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THE SHARE OF LAND COVER CLASS AND THE LANDSCAPE STRUCTURE. QUANTITATIVE AND QUALITATIVE ANALYSIS OF WIELKOPOLSKO-KUJAWSKA LOWLAND USING GIS TECHNIQUES

key words: landscape statistic analyses, landscape changes, Poland, Wielkopolska, Kujawy

INTRODUCTION

The increasing interest in landscape stems from the increasing conviction among researchers that it has an indicative role with regard to the functioning of eco-systems. There are more and more studies which confirm the influence of landscape changes on biodiversity changes (Reidsma et al., 2006), climate changes (Foley et al., 2005; Kędziora, Ryszkowski, 1999, Kueppers et al., 2004), the quantity and quality of surface and subsurface water (Hwang et al. 2007; Karg, Karlik, 1993), soil fertility (Kong et al., 2006) and, last but not least, human health (Foley et al., 2005). The easiest way to study landscape is to analyse the land cover. Land cover data are very easy to use in statistical processing and map imaging. However, analyses of this kind are usually performed for individual landscape components, and not the landscape as a whole. In many cases it is the structure, i.e. the configuration and composition of land cover forms, that determines landscape functions (Forman, Godron, 1986). The measures of landscape configuration and composition are applied in many studies aiming to describe and assess the functioning of the environment. They are used to assess the quality of water (Uuemaa et al., 2005) and the retention functions of marshy areas (Li et al., 2005). According to Wiens (2002), Otte et al. (2007), Kim and Pauleit (2007) and Atauri and Lucio (2001) they are also good measures of biodiversity.

PURPOSE OF STUDY

The basic purpose of this study is to present the possibility of employing statistical analysis of numerical maps to describe landscape and predict the consequences of its changes. This paper considers the issue of landscape diversity measured by the share of land cover forms and the distribution of such forms in different geomorphologic forms of the Wielkopolsko-Kujawska Lowland. Assuming that variability in space can be translated into variability in time it is possible to predict the impact of a change in the share of specific land cover forms on the landscape structure. This in turn may facilitate forecasting changes in ecological functions of an area caused by the changes in distribution of specific land cover forms. The secondary purpose of this study is to make a quantitative description of the differences in landscape structure of individual geomorphologic units of the Wielkopolsko-Kujawska Lowland.

STUDY AREA

The study area is the Wielkopolsko-Kujawska Lowland (Krygowski, Czekalska, 1961). It is part of the Polish Lowland occupying 68630 km^2 located in western Poland and surrounded by Pomerania on the north, the Silesian Lowland on the south, and the Mazovian Lowland on the east. Its characteristic features are sloping in the northern and north western directions and relatively strong surface undulation ranging from 13 to 284 m above sea level.

DATA AND METHODOLOGY

The source of data on the landscape structure of the Wielkopolsko-Kujawska Lowland were vector maps of geomorphologic and land cover features. The geomorphologic division map[1] was combined with the CORINE Land Cover 2000 map[2]. The degree of detail of the maps corresponds to map scales of 1:300 000 and 1:100 000 respectively. Those particular maps were chosen because of the vector format and a uniform making method for the entire study area. Because of the amount of data and the processing power of the computer used both of the maps were generalised by adding units similar in respect of landscape. As a result 17 geomorphologic and 16 land cover types were obtained[3]. The land cover data for all geomorphologic types, which further in this paper will be referred to as landscape

[1]The vector version of the map was obtained from the Institute of Paleogeography and Geoecology, Adam Mickiewicz University.

[2]European Environment Agency website (http://reports.eea.europa.eu/COR0-landcover/en).

[3]The complete list of types is shown in tab. 1.

types, was converted using ArcInfo 9.2 into the ArcGrid raster format (100 m resolution) and analysed in Fragstats. The analysis was performed using a selection of 16 indices characterising the landscape structure and 14 indices describing the structure of individual land cover types. Three of the indices described the surface and boundaries, two indices for each of the following described the shape, core area and isolation of patches, contrast of boundaries, connectivity between patches, diversity of patches (applies to the landscape), and one index characterised the division of patches[4]. The statistical analysis of the data collected was made using Statistica 7.1. It consisted in the analysis of *Pearson's* correlation between the share of a particular land cover form and measures of the configuration of a particular type of patches in all landscape types, as well as between the shares of all land cover forms and the measures of the configuration of patches in a particular landscape type.

RESULTS

Landscape composition

The measures of landscape composition describe the diversity of patches within the landscape taking into account only the number of its components. The simplest measures of landscape composition are the number of cover types and the share of the surface area of each type in the landscape. One of more complex measures is *Shannon's* index, which describes the probability of two random pixels representing different land cover types.

Tab. 1 shows land cover diversity in different types of landscape of the Wielkopolsko-Kujawska Lowland. The most varied composition of land cover forms measured with *Shannon's* index can be found in the lake channeis, and flood and middle terraces. Flood terraces are also characterised by the greatest variety of land cover forms. The least varied land cover is observable in geomorphologic forms, in which there is a very strong dominance of forests and arable land. The first group includes dune hills, whose forestation rate exceeds 82%. The second group includes flat morainic plains, where the arable land share exceeds 81%. The most urbanised areas are flood terraces, outwash plains and flat morainic plains. Those areas include about 73% of all continuous urban fabric and about 57% of all the industrial areas of the Wielkopolsko-Kujawska Lowland. However, due to a large surface area of the above types of landscape, those land cover forms are not easily noticeable in the landscape.

[4]The description is available on the website of the University of Massachusetts Amherst (http://www.umass.edu/landeco/research/fragstats/fragstats.html).

Tab. 1. Diversity of land cover in geomorphologic units of the Wielkopolsko-Kujawska Lowland (in surface area percentage).
Values higher than the mean plus standard deviation were marked in dark grey, values lower than the mean minus standard deviation were marked in pale grey.

Type of landscape/Land cover class	Continuous urban fabric	Discontinuous urban fabric	Industrial or commercial units	Road and rail networks and associated land	Green urban areas	Mineral extraction sites	Arable land	Fruit trees and berry plantations	Complex cultivation patterns, agriculture with	Sparsely vegetated areas, moors and heathland, sands	Natural grassland	Pastures	Forests	Inland wetlands	Water courses	Water bodies
Kame hills	0,11	1,32	0,08	0,00	0,07	0,07	43,96	0,00	5,04	0,00	0,00	2,30	46,44	0,34	0,00	0,28
Moraine hillocks	0,01	1,36	0,07	0,15	0,09	0,51	51,26	0,05	6,08	0,11	0,13	1,93	37,86	0,04	0,00	0,35
Dunes	0,00	0,46	0,04	0,00	0,01	0,07	7,88	0,03	2,42	0,46	2,53	3,40	82,24	0,12	0,02	0,31
Outwash plains	0,01	1,33	0,14	0,22	0,18	0,09	31,50	0,04	3,23	0,07	0,23	3,04	58,99	0,09	0,00	0,83
Elluvial and denudation plains	0,00	2,43	0,37	0,04	0,24	0,07	48,60	0,05	6,95	0,00	0,00	3,72	36,67	0,12	0,00	0,73
Edges	0,09	3.95	0,42	0,14	0,28	0,08	51,73	0,09	6,59	0,00	0,05	5,47	30,29	0,11	0,34	0,38
Middle terrace	0,06	3,39	0.68	0,10	0,22	0,14	37,94	0,04	6,33	0,25	0,28	7,17	42,62	0,08	0,15	0,56
Upper terrace	0,02	2,26	0,34	0,28	0,15	0,11	30,25	0,05	5,54	0,26	1,91	4,93	53,36	0,19	0,01	0,35
Flood terrace	0,06	2,14	0,32	0,03	0,24	0,15	33,62	0,08	7,92	0,03	0,01	32,33	17,59	0,98	0,37	3,15
Rampart of the relict type	0,00	0,76	0,00	0,03	0,00	0,00	53,77	0,00	10,60	0,00	0,02	4,58	29,75	0,01	0,00	0,48
Cat Hills	0,00	1,50	0,17	0,00	0,02	0,00	50,43	0,75	12,15	0,00	0,00	1,01	33,98	0,00	0,00	0,00
Slopes	0,00	3,59	0,14	0,01	0,12	0,08	65,80	0,08	8,52	0,01	0,04	3,02	18,40	0,02	0,01	0,15
Undulated and hillocky moraine plain	0,01	1,71	0,15	0,09	0,10	0,14	67,68	0,16	5,02	0,03	0,22	1,77	22,56	0,12	0,00	0,23
Flat ground moraine plain	0,00	2,22	0,23	0,11	0,12	0,26	81.12	0,17	4,95	0,03	0,01	1,33	9,31	0,06	0,00	0,08
Melt-out areas	0,00	1,53	0,00	0,00	0,12	0,00	28,67	0,00	4,70	0,00	0,00	4,77	58,78	0,81	0,00	0,63 16,66
Lake channeis	0,01	2,45	0,03	0,00	0,36	0,00	30,69	0,00	8,31	0,01	0,00	8,77	31,58	1,11	0,01	16,66
Small valleys	0,03	3,87	0,11	0,00	0,19	0,06	59,30	0,07	9,73	0,00	0,09	8,21	17,84	0,18	0,02	0,33

Source: *compiled by the author.*

Large cities are an exception – in Kalisz, Bydgoszcz or Poznań continuous urban fabric and industrial areas occupy from 14 to 11% of the flood terrace respectively.

Landscape configuration

Contrary to composition measures, configuration measures describe the spatial orientation of landscape elements. They are multi-aspect, and therefore hard to grasp, descriptions of the landscape. Configuration measures can be divided into indices of the surface and boundaries of patches, shape, core, isolation, contrast, division, connectivity and diversity. Some of measures are used to describe both individual patches and classes of patches (land cover types) or entire landscapes (e.g. shape and boundary contrast indices). Other are only employed to describe types of the land cover and landscape (connectivity indices), and yet other only describe the landscape as a whole (patch diversity indices).

Landscapes in the Wielkopolsko-Kujawska Lowland are very diverse as regards the configuration of components. The highest diversity among landscapes concerns such indices as the mean distance to the nearest patch of the same type (ENN_MN), mean proximity (PROX_MN) and mean size of the patch (AREA_MN). The last index ranges from 18.7 ha to 147.9 ha for small valleys and flat morainic plains. The mean distance to the nearest patch of the same type ranges from 1.1 km in the case of slopes to 22 km in the case of melt-out areas. Little diversity is noted mainly in the patch core area, i.e. the area inside the patch 1000 m away from the edge. It is a result of a lack of those areas or their small surface area. The highest cohesion of patches is characteristic for flat morainic plains and outwash plains, which have the largest mean surface area of the patch (AREA_MN) and the proximity index (PROX_MN), and the lowest patch density index (PD). It is a consequence of the dominance of arable land forests, which are characterised by large surface area and high cohesion of patches. The shortest distance between patches of the same kind is observable in the landscapes of edges, melt-out areas and small valleys. Such landscape is very diverse, also because of the smallest mean surface area of the patch, high density of patches, the lowest cohesion of patches of the same kind and the smallest core area of the patch. What is characteristic for those landscape types is a high share of grassland and pastures, and arable land with a high share of natural vegetation, as well as a high share of discontinuous urban fabric and a low share of arable land.

Tab. 2. Selected correlations between the shares of individual land cover types and indices of their composition and configuration within the Wielkopolsko-Kujawska Lowland. Statistically significant values for p≤0.05 were marked in grey. AREA_MN-mean area of patch, PD-patch density, ED- edge density, SHAPE_MN–mean compactness of patch, PARA_MN-mean perimeter-area ratio of patch, CAI_MN-ratio: mean core area of patch (1km away from the edge) to the mean patch area, CORE_MN-mean core area of patch (1km away from the edge), ENN_MN-the shortest distance to the patch which represent the same type, PROX_MN-ratio: mean sum of patches area within 1km zone which represent the same type to the mean sum of distances among this patches within 1km zone, CONNECT-ratio: number of patches within 1km zone which represent the same type to the number of all patches of this type in the landscape.

Metric/Land cover class	Continuous urban fabric	Discontinuous urban fabric	Industrial or commercial units	Road and rail networks and associated land	Green urban areas	Mineral extraction sites	Arable land	Fruit trees and berry plantations	Pastures	Natural grassland	Forests	Inland wetlands	Water courses	Water bodies
Area/edge														
AREA_MN	0,43	0,28	0,72	0,63	0,07	0,82	0,62	0,56	0,83	0,34	0,45	0,84	0,97	0,87
PD	0,54	0,72	0,49	0,31	0,66	0,63	0,00	0,61	0,39	0,74	0,39	0,41	0,39	0,54
ED	0,99	0,93	0,98	0,85	0,90	0,91	0,13	0,99	0,92	0,98	0,86	0,98	1,00	1,00
Shape														
SHAPE_MN	0,58	0,19	0,40	0,61	0,00	0,34	0,37	0,02	0,30	0,17	0,35	0,40	0,87	0,76
PARA_MN	-0,30	-0,29	-0,42	-0,57	-0,07	-0,37	-0,76	-0,28	-0,43	-0,22	-0,18	-0,48	-0,17	-0,61
Core area														
CAI_MN	0,00	-0,03	0,00	0,00	0,00	0,78	0,43	0,00	0,88	0,67	0,32	0,17	0,00	0,06
CORE_MN	0,00	-0,04	0,00	0,00	0,00	0,78	0,48	0,00	0,88	0,67	0,32	0,17	0,00	0,06
Isolation/proximity														
ENN_MN	-0,27	-0,24	-0,18	0,52	-0,42	-0,17	-0,30	-0,26	0,00	-0,19	0,03	0,45	-0,17	-0,10
PROX_MN	0,13	0,16	0,53	0,14	0,37	0,20	0,62	0,90	0,89	0,60	0,46	0,84	0,97	0,78
Connectivity														
CONNECT	-0,02	0,01	0,02	-0,04	0,08	-0,11	0,26	0,70	-0,18	-0,21	0,04	0,23	-0,18	0,07

Source: *compiled by the author.*

Relationship between the share of land cover forms and measures of landscape configuration

The analysis of the correlation between the shares of individual land cover forms and the indices of their structure shows a close relationship between those parameters (tab. 2). It applies particularly to the indices of the surface area and boundaries. The higher the share of a particular land cover form in a particular landscape type, the larger the surface area of an average patch, and the density of patches and patch edges of the particular land cover form. Four types of landscape changes were distinguished according to the four basic patch indices, namely the surface area and boundaries (AREA_MN, PD, ED) and the shape of the patch (PARA_MN) (fig. 1). The first one (fig. 1, part A) is characteristic for land cover forms with a fragmented structure (small mean surface area and low density of patches) such as wetlands, watercourses, industrial and transportation areas. The spatial variability of those land cover types, associated with the increase in their surface area, applies primarily to the growth in the mean patch size and the increase in the length of boundaries in relation to the surface area of all patches of those land cover forms. In contrast, no increase in the patch quantity and no change in the ratio of the perimeter to surface area is observed. The latter feature is connected with the qualities of the index, which can decrease with the growth in the patch surface area even if the boundary length increases. The second type of landscape composition and configuration changes (fig. 1, part B), which is linked with an increase in the share of a particular land cover type, consists in the growth in the number of patches. It is not accompanied by an increase in the surface area or a significant change in the shape of the patches but only by an increase in the boundary length for the entire landscape. This type of variability is characteristic for urban areas and natural grassland and pastures as well as complex systems of cultivated areas and plots, and occurs mainly in areas where there is a high share of those types of land cover, i.e. in flood and middle terraces. The third type of variability (fig.1, part C) concerns mainly arable land, where the change in surface area is only connected with the change in the surface area and shape of the patch. The larger the surface area of arable land, the larger the mean surface area of the patch and its shape closer to square. The last type of changes (fig.1, part D) consists in the increase in both the quantity and mean surface area of patches, which is associated with the increase in boundary length of those types of land cover forms and the simplification of the shape of patches. It is characteristic for water bodies, plantations and mineral extraction sites.

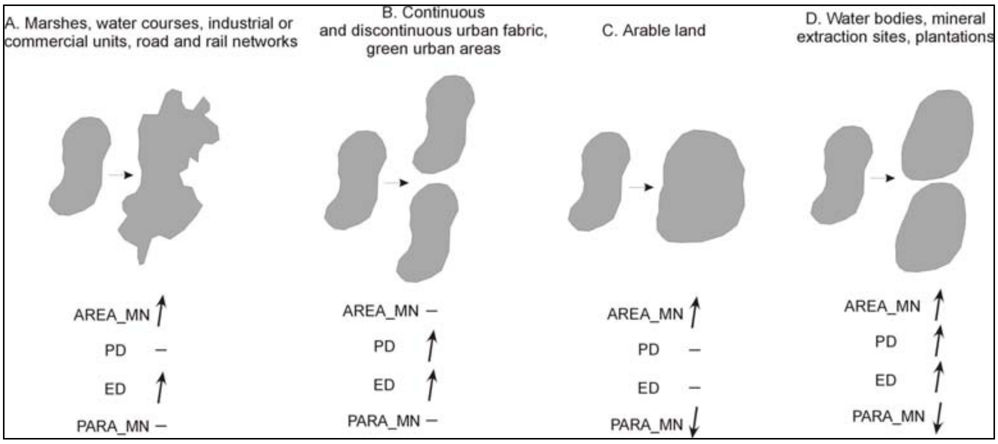

Fig. 1. The results of the increase in the share of different land cover types for selected landscape parameters. Index changes: ↑ increase, ↓ decrease,— no change. AREA_MN-mean area of patch, PD-patch density, ED-edge density, PARA_MN-mean perimeter-area ratio of patch. ***Source:*** *compiled by the author.*

The relationships described above concern the vast majority of landscape types because the diversity of geomorphologic units in respect of the influence of a change in the share of a particular land cover form on landscape structure is slight.

CONCLUSIONS

The results of this study show that vector databases are very useful in landscape structure analysis. The Fragstats programme enables a rapid analysis of landscape composition and configuration even for very large areas, which makes it possible to draw conclusions concerning general tendencies in landscape development on the regional and higher levels. Because of a large area analysed and the degree of conclusion generalisation the preciseness of the databases used is optimal.

Depending on the study object the change in various land cover forms entails different ecological consequences. They depend not only on the land cover type but also on its structure. The ability to predict those consequences and counteract adverse phenomena is very important. This study confirms that it is possible to draw conclusions on landscape consequences of land cover changes on the regional level only on the basis of quantitative data. It applies both to the future and the past.

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SUMMARY

More and more concern on landscape is a resulting from growing conviction of researchers about it's indicating role in regard to ecosystem functioning. Number of research that confirm influence of landscape changes on biodiversity, climate, soil productivity, human health or quantity and quality of water courses and bodies is increasing. The simplest form of landscape study is an analysis of land cover. The data of this type can be easily treated by statistic methods and illustrated on the map. However, this sort of analysis concern mostly on particular component of landscape, not on the landscape as a whole. In many cases the structure, in terms of configuration and composition of land cover classes, determines landscape functions. Additional factor, usually not taken into account, is geomorphology of study area. The landform and his origin strongly affect landscape and it's functions.

The basic purpose of this study is to present the possibility of employing statistical analysis of numerical maps to describe landscape and predict the consequences of its changes. This paper considers the issue of landscape diversity measured by the share of land cover forms and the distribution of such forms in different geomorphologic forms of the Wielkopolsko-Kujawska Lowland. Author analyzed landscape structure of Wielkopolsko-Kujawska Lowland in 17 landscape types distinguished according to geomorphological division of Krygowski. In each geomorphological unit the share and structure of 16 land cover classes, obtained by data from CORINE Land Cover 2000 generalization, was counted. Analysis affected chosen indicators of patches area, density of their edges, shape, core zones, isolation and connectivity and was supported by Spatial Pattern Analysis Program Fragstats.

Depending on the study object the change in various land cover forms entails different ecological consequences. They depend not only on the land cover type but also on its structure. The ability to predict those consequences and counteract adverse phenomena is very important. This study confirms that it is possible to draw conclusions on landscape consequences of land cover changes on the regional level only on the basis of quantitative data. It applies both to the future and the past.