraxinus excelsior*)	0.4224	0.04
19	– the secondary forest communities with domination of linden (*Tilia cordata*)	0.0527	0.01
TOTAL		**1041.8386**	**100**

* The forest area (km²) of the Knyszyńska Forest; seminatural, synanthropic and unidentified vegetations excluded.
** Percent contribution in the area of the Forest; seminatural, synanthropic and unidentified vegetations excluded.

lower (Tab. 5). For example, the young-tree communities with domination of spruce (*Picea abies*) make only 2.3%, with domination of oak (*Quercus robur*) – 1.8% and with domination of birch tree (*Betula pendula*) – 1% (Tab. 5).

The observed types of the present-day real vegetation are surprising. It is interesting to find why the pine tree stands dominate in the vertical structure of the majority of the forest communities despite a considerable presence of the potentially fertile oak-hornbeam habitats. The question is what are the reasons for the inconsistencies between the species composition and the type of habitats.

The answer to this question was found on the basis of the spatial modelling. Using the method of construction of logical expressions applied to the spatial GIS database the co-occurrence of particular types of the present-day real vegetation was analysed versus the units of the potential natural vegetation (Tab. 6). Particular attention was put to the contribution of the pine tree stands in all habitats studied, both coniferous and oak-hornbeam ones.

3.4. Correlation of occurrence of the present-day real vegetation with respect to the units of the present-day potential natural vegetation

As follows from analysis of the spatial relations between the two types of vegetation, within the Knyszynska Forest, the dominant types of the present-day real vegetation are the forest secondary communities in the stickstand type with predominance of pine, irrespective of the potential types of the habitat studied. The pine tree stands make from 70 to 100% of the studied units of the present-day real vegetation in the structure of forests of all Knyszyńska Forest divisions and districts, in the coniferous habitats of fresh *Peucedano-Pinetum* and mixed fresh coniferous habitats of *Serratulo-Piceetum* and *Carici digitatae-Piceetum* (Tab. 6). However, according to the statistical analyses, pine tree stands are dominant not only in the coniferous habitats but also in the oak-hornbeam habitats. The pine tree stands make from 50 to 94% of the forest secondary communities in the Knyszyńska Forest divisions and districts, except the districts Kumiałka and Czarna Białostocka in the Czarna Białostocka division in the oak-hornbeam habitats of the mixed fresh forest *Melitti-Carpinetum* and fresh forest *Tilio-Carpinetum* (Tab. 6). The pine trees artificially introduced into fertile oak-hornbeam habitats often grow in the form of one-age and one-generation populations of a low capability of natural renewal. This is the reason why in later developmental phases in the upper layers of the tree stand the expansive spruce trees begin to dominate. Consequently, spruce trees (Knyszyn district – 1.1322 km^2, Zajma district – 0.8315 km^2) begin to co-occur with the pine trees (3.2146 km^2, 1.3694 km^2, respectively). Sometimes the pine trees (Czarna district – 4.4704 km^2, Waliły district – 2.6416 km^2) are accompanied by the oak trees (Czarna district – 4.2584 km^2) or birch trees (Waliły district – 1.5331 km^2). Only in the northern skirts of the Knyszyńska Forest in the Kumiałka district, the oak tree stands (23.5867 km^2) are dominant in the forest secondary communities in the typical oak-hornbeam habitats *Tilio-Carpinetum* (35.8165 km^2).

As follows from the analysis of the spatial relations between the two types of vegetation, the present-state real vegetation in the Knyszyńska Forest is a consequence of the forest management policy. The analysis has shown that besides the pine tree stands dominant in the species composition of forest communities, pine trees have also dominated the younger developmental stage communities (young tree stands). In the forest structure of all divisions and districts the young pine tree communities are the dominant types of real vegetation in the younger developmental stages growing in the coniferous habitats. In the oak-hornbeam habitats the young pine tree communities dominate among the birch, spruce, oak and alder tree stands in the districts Supraśl, Sokółka, Złota Wieś, Knyszyn, Zajma and Żednia (Tab. 6). This concerns in particular the oak-hornbeam habitats of the mixed fresh forest *Melitti-Carpinetum*. Only in the northern fragment of the Knyszyńska Forest in the districts Kumiałka and Czarna Białostocka, the young oak tree communities dominate (2.8160 km^2; 6.0063 km^2, respectively) among the young tree stands in the oak-hornbeam habitats (5.3189 km^2; 8.6972 km^2, respectively). In the other districts in the oak-hornbeam habitats the young pine trees accompany the young birch tree stands (districts Krynki, Waliły, Katrynka) or young spruce and oak trees (districts Złota Wieś, Dojlidy) (Tab. 6)

The secondary forest communities and the young tree communities with dominant pine appeared as a consequence of application of the clear-cutting as the most popular forest management measure, not only in the coniferous but also in the oak-hornbeam habitats in which such a measure should not be applied. The clear cutting means that all trees over a given area are cut out and artificial forest crop are introduced. This type of cutting was commonly applied in coniferous habitats and oak-hornbeam habitats in the districts Krynki, Waliły, Knyszyn, Żednia and Sokółka. The partial cutting was applied in oak-hornbeam habitats less frequently, mainly in the districts Złota Wieś, Czarna Białostocka, Katrynka and Zajma. In the other districts (Krynki, Supraśl, Dojlidy), the two types of cutting were applied (Tab. 6).

As follows from the analysis of the spatial GIS data, in the area of the Knyszyńska Forest, the natural communities dominate in the present-day real vegetation only in the habitats of coniferous and deciduous bog forests in all divisions (Tab. 6). The high degree of their natural character is a result of the unique hydrological conditions preventing the use of simple forest management measures like clear-cutting.

3.5. Range of the anthropogenic changes of vegetation in the Knyszyńska Forest

The final result is determination of the range of anthropogenic changes in the vegetation allowing a determination of the difference between the potential natural vegetation and real vegetation, caused by anthropogenic factors. The post-clear-cutting and forest crops communities, the

Table 6. Generalization of the data on the correlation of occurrence of the present-day real vegetation (Rosr) with respect to the units of the present-day potential natural vegetation (Rosp) taking into regard the dominant types of the secondary communities

Forest Districts	The real vegetation (Rosr)	The present-day potential natural vegetation (Rosp)						
		1*	2	3	4	5	6	7
		The forest area [km^2]						
Złota Wieś	The natural forest communities	–	–	0.4644	0.7055	1.6771	0.1329	11.8240
	The post-clear-cutting and forest crops	0.0993**	0.1580	0.5650	0.6459	1.8054	0.0653	1.1955
	– including used clear cutting	0.0841	0.1500	0.3757	0.2390	0.6112	0.0653	0.5268
	– including used partial cutting	0.0152	0.0080	0.1893	0.4069	1.1942	–	0.6687
	The young tree communities, in this:	0.1960	–	4.6806	1.8594	2.7076	0.0742	0.0857
	with pine tree (*Pinus sylvestris*)	0.1643	–	4.2511	1.3508	0.4881	0.0250	–
	with spruce (*Picea abies*)	0.0042	–	0.1910	0.0459	0.8397	–	–
	with oak (*Quercus robur*)	0.0275	–	0.0837	0.2390	0.8841	0.0492	–
	The secondary forest communities, in this:	2.4677	1.7663	13.0106	10.9960	10.5227	0.4408	0.0381
	with pine tree (*Pinus sylvestris*)	2.4614	1.54027	12.2700	9.8061	8.1434	0.4408	0.0102
Czarna Białostocka	The natural forest communities	–	0.3508	–	–	1.9652	0.2159	6.9333
	The post-clear-cutting and forest crops	0.0337	0.7499	0.2078	–	4.2437	0.4000	1.1809
	– including used clear cutting	0.0337	0.5814	0.1062	–	1.3843	0.2644	0.8689
	– including used partial cutting	–	0.1685	0.1015	–	2.8594	0.1355	0.3119
	The young tree communities, in this:	0.3338	1.5493	0.4101	–	8.6972	0.3932	0.0056
	with oak (*Quercus robur*)	–	0.1489	0.1007	–	6.0063	0.0653	–
	with pine tree (*Pinus sylvestris*)	0.3273	0.9333	0.1944	–	0.3432	0.2284	–
	The secondary forest communities, in this:	3.0167	12.7393	4.1394	–	17.5167	2.9845	–
	with oak (*Quercus robur*)	–	0.1594	0.4284	–	4.2584	0.0293	–
	with pine tree (*Pinus sylvestris*)	3.0032	11.0435	2.9321	–	4.4704	2.1042	–
Kumiałka	The natural forest communities	–	0.0577	0.3068	1.4222	1.3754	0.0865	1.8885
	The post-clear-cutting and forest crops	–	0.1036	0.5987	1.7638	1.0928	0.4623	0.1686
	– including used clear cutting	–	0.1036	0.2788	0.5592	0.6570	0.0836	0.1387
	– including used partial cutting	–	–	0.3198	1.2046	0.4358	0.3787	0.0299
	The young tree communities, in this:	–	2.0174	3.0753	5.3189	5.5566	0.8340	–
	with oak (*Quercus robur*)	–	–	0.7401	2.8160	3.7123	0.6580	–
	with pine tree (*Pinus sylvestris*)	–	2.0174	2.1987	1.5606	1.1351	0.0942	–
	The secondary forest communities, in this:	–	1.0626	10.6663	24.7000	35.8165	3.7171	0.0324
	with oak (*Quercus robur*)	–	–	0.8911	6.8594	23.5867	0.7943	–
	with pine tree (*Pinus sylvestris*)	–	0.8242	7.8310	15.2775	6.5755	2.1370	0.0324
Supraśl	The natural forest communities	0.2336	1.8006	1.6249	0.6551	0.3991	0.2615	8.7106
	The post-clear-cutting and forest crops	0.0781	0.6376	0.6100	0.9028	0.5967	0.1616	0.8260
	– including used clear cutting	0.0781	0.5804	0.5499	0.6317	0.2568	0.1149	0.1945
	– including used partial cutting	–	0.0573	0.0601	0.2711	0.3399	0.0466	0.6315
	The young tree communities, in this:	0.2946	2.9703	2.2377	2.3965	1.4337	0.3508	0.0091
	with pine tree (*Pinus sylvestris*)	0.2946	2.6539	1.8735	1.2571	0.4108	0.2795	–
	The secondary forest communities, in this:	1.6026	12.1768	12.6526	12.5255	4.4503	1.9460	–
	with pine tree (*Pinus sylvestris*)	1.5655	11.2523	11.3117	9.6231	3.0402	1.8339	–
Sokółka	The natural forest communities	–	0.5448	0.1724	–	0.7946	0.2618	13.1665
	The post-clear-cutting and forest crops	–	1.2779	0.2455	0.0424	0.8113	0.4408	0.4033
	– including used clear cutting	–	1.0930	0.0952	0.0424	0.5878	0.1785	0.3727
	– including used partial cutting	–	0.1849	0.1503	–	0.2236	0.2623	0.0306
	The young tree communities, in this:	0.0574	2.9073	1.8154	0.0618	3.7765	0.9278	–
	with pine tree (*Pinus sylvestris*)	0.0574	2.3900	1.1148	0.0312	2.5064	0.5442	–
	The secondary forest communities, in this:	0.6864	23.0366	12.1174	2.6976	16.6037	7.5764	–
	with pine tree (*Pinus sylvestris*)	0.6864	21.6709	11.2125	2.1753	13.8284	6.7430	–

Forest Districts	The real vegetation (Rosr)	The present-day potential natural vegetation (Rosp)						
		1*	2	3	4	5	6	7
		The forest area [km^2]						
Dojlidy	The natural forest communities	0.0932	0.9320	0.1259	0.0748	0.6103	0.1198	3.8391
	The post-clear-cutting and forest crops	0.3150	0.7710	0.0318	0.2733	0.7755	0.1529	0.3124
	– including used clear cutting	0.3150	0.5895	0.0318	0.0679	0.4542	0.1529	0.3124
	– including used partial cutting	–	0.1815	–	0.2054	0.3213	–	–
	The young tree communities, in this:	0.3090	0.5000	0.3828	0.2052	0.7875	0.1730	–
	with pine tree (*Pinus sylvestris*)	0.1678	0.3851	0.1363	–	0.0318	–	–
	with spruce (*Picea abies*)	0.0615	0.0524	–	0.0292	0.2064	0.0911	–
	with oak (*Quercus robur*)	–	–	0.1207	0.1390	0.3547	–	–
	The secondary forest communities, in this:	11.7545	5.7601	0.2491	1.3555	3.6523	1.9272	–
	with pine tree (*Pinus sylvestris*)	11.5820	5.2262	0.2491	0.7459	2.3596	1.7710	–
Katrynka	The natural forest communities	0.0086	0.3901	0.1145	–	–	–	4.0264
	The post-clear-cutting and forest crops	0.1800	0.4674	0.2867	–	0.2984	0.1814	0.1334
	– including used clear cutting	0.1734	0.4085	0.2867	–	0.1085	0.0492	0.1334
	– including used partial cutting	0.0066	0.0589	–	–	0.1899	0.1322	–
	The young tree communities, in this:	1.4212	2.8909	0.8735	–	1.6727	0.0425	–
	with pine tree (*Pinus sylvestris*)	1.4041	2.7358	0.8228	–	0.3635	0.0425	–
	with birch tree (*Betula pendula*)	–	–	0.0290	–	1.1837	–	–
	The secondary forest communities, in this:	13.1860	25.0388	83.1964	–	3.9436	2.0754	0.0742
	with pine tree (*Pinus sylvestris*)	12.9360	24.2420	82.9328	–	2.7085	1.8642	0.0047
Knyszyn	The natural forest communities	0.2263	0.3272	0.3975	0.5716	0.6776	0.2559	10.2432
	The post-clear-cutting and forest crops	0.0028	0.7850	0.8054	0.2018	0.9529	0.3946	1.0874
	– including used clear cutting	0.0028	0.6295	–	0.1775	0.7943	0.3946	1.0874
	– including used partial cutting	–	0.1555	–	0.0243	0.1586	–	–
	The young tree communities, in this:	0.5009	1.4748	2.4754	0.9561	0.2123	0.6724	–
	with pine tree (*Pinus sylvestris*)	0.5009	0.8555	1.8091	0.8403	0.0293	0.4156	–
	The secondary forest communities, in this:	2.6331	15.3841	13.5477	5.6032	4.9401	3.9000	–
	with spruce (*Picea abies*)	0.0305	1.2203	0.2706	0.1870	1.1322	0.5203	–
	with pine tree (*Pinus sylvestris*)	2.6026	13.8875	12.2558	5.2500	3.2146	3.0622	–
Walily	The natural forest communities	0.1390	1.1424	0.1120	–	1.7911	0.0664	4.9085
	The post-clear-cutting and forest crops	0.1469	0.6436	0.1586	–	0.7485	0.0219	0.8268
	– including used clear cutting	0.1469	0.4373	0.1586	–	0.4753	0.0219	0.6503
	– including used partial cutting	–	0.2063	–	–	0.2732	–	0.1765
	The young tree communities, in this:	1.8969	2.3089	0.0735	–	0.8567	0.0495	0.0134
	with pine tree (*Pinus sylvestris*)	1.8969	1.8496	0.0418	–	0.0962	–	–
	with birch tree (*Betula pendula*)	–	0.1358	0.0070	–	0.3354	–	–
	The secondary forest communities, in this:	8.8128	19.6443	2.1551	–	5.6877	0.2473	–
	with birch tree (*Betula pendula*)	0.0086	0.5794	0.0763	–	1.5331	–	–
	with pine tree (*Pinus sylvestris*)	8.7889	18.8230	1.8209	–	2.6416	0.2473	–
Krynki	The natural forest communities	1.1561	1.4565	0.3751	–	0.4601	0.0870	1.1932
	The post-clear-cutting and forest crops	0.2863	0.4268	0.3676	–	1.1285	0.1157	0.2962
	– including used clear cutting	0.2746	0.3528	0.2397	–	0.8443	0.0597	0.2962
	– including used partial cutting	0.0117	0.0740	0.1279	–	0.2842	0.0560	–
	The young tree communities, in this:	0.4790	1.7155	0.3694	–	0.9516	0.1101	–
	with pine tree (*Pinus sylvestris*)	0.3620	1.5327	0.2172	–	0.1151	0.0067	–
	with birch tree (*Betula pendula*)	0.0422	0.0175	0.0820	–	0.3729	0.0714	–
	The secondary forest communities, in this:	6.8486	14.2413	8.9913	–	8.6666	0.4376	–
	with pine tree (*Pinus sylvestris*)	6.8075	14.1944	8.6545	–	6.0152	0.3161	–

Forest Districts	The real vegetation (Rosr)	The present-day potential natural vegetation (Rosp)						
		1*	2	3	4	5	6	7
		The forest area [km^2]						
Żednia	The natural forest communities	0.0654	0.0496	–	0.1468	0.1018	0.0175	4.7324
	The post-clear-cutting and forest crops	0.5106	0.4882	–	0.2752	0.2539	0.2919	0.6351
	– including used clear cutting	0.5106	0.4882	–	0.2752	0.2539	0.2659	0.6351
	– including used partial cutting	–	–	–	–	–	0.0259	–
	The young tree communities, in this:	1.8112	2.2907	–	0.4691	0.0905	1.4361	0.0146
	with pine tree (*Pinus sylvestris*)	1.8112	2.0678	–	0.4256	0.0176	1.3269	–
	The secondary forest communities, in this:	8.1799	14.3165	–	5.0182	1.6634	12.3947	0.0661
	with pine tree (*Pinus sylvestris*)	8.0697	13.5856	–	4.9327	0.9849	11.7013	0.0661
Zajma	The natural forest communities	0.5867	3.1506	2.3077	0.8479	1.9289	0.2978	9.0150
	The post-clear-cutting and forest crops	0.3388	2.3303	0.7251	0.9156	0.8583	0.1263	0.6274
	– including used clear cutting	0.3388	1.6636	0.6442	0.4083	0.3042	0.1140	0.3121
	– including used partial cutting	–	0.6667	0.0809	0.5073	0.5541	0.0123	0.3153
	The young tree communities, in this:	3.4197	2.5045	1.6646	0.9086	0.5958	0.2223	–
	with pine tree (*Pinus sylvestris*)	3.1209	1.4300	1.2969	0.5988	0.0063	0.1802	–
	The secondary forest communities, in this:	18.3027	20.8567	9.3534	2.4304	3.3447	3.1255	–
	with spruce (Picea abies)	0.6310	2.1657	1.0279	0.8315	0.4824	0.3737	–
	with pine tree (*Pinus sylvestris*)	17.2179	17.8472	7.3426	1.3694	2.1862	2.4143	–

Legend:
* Number of attributes of the spatial database of the present-day potential natural vegetation (Rosp).
1 – Subcontinental East-European pine forest – *Peucedano-Pinetum*
2 – High coniferous forest – *Carici digitatae-Piceetum*
3 – Fresh mixed coniferous forest – *Serratulo-Piceetum*
4 – Thermophilous oak-hornbeam forest – *Melitti-Carpinetum*
5 – Subcontinentale lowland linden-oak-hornbeam – *Tilio-Carpinetum*
6 – Wet mixed coniferous forests – *Querco-Piceetum*, *Myceli-Piceetum*
7 – Flood plain forests, bog forests, bog-spruce and bog-pine forests
** Area of forest units in km^2 to the fourth place after comma, given for easy change of units to ha units.

young-tree communities and forest secondary communities, in which the stable species making previous phytocenoses disappeared, make 10% in the area 106.02 km^2. Young-tree communities and forest secondary communities represent an artificially planted tree stand, where the species composition is in disharmony with the habitat conditions. The young-tree communities (13.5%) and the forest secondary communities (52%) of artificial tree stand but of the species composition in harmony with the habitat conditions occupy the area of 142.29 km^2 and 547.99 km^2, respectively. The forest secondary communities with spontaneous tree-stands (7.9%) take only 83.55 km^2.

4. Discussion and conclusions

In ecology mathematical modelling has no better alternative for explanation and prediction of the natural phenomena. There are simple analytical models solvable by analytical methods along with advanced models solvable by approximate numerical methods known as the simulation or empirical models. In ecology, mathematical modelling permits precise prediction of biological phenomena on all levels of organisation i.e. individuals (Gimenez et al. 2007), populations (Wang 2007), communities (Lek et al. 2005), ecosystems (Tews et al. 2006) and landscapes (Gough & Rushton 2000).

Complex ecological systems and the transformations they undergo can hardly be described without ecological modelling, for which one of the best tools is GIS. The GIS procedures applied in the study permitted multifaceted spatial analyses of vegetation relations thanks to the use of construction of logical expressions. GIS is a system of hardware and software used for storage, retrieval, mapping, and analysis of geographic data (ArcView GIS 1997; Kistowski & Iwańska 1997; Urbański 1997). Practitioners also regard the total GIS as including the operating personnel and the data that go into the system. Spatial features are stored in a coordinate system (latitude/longitude, state plane, UTM etc.), which references a particular place on the Earth. Descriptive attributes in tabular form are associated with spatial features. Spatial data and associated attributes in the same coordinate system can then be layered together for mapping and analysis. The increasing interest in GIS is a consequence of its analytical possibilities based on construction of models of spatial relations and their changes (Aalders 2001; Olenderek et al. 2001; Van der Zee 2001). Rapid development of computation methods and availability of increasing number of GIS software packages have offered a possibility of spatial analyses of vegetation relations. In particular, they permit analysis of anthropogenically induced changes in vegetation caused by forest management measures (Łaska & Hildebrand 2001; Łaska 2006a).

The mathematical modelling with the use of constructions of logical expression employed for the GIS database has facilitated analysis of vegetation changes in the area of the entire Knyszyńska Forest. The application of a number of combinations of logical expressions and the objects studied has permitted construction of many models revealing new information on relations of the co-occurrence of the present-day real and potential vegetation. As follows from our study, the dominant types of real vegetation in the Knyszyńska Forest are secondary forest communities and young-tree communities with pine domination, occupying not only potential coniferous habitats but also oak-hornbeam habitats. The pine tree stands make from 70 to 100% in the coniferous habitats and make from 50 to 94% in the oak-hornbeam habitats of the studied units of the present-day real vegetation in the structure of forests of all Knyszyńska Forest divisions and districts. The analysis has indicated that the forest management measures should aim at developing effective ways of conservation of plant communities in given geographic space and monitoring changes caused by increasing anthropogenic stress.

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