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TEMPORAL CHANGES OF LAND COVER IN RELATION TO CHOSEN ENVIRONMENTAL VARIABLES IN DIFFERENT TYPES OF LANDSCAPE

Abstract: Good understanding of relations between historical land cover changes and accompanying environmental components should be a starting point for landscape modelling and forecasting its future patterns. Analysis presented here focuses on the relationships between chosen environmental conditions and agricultural land cover changes in the period of over 150 years. The study area consisted of fragments of Nidziańska Basin and South Pomeranian Lake District macroregions. The land cover data was derived from a number of archival and contemporary topographical maps. Long-term changes of land cover were then related to underlying landscape elements (geological deposits and morphometric landforms). With the help of canonical analysis major correlations were identified and described.

Keywords: Land cover changes, redundancy analysis (*RDA*), abiotic components.

INTRODUCTION

Proper identification of the complicated order of relations between historical land cover changes, human activities and the conditions of natural environment constitutes a serious problem in detecting landscape transformations. The forces driving landscape transformations are usually very complex and vary in space and time.

This study aims to identify the major directions of land cover changes for diverse landscape types in the time period of about 150 years and to relate these temporal patterns to chosen environmental factors.

In the landscape geography, an assumption of the leading role of lithogenic components in landscape components' hierarchy is often used (Richling 1992). Being familiar with the manner in which dominant components develop it is possible to draw conclusions about remaining (subordinated) components. Moreover, the characteristics of the dominant components may be regarded as relatively constant in time. Thus, for the purpose of analysis presented in this paper, the types of geological substratum and morphometric landforms were employed as environmental landscape attributes. Both types of attributes were adopted as stable factors, without variation in time.

RESEARCH AREA

The research area comprised of two different study regions: Wiele and Pińczów, each with the area of 18 × 18 km (Fig. 1.).

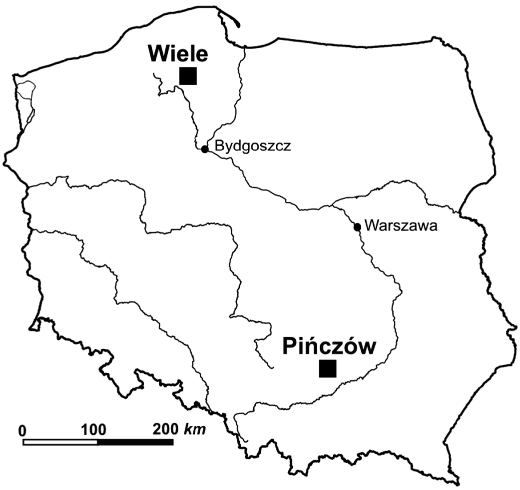

Fig. 1. Location of the research regions

The Wiele study area is situated on the border of the two mesoregions: Tuchola Pinewoods and Charzykowska Plain (Kondracki 2001), for the most part overgrown with coniferous pine forests. Only two moraine islands (Wielewska and Bruska), located in the central and southern parts of the area, are farmed. The diverse relief of the areas include: the aforementioned moraine islands, glacial channels and valleys gullying the sandr.

The Pińczów study region, being a part of Ponidzie Pińczowskie, is situated at the meeting point of the following mesoregions: Jedrzejowski Plateau, Wodzisławski Hummock, Nida Valley, Solecka Basin, Pińczowski Hummock and Połaniecka Basin (Kondracki 2001). The great variety of geological substratum and diversified relief contributes to the richness of natural habitats in this area. The area distinguishes itself with a mosaic land cover and traditional rural character.

METHODS

Land cover data

Archival and contemporary topographic maps served as a source of information on land cover for particular moments in time.

The interpretation of the land cover changes for the Pinczów research region was based on the following maps: 1839 (*Topograficzna Karta Królestwa Polskiego*, 1:126 000), 1915 (*Karte des Westlichen Russlands*, 1:100 000), 1938 (WIG – *Mapa taktyczna Polski*, 1:100 000), 1974 (*Wojskowa mapa topograficzna*, 1:50 000), 2000 (*Mapa topograficzna* 1:50 000, Head Office of Geodesy and Cartography).

For the Wiele research region, the land cover data was derived from the subsequent maps at a scale of 1:100 000: 1878 (*Karte des Deutschen Reiches,* series A), 1936 (WIG – *Mapa taktyczna Polski*), 1954 (*Mapa Sztabu Generalnego WP*), 1980 (*Mapa topograficzna*) and 2000 (Corine Land Cover vector database).

The cartographic materials underwent rectification and registration in the 1992 Coordinate System. Contemporary topographic maps at a scale of 1:50 000, published by the Head Office of Geodesy and Cartography, were used as the reference layers. The materials, thus prepared, were manually vectorized and classified into three main land cover types: "forests", "grasslands", "others" (for the Pińczów research region) and "forests", "waters", "others" (for the Wiele research region). Finally, the data underwent conversion to raster format, with the resolution of 50 × 50 m.

The maps were compared in pairs, separately for each research region. As a result, the transformation layers were extracted (for the Pińczów area: 1839–1915, 1915–1938, 1938–1974, 1974–2000 and for the Wiele area: 1878–1936, 1936–1954, 1954–1980, 1980–2000). The comparison process was carried out in accordance with the procedure described by Giętkowski and Zachwatowicz (in press). By linking elements of fuzzy logic (Hagen, 2003), simple map algebra and Kappa statistics (Pontius, 2000), it was possible to reduce the distortions stemming from dissimilar quality of the archival maps, and to make a distinction between real land cover changes and artefacts.

The maps of land cover changes were used for subsequent transformation matrix analysis in order to investigate the quantitative land use transformations in different periods of time.

Environmental data

The lithological diversity of the Pińczów study region was described on the basis of the Detailed Geological Map of Poland at a scale of 1:50 000. Particular sections of the map legend were aggregated into seven major categories: 1 – sands, 2 – alluvial deposits and peats, 3 – chalky clay and limestone, 4 – clay and silt, 5 – diluvium, 6 – loess, 7 – gypsum.

The map of surface deposits for the Wiele area was elaborated on the basis of the lithological map series A at a scale of 1:50 000 (acting as an annex to the *Mapa geologiczna Polski* 1:200 000). The following categories were distinguished: 1 – peats and lake deposits, 2 – fluvial deposits, 3 – moraine deposits, 4 – sandr sands.

The maps of morphometric landforms were developed by unsupervised classification of selected digital elevation model derivates (see Giętkowski, Zachwatowicz, 2008). As the result, the main types of landforms were obtained (for the Pińczów study region: 1 – plains in valley-floors and terraces, 2 – gentle and moderately steep slopes, 3 – steep slopes and escarpments, 4 – ravines, 5 – hilltops and upper slope parts; for the Wiele area: 1 – plains, 2 – lower parts of slopes with a gentle gradient, 3 – convex middle parts of slopes located near the escarpment, 4 – hilltops).

The aforementioned data was registered with the raster resolution of 50 × 50 m.

Canonical analysis

In order to determine relations between the environmental variables (geological substratum, morphometric landforms) and the types of land cover transitions at individual time intervals, the redundancy analysis (RDA, Rao 1964) was carried out. This method, belonging to the multivariate technique, is frequently used to examine relations between two sets of variables.

The data used in RDA consisted of dependent variables (6 types of land cover variables: forests→grasslands, grasslands→forests, grasslands→others, others→grasslands, forests→others, others→forests – for the Pińczów study region; forests→waters, waters→forests, forests→others, others→forests, waters→others, others→waters – for the Wiele study region) and independent variables (types of geological substratum and morphometric landform types).

Both research areas were overlaid with a grid of squares 250 × 250 m. Each square was then described by the shares of types of: land cover change, geological substratum and morphometric landforms. Stable areas (i.e. with no transition in a given time period: forests→forests, grasslands→grasslands, others→others) were excluded from further analysis.

The redundancy analysis was performed using the Canoco for Windows 4.5 software (Ter Braack, Smilauer, 2002). Results were displayed in the ordination diagrams. The significance of relationships between land cover transition data and environmental variables was checked by the means of Monte Carlo permutation tests. In all cases the tests confirmed the overall significance of the canonical ordination (p<0,05).

RESULTS

General directions of land cover change

In the Pińczów area, the general patterns of forests and meadows showed a relatively high durability through time (Fig. 2).

The growth of the forest area was observed in the years 1839–1915 and 1938-2000 (Table 1). In both cases it correlated with the diminishing proportions of farming areas (the "others" category). A distinct decrease in forests and, at the same time, an increase in the proportion of fields occurred in the years 1915–1938. During the period of 23 years (1915–1938), a somewhat larger area underwent deforestation than afforested in the last 76 years (1839–1915). New afforestations in the period of 1938–2000 (62 years) led to a return to the percentage of forests from 1915. The proportions of grass-

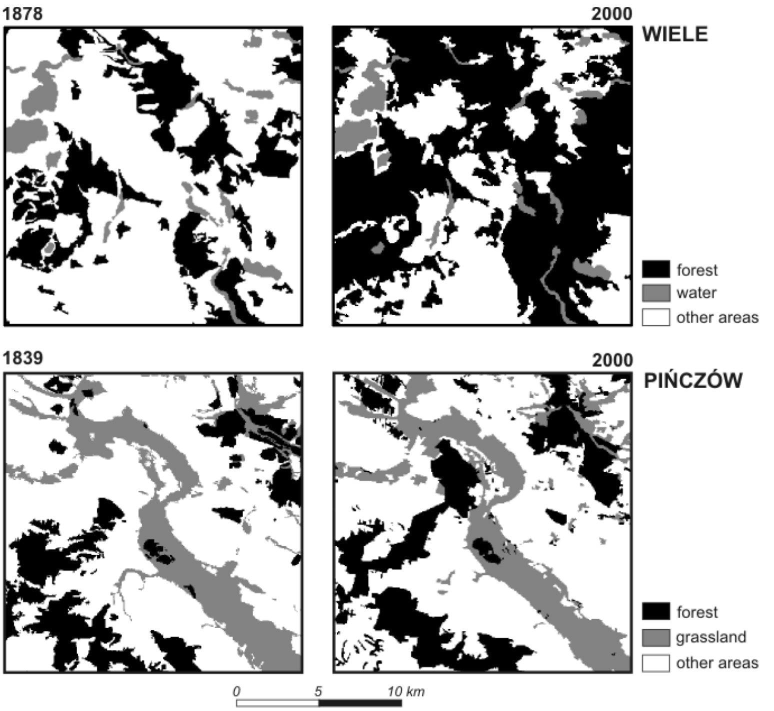

Fig. 2. Land cover in the initial and final time periods for both research areas

lands showed only small fluctuations in the period of 160 years, whereas grasslands occupied the greatest area in 1839.

The transition matrix (Table 1) underlines the dynamics of land cover in the successive time periods.

In 1839–1915, afforestations dominated the area, although the transition matrix indicates activities in both the directions: “others→forests” and “forests→others”. The grasslands diminished mainly in favour of the farming areas. The percentage share of the area of all the changes in reference to the total area of the research region was 18,6% (i.e. 2,4%, calculating for 10 years).

The years 1915–1938 comprised a period of visible intensification in agricultural use of the region. Almost one fourth of the 1915 forest area underwent deforestation. Grasslands were also transformed into farming areas, however less intensively. In general, the increase of the cultivated areas was accompanied by a significant decrease in the forest areas and an insignificant decrease in the proportions of grasslands. The percentage share of the total change amounted to 9,7% (i.e. 4,2%/10 years).

A slight decrease in the grassland areas in favour of fields and quite intense afforestations were observed in the years 1938-1974. The percentage share of the total change amounted to 6,3% (i.e. 1,7%/10 years).

Table 1. Transition matrix for particular types of land cover in successive time periods (%)[1)]

WIELE

1878-1936	**forest**	**others**	**water**	***1878***
forest	92.9	7.0	0.1	*25.1*
others	25.5	74.2	0.3	*68.7*
waters	4.0	6.0	90.0	*6.2*
1936-1954				1936
forest	97.7	1.9	0.4	*41.5*
others	15.8	84.0	0.2	*52.7*
waters	2.4	2.9	94.8	5.8
1954-1980				1954
forest	98.5	1.5	0.1	*49.5*
others	13.8	86.0	0.1	*44.8*
waters	0.7	2.9	96.4	*5.7*
1980-2000				1980
forest	96.3	3.2	0.5	55.5
others	7.4	92.0	0.6	*39.0*
waters	2.9	2.8	94.4	*5.6*
2000	56.5	37.7	5.7	

PIŃCZÓW

1839-1915	**forest**	**grass-land**	**others**	***1839***
forest	76.4	5.0	19.6	*17.9*
grassland	3.1	78.2	18.7	*19.5*
others	12.7	3.6	83.7	*62.6*
1915-1938				***1915***
forest	74.4	2.0	23.6	*22.3*
grassland	0.4	89.7	9.9	*18.4*
others	1.2	2.3	96.5	*59.3*
1938-1974				***1938***
forest	98.9	0.0	1.1	*17.4*
grassland	2.2	87.8	10.0	*18.3*
others	4.0	2.0	94.0	*64.3*
1974-2000				***1974***
forest	99.2	0.2	0.6	*20.2*
grassland	1.5	95.1	3.4	*17.4*
others	2.3	3.2	94.5	*62.4*
2000	*21.7*	*18.6*	*59.7*	

[1)] The percentage values are given in reference to the area occupied by the particular land cover categories at the beginning of a given time period. Only in the last column and in the last row, the shares of land cover types are presented in reference to the total research area.

In the period of 1974–2000, an increase of the grassland and forest areas was observed in place of previously cultivated areas. There was a further slowdown of the pace of changes. The percentage proportion of changes in reference to the total area examined was 4,4% (i.e. 1,6%/10 years).

In the Wiele research region, the rates of changes varied, as well. The percentage share of the changes in reference to the total area of the region, in a given time period and in calculation for 10 years amounted to, respectively: 20,2%, i.e. 3,4%/ 10 years (1878–1936); 9,7%, i.e. 5,3%/10 years (1936–1954); 7,3%, i.e. 2,8%/10 years (1954–1980); and 5,5%, i.e. 2,7%/10 years (1980–2000). An especially quick pace of changes may be observed during the II World War and immediately after it. Of special significance here, was the intensity of the afforestation trend. This transition having always the greatest proportion among all kinds of changes, resulted in an over 30% increase of the proportion of forest area in the reviewed 122-year timeframe (Fig. 2.).

In addition, in the first step of the transition matrix (Table 1) a relatively large decrease of the lake area may be observed, mainly in favour of non-forest areas. However, in subsequent stages, changes associated with the "waters" category were balanced, which led to maintaining the area of water reservoirs at the level of 5,6–5,8% of the total research region.

Relations between land cover changes and environmental variables

The results of the canonical analysis for the Pińczów area are presented in figure 3.

In the years 1839–1915, the transformation of forests into fields (into the "others" category) took place mainly in loess plateau, whereas areas covered with sands were afforested. The two-way transitions between grasslands and fields occurred mostly in valley-floors, while grassland areas diminished primarily on alluvial and deluvials deposits. The transformations of grasslands into forests took place mainly on the sandy substratum. The transitions of forests into grasslands in alluvial valley-floors are possibly an indication of the destruction of riverside forests.

During the years 1915–1938 deforestation shows the greatest relation with gentle slopes and plateaus. Evidently, there was an attempt to farm all the possible types of strata (loess, sands, carbonates, clays and silt) of favourable locations. On the other hand, the ravine bottoms and steep loess slopes were afforested. Grasslands in alluvial valley-floors were transformed into fields even though, as in the earlier period, a reversed process was also observed.

In 1938–1974 the forest area increased almost exclusively on sands, while afforestations incorporated all the landforms characteristic of loess sediments. Grasslands diminished in favour of fields, mainly on deluvial and clay deposits, in conditions of poorly diversified relief. Transition of fields into grasslands took place in plain areas and on limestone deposits.

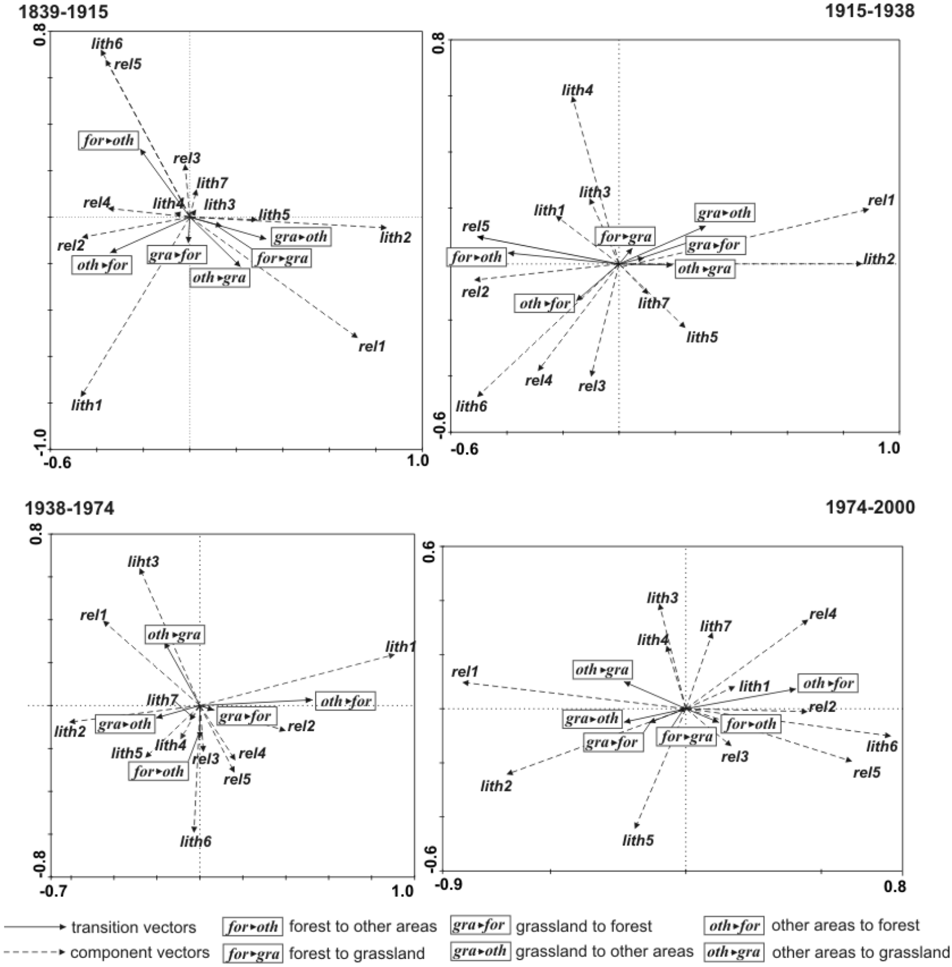

Fig. 3. Ordination diagram for the Pińczów area

In the years 1974–2000 there were observed fluctuations of the forest areas on loess deposits and on gentle slopes. In addition, afforestations correlated with ravine bottoms whereas deforestations showed a relationship with plateaus and, to a lesser degree, with steep slopes. Noticeable is also the afforestation process, or spontaneous entrance of the forest, into sandy areas. To a lesser degree, forests increased their area on alluvial deposits in the valleys. Transformations of fields into grasslands and of grasslands into fields occurred in the valley-floors. Areas on alluvials and deluvials were more often transformed into fields, whereas areas on clays and limestones into grasslands.

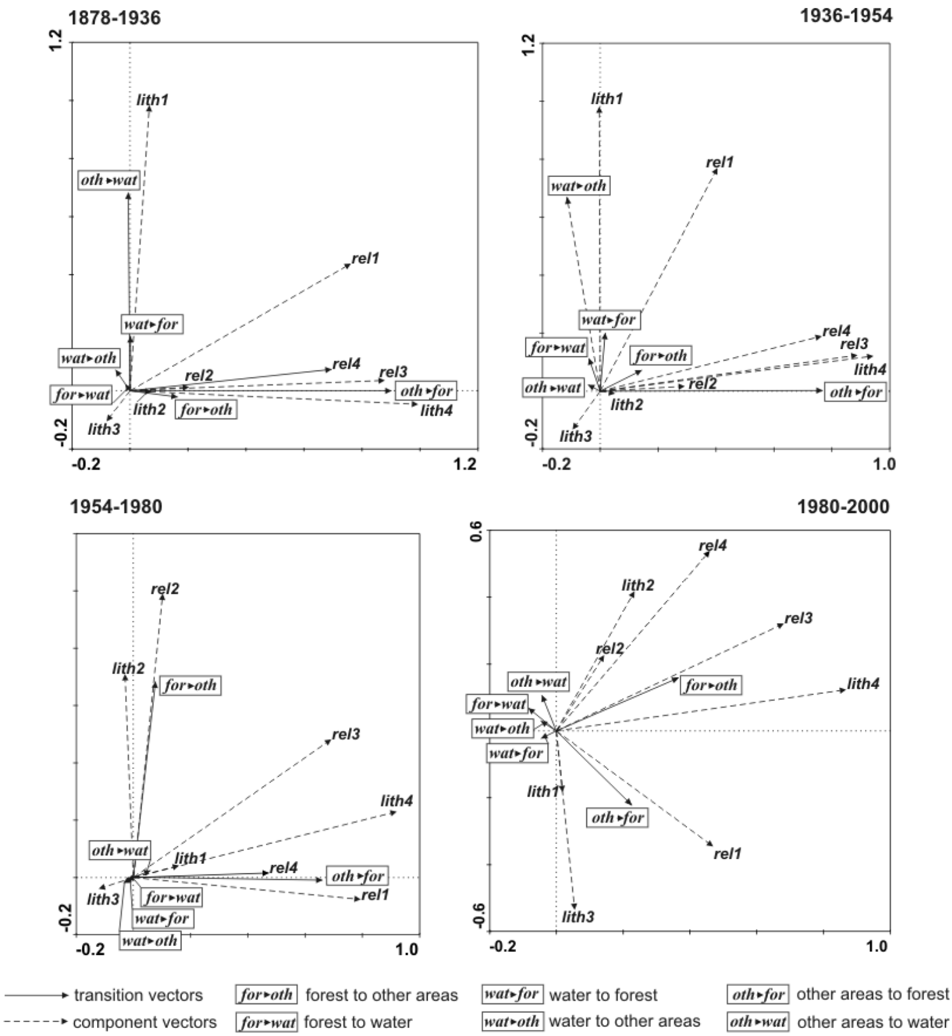

Fig. 4. Ordination diagram for the Wiele area

In the Wiele research region, the relations between environmental variables and land cover changes took shape in a different manner. In all periods, kind of division into two groups of relationships may be observed (Fig. 4).

The first group includes the transitions: “forests→others” and “others→forests”. In the earliest phases (1878–1936, 1936–1954), they occurred mainly on sandy sandr substratum in the high topographic locations (convex middle parts of slopes and hilltops). The situation changed somewhat in the next periods (1954–1980, 1980–2000), when the transformation in the direction of "others→forests" took place also on plains and in the final phase (1980–2000) even the moraine deposits underwent afforestation. In 1954–1980, deforestations were associated with the lower parts of slopes and the fluvial sediments, while in the subsequent period with the convex middle parts of slopes.

A second group relates to transitions among the categories: "forests", "others" and "waters". In most of the cases, their vectors are visibly correlated with one category of surface sediments – peat and lake deposits (see Fig. 4).

In some situations, vectors of changes were very short and concentrated in the centre of ordination diagram. Drawing conclusions of their relationships with environmental variables would be imprecise. In such circumstances the interpretation was refrained.

DISCUSSION AND CONCLUSIONS

By linking GIS tools and multivariate techniques it was possible to show the main temporal directions of landscape change and to identify the correlations between long term land cover dynamics and environmental conditions. The results of the canonical analysis indicate that the distributions of land cover changes were not random.

In the Pinczów area, the proportion of land transformations was relatively low, however their diversity was clear. In the Wiele area, changes occurred throughout large areas but had relatively simple character.

The above observations may be associated with clear differences in the development of abiotic components in both research regions. The Pińczów area is characterized by an extreme complexity of lithological conditions and contrasting relief. The Wiele area is, on the one hand, highly diversified in regard to morphometric landforms, on the other however, it is quite homogeneous due to geological construction. Therefore, it is reasonable to assume that, among the reviewed natural conditions, the main factors which differentiate relations between land cover changes in the Wiele area were the characteristics of geological deposits, while in the Pińczów area – lithology and relief on the whole.

In addition, in the Wiele area a phenomenon, typical for the entire area of Tuchola Pinewoods, can be observed. During the initial transformation stages, afforestation took place on sandy sandr. Finally however, fertile moraine areas favourable for agriculture underwent afforestation, as well. This observation, linked to the knowledge on the decreasing afforestations taking place in the last few years in this region (Giętkowski, 2009), may suggest the approaching "exhaustion" of acreage favouring such transformations.

Nidziańska Basin, where Pińczów area lies, is a historical rural region. The spatial arrangement of forests, grasslands and fields has been preserved there for thousands of years and is very well incorporated into the conditions of the natural environment. Therefore, land cover changes are not of a largeareal extend. This observation corresponds with the results of research conducted by Plit (1994), who analysed the historical landscape transitions in this area by quantitative methods.

The results allow to draw a conclusion about the regulatory and organizing role of abiotic components in landscape transformations. This is also confirmed by the research of other authors, who prove that, although in most cultural landscapes the major forces affecting the changes are of various socio-economic origins, the underlying environmental conditions can constrain land-use and modify the directions of land cover transition (among the others, Baudry, 1993, Veldkamp, Fresco 1996, Hietel et al., 2004, 2005, 2007).

At last, a short evaluation of methods should be done. Historical research of a quantitative character is a difficult task. The fundamental problem is the irregularity of map series and their different quality. A lack of data on individual environmental components also constitutes a significant inconvenience. It was impossible to construct a continuous database including all the geocomponents for the period of over 150 years. Therefore, the indirect method employing the dominant lithogenic attributes appears to be an optimal and effective solution.

Multivariate ordination techniques, previously used mainly in ecological analysis (Leps, Smilauer 2004), represent a large potential for application in landscape research. Nevertheless, an issue which needs to be resolved is the selection of an adequate basic field of analysis. In this study, in an arbitrary manner, a grid of squares of 250 m × 250 m was used. In a few studies on landscape transformations, employing ordination techniques, single raster cells (Pan et al., 1999, Fu et al., 2006), as well as land register allotments (Hietel et al., 2004) and administrative units (Hietel et al., 2006, 2007) were used. It seems however, that the application of natural spatial units, i.e. geocomplexes, would serve as a beneficial solution for landscape geography. Further research is necessary to verify this presumption.

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Digital elevation data (ASCII) from LPIS campaign, Centralny Ośrodek Dokumentacji Geodezyjnej i Kartograficznej.