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Land use changes and landscape pattern dynamics of a peatland area under diversified human impact: the Grójec Valley (Central Poland)

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Abstract. The paper aims to assess the land use changes and the dynamics of the landscape pattern of the Grójec Valley in the scope of diverse anthropogenic impacts. The study site is located in the border of the Koło Basin and Kujawy Lakeland, Central Poland. This area was originally covered with wetlands. Since the beginning of the 20th century it has been influenced by intensive agricultural use, peat extraction and open-pit mining. The research is based on cartographic materials from 1941, 1981 and 2012. The most relevant finding was that in the first study period (1941–1981) the most common changes in land use (transformation of wetlands into grasslands with shrubs) took place. These were caused mainly by a change in hydrological conditions due to drainage for agricultural use (meadows and pastures) and peat extraction. The study confirmed that these land use changes significantly influenced the landscape structure in each of the analysed parameters (patch density and size, edge, shape and diversity metrics).

Key words:
land use changes,
agriculture use,
peat extraction,
open-pit mining,
wetlands

Introduction

Information about temporal changes in land cover is regarded as essential for natural resources management studies, environmental studies and sustainable development (Foley et al. 2005; Chen et al. 2015). The effects of land cover changes may be visible in a broad spectrum of environmental systems including atmospheric, hydrologic, geomorphologic, pedologic and ecologic ones (Olofsson et al. 2013; Muñoz-Rojas et al. 2015). Land use changes could be caused by alternations in hydrological conditions, but they can also cause changes in the water cycle. Moreover these changes are very important at scales both regional (Zhang et al. 2017; Fu et al. 2013; Wright and Wimberly 2013) and global (Sterling et al. 2013). That is why the interdependencies between the anthropogenic impact, water management and land cover changes in wetland areas are widely studied.

Landscape structure and its changes are examined with various research methods (Kunz 2006a). Landscape patterns dynamics and landscape ecology are studied using tools provided by the Geographical Information System (Kunz 2008). Quantification of landscape structure is considered crucial in determining the function and dynamics of various landscapes. Therefore, landscape metrics are commonly used in such research as a useful tool for characterising landscape dynamics (Herzog and Laush 2000; Kunz 2008; Rendenieks 2017; Fu et al. 2013).

The Grójec Valley is an area that was originally covered with wetlands. It has been under anthropogenic influence since the beginning of 20th century (intensive agricultural use, peat extraction, open-pit mining). The objective of the study was to assess the land use changes and dynamics of the landscape pattern of the Grójec Valley in the context of various anthropogenic impacts.

Material and methods

Study area

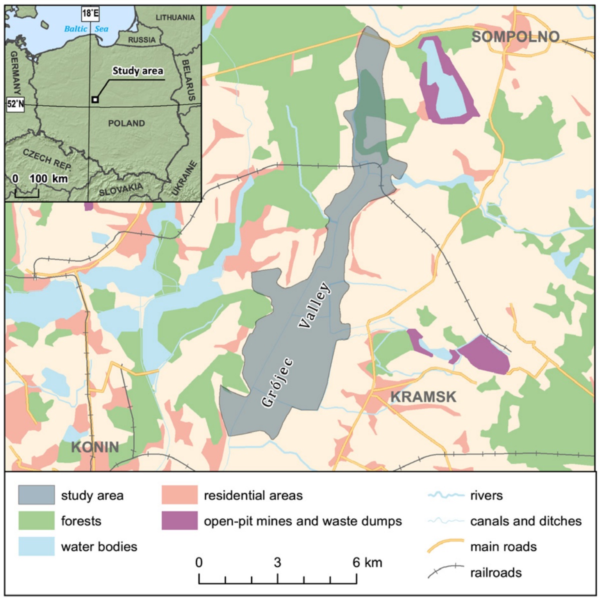

Fig. 1. Location of the study area

The study was carried out for the area of Grójec Valley, which is located in the border of the Koło Basin and Kujawy Lakeland, Central Poland (Fig. 1). It is a NNE–SSW-oriented, flat-bottomed valley bordering on the south with the Warsaw–Berlin ice-marginal valley (Solon et al. 2018; Szałamacha 2002). Most of the area is covered with Holocene peat deposits underlain by fluvial sands of alluvium terrace and telmatic muds (Szałamacha 2002). According to the Köppen–Geiger climate classification, this region is located in a fully humid, warm temperate climate zone, with a warm summer (Kottek et al. 2006). The mean annual air temperature is 8.7°C and the mean annual sum of precipitation can reach 520 mm in the period 1985–2004 (Stachowski et al. 2013). The Grójec Valley has a relatively complex soil cover consisting mainly of Gleysols and Histosols (Gajewski et al. 2006; Glina et al. 2016). The study area was about 16.5 km long, 4.3 km wide (maximum) and covered 3,057.7 hectares.

Cartographic materials

Land use changes were defined using Polish and German topographic maps and the Polish Database of Topographic Objects (Baza danych obiektów topograficznych – BDOT); each material covers a different time (from 1941, 1981 and 2012). Topographic maps were scanned and georeferenced by spline transformation (Podobnikar 2009; Affek 2012) into the PUWG 1992 (ETRS89 / Poland CS92) coordinate system using ESRI ArcGIS 9.3 software. The Database of Topographic Objects is provided as vector layers in ESRI shapefile format developed using the PUWG 1992 coordinate system.

The following materials were used:

a) German topographic maps at the scale 1:25,000:
- the Lustenau sheet (Lubstów) 3927D, Meβtischblatt, mapped 1941;
- the Kramsk sheet 3927G, Meβtischblatt, mapped 1941.

b) Polish Topographic Maps at the scale 1:25,000:
- the Ślesin sheet 424.41, mapped 1981;
- the Konin-Północ sheet 424.41, mapped 1981.

c) Database of Topographic Objects:
- Konin district, mapped 2012.

The topographic maps and vector layers used in the study were produced during different periods and using various cartographic presentation methods. This resulted in a different number of land use classes being distinguished for each map (period of time). Thus the process of standardising the land use and land cover classes was essential (Kunz 2006b). To standardise all cartographic materials, nine categories of land use were determined, as shown in Table 1. New categories were established based on generalisation of the categories from the most current data source (BDOT – 2012). As some of the objects (roads and railroads) are available as vector polygonal features within the BDOT (2012), the analogue cartographic materials (Meβtischblatt – 1941; and Polish Topographic Map – 1981) were digitised in the same way. Further in the text and tables only the year of mapping is provided to distinguish each of the individual cartographic sources. The area of each land use/land cover category was calculated for every polygon (Table 2).

Landscape metrics

Landscape characteristics for the area were calculated using the Patch Analyst extension for ArcGIS software (Rempel et al. 2012). Density of watercourses and peat extraction sites were determined using hexagons of a 2.5-ha surface area.

The following landscape metrics were selected for this study (abbreviations and designations of metrics groups as in Table 3):

Table 1. Land use categories determined and used in the GIS analysis

Feature type	Land use class	Data source; map actuality		
		Messtischblätter 1:25,000; 1941	Polish Topographic Map 1:25,000; 1981	Database of Topographic Objects 1:10,000; 2012
		Features from each of the analysed map		
Polygon	Built-up areas	Building Built-up area	Building Built-up area Single farm	Building Industrial and services built-up area Residential built-up area Single building
	Main roads, railroads	Main road Railroad	Main roads Railroads (under construction)	Area covered with road, railroad or airport strip
	Arable lands and permanent croplands	Orchard	Arable land	Arable land
		Arable land	Orchard	Permanent cropland
	Grasslands and shrubs	Meadow Shrub	Meadow Shrub	Grassland Shrub
	Forests	Deciduous forest Coniferous forest Mixed forest	Forest	Forest
	Wetlands	Marshy meadow Wetland Swamp	Marshy meadow Rush Swamp	Marsh Rush
	Waterbodies	Lake	Waterbody	Waterbody Water supply reservoir
Line	Watercourses	Canal River	Canal Ditch River	Canal Drainage ditch River and stream
Point	Peat extraction sites	Peat extraction site	Peat extraction site	Peat extraction site

Table 2. Changes of land use cover

Land use class	Messtishblätter 1:25,000; 1941		Polish Topographic Map 1:25,000; 1981		Database of Topographic Objects 1:10,000; 2012	
	Cover area [ha] and [% of total]					
	1941		1981		2012	
Built-up areas	19.1	0.6	6.8	0.2	13.6	0.4
Main roads, railroads	1.1	<0.1	6.9	0.2	6.7	0.2
Arable lands and permanent croplands	338.0	11.0	286.0	9.4	572.0	18.7
Grasslands and shrubs	613.8	20.1	2061.1	67.4	2050.7	67.1
Forests	5.2	0.2	43.1	1.4	292.0	9.6
Wetlands	2078.8	68.0	564.5	18.5	98.3	3.2
Waterbodies	1.7	0.1	89.4	2.9	24.3	0.8
Total area	3057.0	100.0	3057.0	100.0	3057.0	100.0

- patch density and size metrics (I): number of patches (NP) – total number of patches (polygons) in the analysed landscape; mean patch size (MPS);

- average patch (polygon) size in the analysed landscape;

- edge metrics (II): total edge (TE) – total length of all patches' (polygons') perimeters in analysed landscape; edge density (ED) – total length of all patches' (polygons') perimeters in analysed landscape divided by the total area of the study area; mean patch edge (MPE) – average length of the patches' (polygons') perimeters;

- shape metrics – measures of shape complexity (III): mean shape index (MSI) – the sum of all patches (polygons) perimeter divided by the square root of the total study area, and adjusted for circular standard (polygons), or square standard (grids), divided by the number of patches (McGarigal and Marks 1994); area weighted mean shape index (AWMSI) – calculated the same way as the mean shape index, with the addition of individual patch area weighting applied to each patch (McGaril and Marks 1994); mean patch fractal dimension (MPFD) – a fractal dimension of all patches (polygons) within the studied landscape; area weighted mean patch fractal dimension (AWMPFD) – a fractal dimension of all patches within the studied landscape with the addition of individual patch area weighting applied to each patch (McGaril and Marks 1994);

- diversity metrics (IV): Shannon's diversity index (SHDI) – a measure of relative patch diversity that will equal zero when there is only one patch in the landscape and will increase as the number of patch types or proportional distribution of patch types increases (McGaril and Marks 1994); Shannon's evenness index (SHEI) – a measure of patch distribution and abundance that will equal zero when the observed patch distribution is low, and approaches one when the distribution of patch types becomes more even. Shannon's evenness (McGaril and Marks 1994).

Despite the fact that some of the landscape metrics applied for the calculations could be used both at individual class level and landscape level (I,II,I-

Table 3. Landscape metrics values changes

DATA SOURCE	I		II			III				IV	
	NP	MPS [ha]	TE [km]	ED [m/ha]	MPE [m]	MSI	AWMSI	MPFD	AWMPFD	SHDI	SHEI
1941	130	23.52	179.77	58.79	1382.85	1.54	3.10	1.38	1.30	0.88	0.45
1981	844	3.62	679.30	222.16	804.86	1.39	10.69	1.37	1.44	0.98	0.50
2012	625	4.89	521.38	170.52	834.22	1.62	7.77	1.44	1.41	0.99	0.51

II), all of the indexes were used for calculations at the landscape level in the presented study.

Results and discussion

Land use changes, 1941–1981

The peatland management in the Grójec Valley can be divided into two periods. First, drainage works were carried out at the beginning of 20th century in order to allow agricultural use and peat extraction (Figs 2, 3 and 4). Drainage ditches discharged the water to the Grójec Channel, which was present on the local maps from 1934 prepared by the Polish Military Geographical Institute. There was a significant increase in the number of individual ditches after 1941 (Figs 2 and 3). Thereafter, intensive agricultural use, mostly as pastures and meadows, was observed after the 1960s, when Grójec Channel was reconstructed (1965–1969) (Mocek and Owczarzak 2003). The effect of the hydrological changes resulting from the land use transformation is clearly visible (Fig. 2) The total area covered with wetlands was more than 2,078 ha in 1941 and comprised 68% of the study area (Table 2). It had the largest decrease among all of the determined land use categories – it covered about 565 ha (18.5%) in 1981. While the class of grassland and shrub was present only in the northern part of the valley (20.1% of the total area in 1941) it was later distributed within the whole study area (67.4% of the total area in 1981). The specific non-monolithic (heterogeneous, combined of several types of land cover) structure of the grassland and shrub area developed for two reasons. First is the fact of enclaves of wetland areas (the southern and central part of the valley, Fig. 2). Second is the appearance of a large number of small water bodies (1981) at the former peat extraction sites (1941, Figs 2 and 4). These two aforementioned land cover classes occur as relatively small polygons within the area of grasslands.

Other land use changes were not so well demonstrated, as the other land use categories did not cover such a large area. Built-up areas decreased from 0.6% to 0.2% of total. This could be also connected with a slight decrease in the area of arable land (from 11.0% to 9.4%). The increase in area covered with roads and railroads from less than 0.1% to 0.2% is the direct result of the development of lignite mine infrastructure.

Land use changes, 1981–2012

Further aggravation of the local hydrological conditions after 1980 was enhanced by lignite open-pit mining. In the direct vicinity of the study area two open-pit mines were located. The first operated from 1982 to 2009, while the second was opened in 2005 and will operate until 2020 (Owczarzak et al. 2003). The central and northern parts of the Grójec Valley are still within the possible impact of the depression cone of the Drzewce open-pit mine (Glina et al. 2016). Furthermore, the peatland areas in the southern part of the valley were damaged by human induced fires in 1982 (obtaining new land for agricultural purposes). The burning of sedge (*Carex* sp.) meadows resulted in a degradation of surface soil layers and a decrease in peat deposit thicknesses, of up to as much as 0.40 m (Ilnicki and Borkowski 1985).

The fragmentation and disappearance of wetland areas has been ongoing. In 2012 wetlands covered only 98.3 ha (3.2% of the study area; Table 2; Fig. 2). In the southern part of the valley the above mentioned distinctively structured (non-monolithic) land use category made of combined wetlands and grasslands has disappeared. The percentage area of grasslands and shrubs class cover remained at a relatively stable level (67.4% in 1981 to 67.1% in 2012). It was replaced by a "fishnet structure" formed by the expanding network of draining ditches. Some blocks of this net are now covered with arable lands and permanent croplands, which have doubled from 286 ha (9.4%) to 572 ha (18.7%). The most prominent changes took place in the northern part of the valley where the external waste dump of the Lubstów open-pit mine was formed. This new element in the valley landscape is elevated to 135 m a.s.l. The relatively steep slopes of this anthropogenic relief form have been covered with forest, which is a common reclamation practice (Kasztelewicz et al. 2010). The vast, flat summit is being used as arable land. This was the main cause of the large increase in forested areas from 43.1 ha (1.4%) to 292 ha

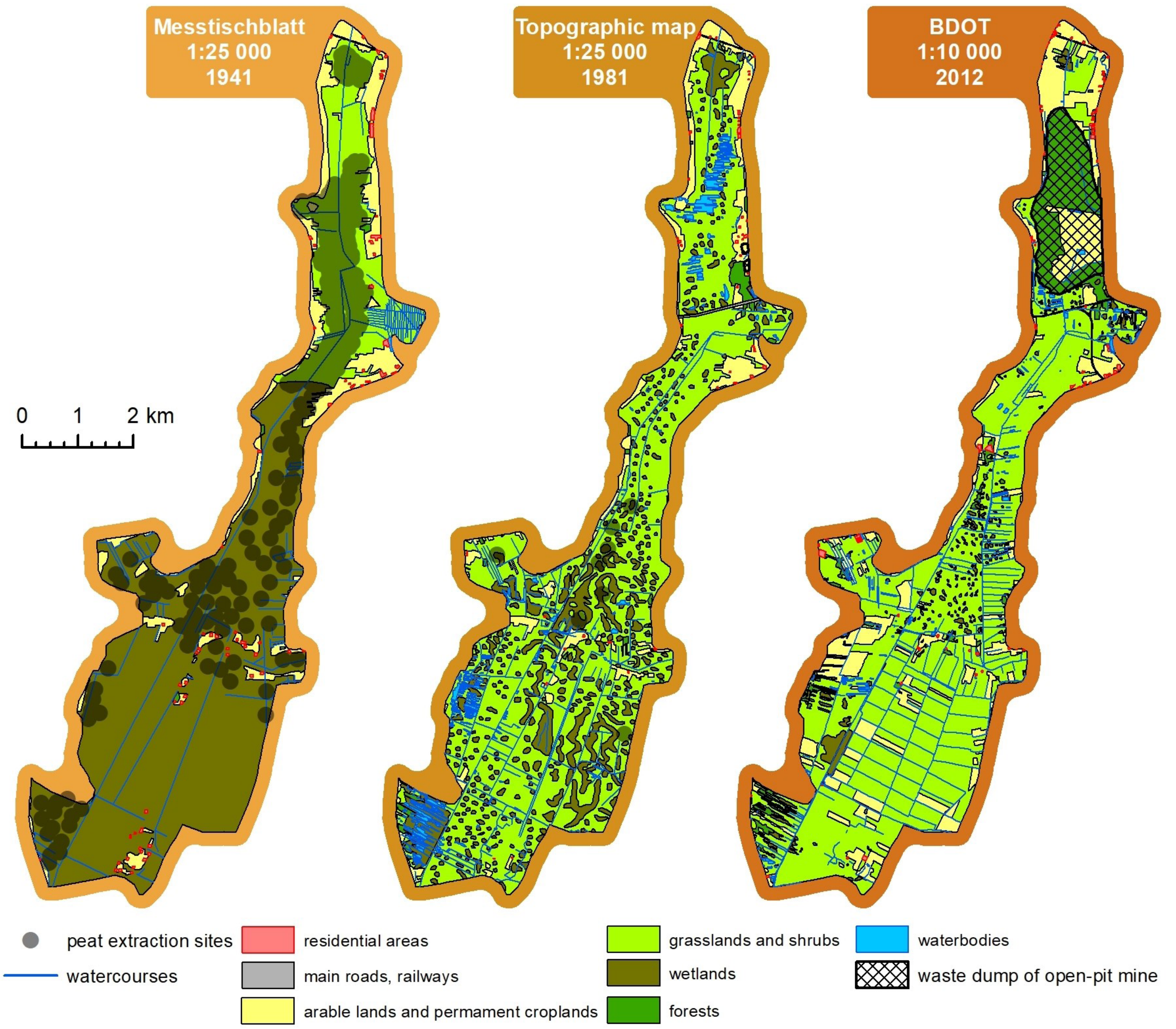

Fig. 2. Land use changes within the Grójec Valley (Messtischblatt: german topographic maps at the scale 1:25,000, the Lustenau sheet (Lubstów) 3927D and the Kramsk sheet 3927G, Messtischblatt, both mapped in 1941; Topographic map: Polish Topographic Maps at the scale 1:25,000, the Ślesin sheet 424.41 and the Konin-Północ sheet 424.41, both mapped in 1981; BDOT: Polish Database of Topographic Objects, provided as vector layers, Konin district, mapped in 2012)

(9.6%). At the same time, the number of waterbodies decreased (from 2.9% to 0.8% of the study area), both as a result of wetland vegetation formation (in the south of the valley) and the disappearance of post-extraction sites due to the establishment of an external waste dump (in the northern part of the valley). Built-up area doubled from 6.8 ha to 13.6 ha, while the road and railroad covered area remained at a stable level (0.2%).

Dynamics of landscape metrics in the study period

The described land use transformations have caused significant changes in the analysed landscape metrics (Table 3). According to patch density and size metrics, NP increased more than six-fold from 130 in 1941 to 844 in 1981, before then decreasing to 625 in 2012. At the same time the MPS decreased considerably (from 23.5 to 3.6 ha) and later in-

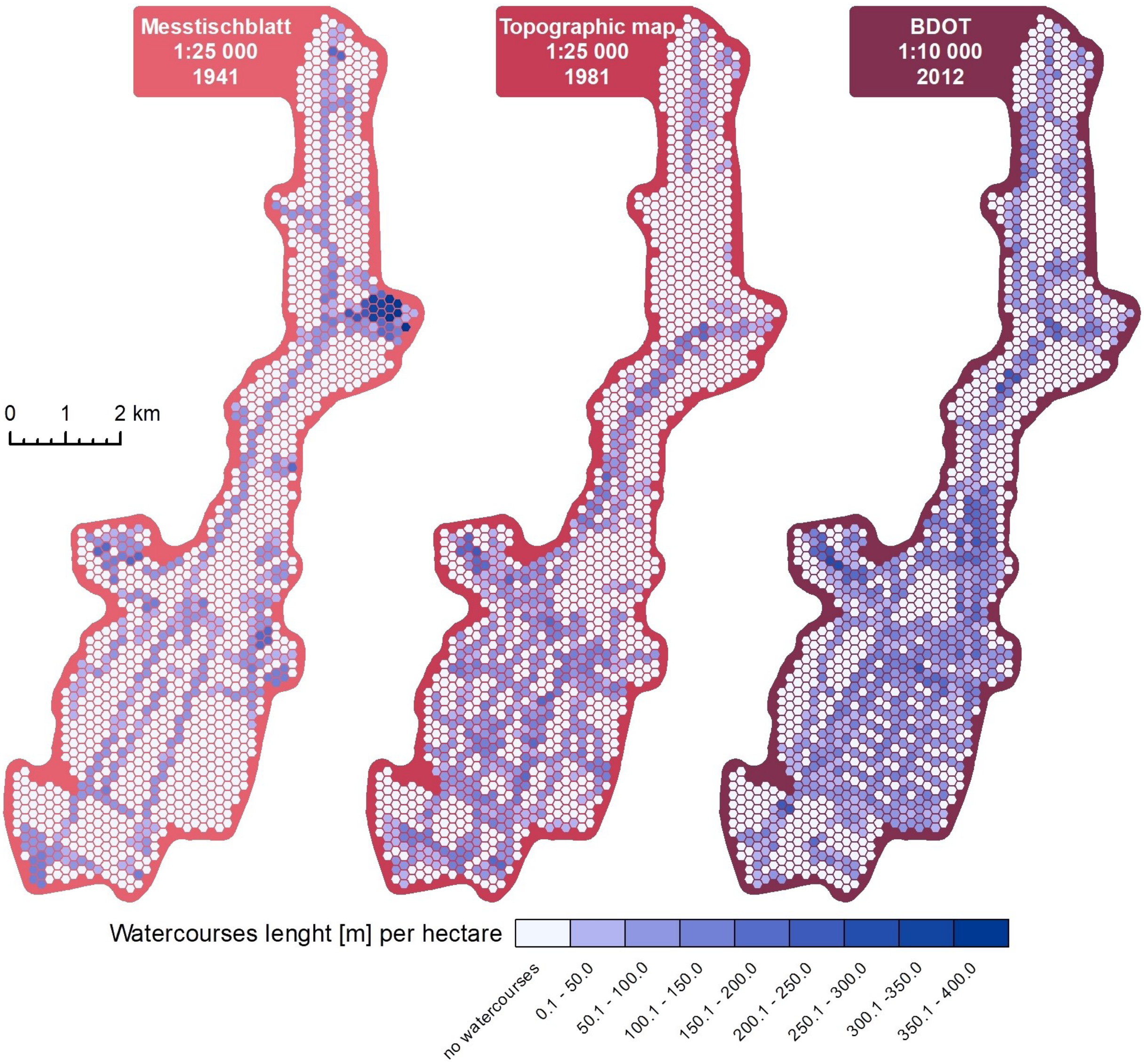

Fig. 3. Watercourses density within the Grójec Valley (Messtischblatt: german topographic maps at the scale 1:25,000, the Lustenau sheet (Lubstów) 3927D and the Kramsk sheet 3927G, Messtischblatt, both mapped in 1941; Topographic map: Polish Topographic Maps at the scale 1:25,000, the Ślesin sheet 424.41 and the Konin-Północ sheet 424.41, both mapped in 1981; BDOT: Polish Database of Topographic Objects, provided as vector layers, Konin district, mapped in 2012)

creased (to 4.9 ha). Similar results were obtained for edge metrics. TE and ED showed large increments (from approximately 180 to 679 and 59 to 222, respectively) which was followed by a decrease (to 521 and 172, respectively). Together with the aforementioned, the MPE values at first decreased (from 1,383 to 805) and later increased to 834. These parameters were mostly influenced by the developing of the above-mentioned inconsistent land cover structure combined of a grassland background with spots of wetlands. First, a large number of wetland spots and small water bodies occurred. As some of them disappeared and a large monolithic area of forest was established in the north of the valley, the discussed values of indices decreased.

The values of mean shape index (MSI) and mean patch fractal dimension (MPFD) seemed to be underestimated due to the presence of the large dominant patches of wetland area in 1941 and grassland with shrub in 1981. As the AWMSI and AWMPFD also take into accounts the individual patches' area (McGarigal and Marks 1994), these two are more

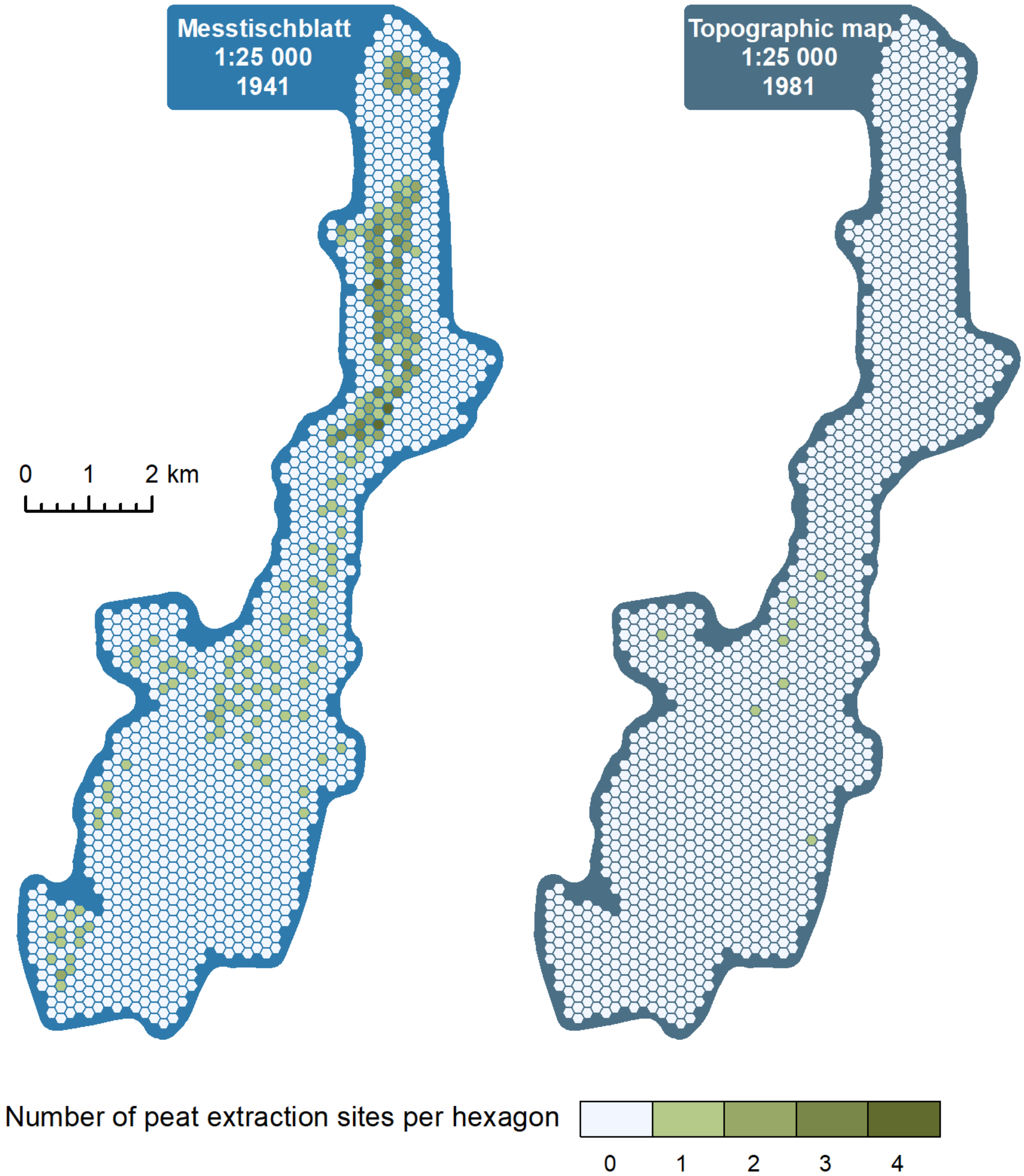

Fig. 4. Peat excavation sites density within the Grójec Valley (Messtischblatt: german topographic maps at the scale 1:25,000, the Lustenau sheet (Lubstów) 3927D and the Kramsk sheet 3927G, Messtischblatt, both mapped in 1941; Topographic map: Polish Topographic Maps at the scale 1:25,000, the Ślesin sheet 424.41 and the Konin-Północ sheet 424.41, both mapped in 1981; BDOT: Polish Database of Topographic Objects, provided as vector layers, Konin district, mapped in 2012)

appropriate in the case of the discussed research. The highest values of the previously mentioned parameters in 1981 confirmed the assumptions about the impact of the irregular patches of wetlands formed within the grasslands-covered area that influenced these shape metrics. Both analysed diversity (SHDI and SHEI) metric indices showed that the landscape diversity increased in 1941–1981 and remained stable afterwards. In general, these findings are in line with those reported by Fu et al. (2013), who proved the increase in SHDI at the area of wetlands under anthropogenic influence (the constructing of dykes).

Conclusions

1. Major changes in land use/land cover took place in the first period of study (1941–1981). This was confirmed by the analysis of maps, the chang-

es in cover area of each determined land use type and the calculated landscape metrics.

2. The most noticeable changes in total area covered by individual land use types were the fragmentation and disappearance of wetland areas, as well as the increase in total area of forests (afforestation of the external waste dump) and arable land.

3. The draining of the Grójec Valley wetlands for agriculture and peat extraction was the most expressed human impact in those times. Thus, we assume this as the main factor influencing the landscape changes of the study area. This was expressed as the ongoing conversion of wetlands into grasslands.

4. The impact of the lignite mining industry on the Grójec Valley is represented mainly by the appearance of large artificial objects, in the form of a forested external waste dump. Despite the size of this anthropogenic facility, it had only a minor impact on the landscape pattern dynamics and on changes in landscape diversity.

Disclosure statement

No potential conflict of interest was reported by the authors.

Author Contributions

Study design: B.G., Ł.M.; data collection B.G, Ł.M., M.S., statistical analysis: Ł.M., M.S.; result interpretation B.G., Ł.M., M.S..; manuscript preparation B.G., Ł.M., M.S.; literature review: B.G., Ł.M.

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