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Land use and land cover changes in small Carpathian catchments between the mid-19th and early 21st centuries and their record on the land surface

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Abstract: Land use and land cover (LULC) changes and their impact on the mountain environment were studied in six catchments (~10 km² each) in the Polish Western Carpathians from the mid-19th century to the early 21st century. The analysis of cadastral and orthophoto maps indicates that during the investigated period, the forest area increased, quantified by an annual change index (Ann_{ch}), between +0.12% to +0.27%, with a decrease of arable land index to −0.45% and −2.28% in the analysed catchments. LULC changes were accompanied by a continuous increase in settlement developments (residential and farming houses) by 50%-140% as well as significant changes related to their spatial distribution. Abandonment of arable land and forest succession have resulted in the geomorphological transformation of hillslopes, which predominantly includes a decrease in used road density, their transformation to road cuts and gorges. Overpopulation and the domination agriculture in the past caused the expansion of unpaved roads density and then the fragmentation of hillslopes, as well as the development of agricultural terraces.

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Introduction

Land use and land cover (LULC) has had a significant influence on the environment, especially in the mountain areas (e.g. MacDonald et al. 2000; Latocha and Migoń 2006; Rutherford et al. 2008; Bucała et al. 2015; Bucała-Hrabia 2017). Massive deforestation has triggered a transition from a natural to a human-dominated landscape (Goldewijk 2001; Foley et al. 2005), and created new ecosystems (Benjamin et al. 2005). Apart from vegetation, LULC changes have had an impact on soil properties (Peco et. al. 2006; Bucała et al. 2015) and water circulation in the catchments: surface runoff, erosion and the sediment supply to river channels (Stankoviansky and Midriak 1998; Łajczak et al. 2014; Kijowska-Strugała et al. 2018). Therefore, knowledge of LULC changes and the factors that affect these changes is fundamental to understanding the present processes and to predict the future functioning of the mountain environment.

In the Carpathians, in the past, economic development has often generated conflicts of interest related to land use. Contemporarily the conflicts between environmental protection and economic development are most visible on a local scale. For example they are related to: tourism infrastructure development, communications infrastructure, urbanization or water management (Łajczak et al. 1996; Young et al. 2004; Bragina et al. 2018). These factors significantly affect the circulation of matter and energy in small catchments and this correlation shows how important the LULC studies are (especially in naturally defined areas such as catchments). Determining and recording the rate and direction of transformations, as well as their impact on the environment, is important. When properly implemented, such studies will help to establish a reasonable balance between the increase in nature preservation (e.g. increased biodiversity) on the one hand, and economic development on the other.

The structure of LULC changes in the Polish Carpathians have often been discussed in publications, but many studies focus on forest cover, as this type of LULC change is the most readable in source materials such as historical and topographical maps, photos and satellite images (e.g. Soja 2002; Kozak et al. 2007; Kozak 2009; Griffiths et al. 2014; Kaim 2017; Kolecka et al. 2017). Besides, the LULC changes are usually investigated in relation to regions and administrative units (e.g. Pietrzak 2002; Kozak et al. 2007; Soja 2008; Kozak 2009; Ciołkosz et al. 2012). In this study, we focused on small catchments, where the influence of LULC changes on the functioning of a mountain environment (e.g. geomorphological changes, the hydrological response of a catchment to rainfall) is more visible. Therefore, in this research, we chose the oldest, cadastral maps (from the middle of the 19th century) uniform for the entire Polish Carpathians and the first high resolution aerial photos (orthophoto maps), uniform for the same area, from 2009.

The authors of this study claim that more detailed investigation of the LULC structure is the more preferred approach in LULC studies (especially where historical analyses are concerned). Such studies are desirable because they contribute to "meta-data studies" and ultimately allow for more comprehensive analyses (Munteanu et al. 2014). Only a few studies were analysed based on large scale cadastral materials from the 19th century, which addressed detailed LULC changes in the Polish Carpathians (Harvey et al. 2014; Bucała-Hrabia 2017; Kijowska-Strugała et al. 2018), and that is why these were the first reason for this investigation. The second reason was an attempt to evaluate whether LULC changes from the 19th century were preserved in the landscape - especially the smallest forms, such as local roads and agricultural terraces. This issue, in relation to historical context, is rarely documented in literature (Pietrzak 2002; Kroczak 2010; Kroczak et al. 2016), therefore it is the one we addressed.

The purposes of this study were: 1) to conduct a detailed analysis of the LULC structure in small Carpathian catchments, focusing on the 19th and 21st centuries, and 2) to link these changes with factors that mainly affect LULC changes 3) to assess, whether and how the effects of changes in the LULC structure have been recorded in the mountain environment.

1 Study Area

The Polish Carpathians (19,600 km^2) cover the region of the high-mountain (the Tatra Mts.), areas of the mid- and low-mountains (the Beskidy and the Bieszczady Mts.), and the foothills. Detailed research was conducted within 6 catchments, located in these three main sub-regions (Figure 1) which differ in terms of natural conditions: climate, relief, soil cover and man-made conditions: land use and settlement conditions.

The Zalasówka (9.2 km^2) and Pożory (7.1 km^2) catchments, at elevations between 230-530 m a.s.l., were selected for the foothills and are located in the Ciężkowickie Foothills (Figure 1A). More than 60% of the catchment area has a slope gradient ranging

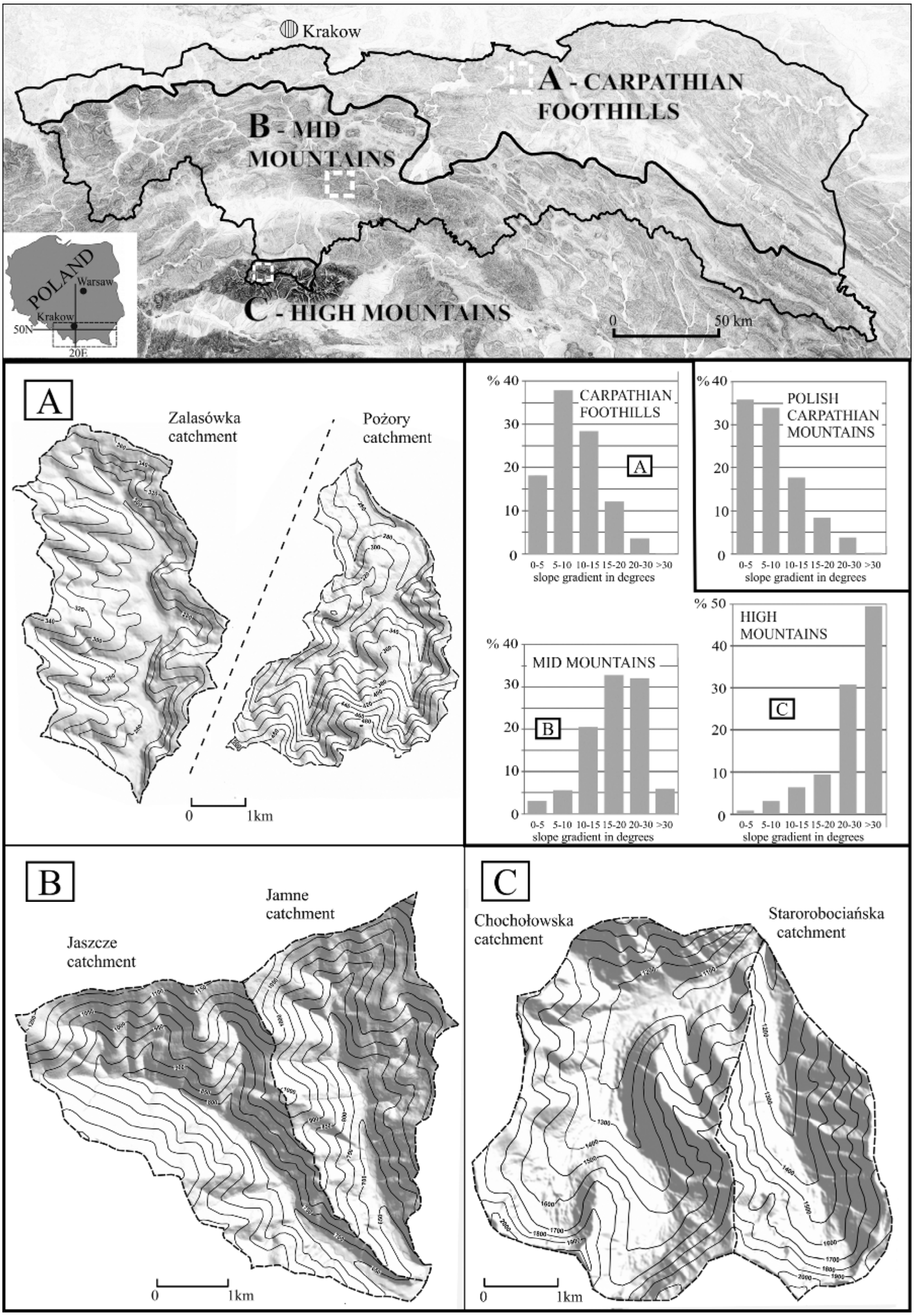

Figure 1 The study area and location of the representative catchments for: foothills - A, mid-mountains (the Gorce Mts.) - B and high-mountains (the Tatra Mts.) – C.

between 5°-15°. The Zalasówka catchment represents a typical agricultural and the Pożory an agricultural-forested type of foothill catchment.

The Jaszcze (11.4 km^2) and Jamne (8.9 km^2) catchments were selected for the mid-mountains (Figure 1B). The Jaszcze and Jamne catchments are located in the southern part of the Gorce Mts. (which includes the Beskidy part of the Polish Carpathians) at elevations 600-1250 m a.s.l. Steep slopes above 15° cover more than 70% of the Jaszcze and Jamne catchments.

The high-mountain region was represented by the Chochołowska (14.3 km^2) and Starorobociańska (7.2 km^2) catchments, which are located in the Tatra Mts. Almost 50% of the catchments have slope gradients higher than 30°. Catchments are located 1020-2180 m a.s.l. (Figure 1C).

2 Materials and Methods

The LULC structure for the first decade of the 21st century was obtained from color aerial orthophoto maps from 2009 with a raster of 0.25 m. This data is provided in the Polish coordinate system called "Poland 1992" (based on the ETRS89 datum, GRS80 spheroid and the Transverse Mercator projection) and the sheets are adapted to the scale 1:5000. These orthophoto maps served as a source of ground control point coordinates during the process of aligning historical data with the coordinate system.

Cadastral maps in 1:2880 scale, which show the LULC structure and ownership: 1848 – foothills, 1886 – mid-mountains and 1846 – high-mountains, were used for LULC reconstruction of the 19th century. These maps, the so-called "Franciscan cadastre", are the oldest large-scale cartometric sources of data about land usage in the Polish Carpathians. Cadastral maps from the mid-19th century are not currently considered documents, they are treated as historical data and are scattered across many archives throughout Poland. The maps of the Foothills are deposited in the Archives of local Geodetic and Cartographic Documentation Center in Tarnów, and of the Gorce Mts. and the surrounding areas in the Archives of the National Museum in Krakow. Georeferenced data for the Tatras Mountains was provided by the Tatra National Park. Non-georeferenced cadastral sheets were scanned at 300 dpi resolutions and saved in BMP format and then imported into the GIS program, where they were aligned with the coordinate system with the smallest possible transformation error. The cadastral maps were constructed in a coordinate system with known parameters, but there are no coordinate lines on the sheets. Therefore, coordinates of ground control points such as: churches, wayside small chapels, river-road junctions and crossroads were used. The best sources of ground control points were border intersections of 3 or more fields. We have determined that in a landscape with heavily fragmented plots such boundaries of fields are the least variable. In the rectification process the affine transformation was used in each case as the one giving the best effect. These operations resulted in the accuracy of 2 to 14 m for individual sheets. Finally all data was converted into the UTM coordinate system.

The baseline for determining the LULC structure was the taxed and non-taxed categorization in the Franciscan cadastre. In the research area, the taxed land included: arable lands, meadows, pastures, forests, used water bodies (ponds) and buildings. The non-taxed land included: wastelands, areas around the homesteads (yards), unused water bodies, mountain areas (rocks), rivers and roads (Fedorowski 1974). Individual types of use were marked with different colors or symbols to distinguish them from each other. To allow for a direct comparison with similar sources, four main structures of land use were defined: arable lands, grasslands (meadows, pastures and yards), forests and buildings (residential and farming buildings). Special attention was paid to the analysis of the distribution of buildings (due to the small areas of land under buildings the distribution was analyzed based on the number of buildings) as this aspect is rarely discussed in publications, but can, in the authors view, be a valuable indicator in LULC change analyses. A fifth category ("others") includes remaining LULC forms such as roads, rivers and bodies of water, etc., but it was omitted in LULC analyses, because it covered a small part of the catchments.

The LULC structure was digitalized using GIS software. All borders at the cadaster sheets were drawn first, after checking all digitalized lines (including topology errors) layers were transformed to polygon types with a LULC attribute. LULC structure of orthophoto maps was digitalized using an interpretation key defined for the LULC based on the cadaster.

In order to explain the changes in the LULC structure, and to detect the driving factors affecting the LULC changes, the anthropogenic and natural factors that determine the LULC changes were studied. The final LULC layers of polygon type (arable land, grasslands, forests and buildings) have also been transformed into point type layers (based on the centroid of each polygon) in order to carry out a cross-cover analysis making it possible to link changes with the catchment features. A centroid was generated for each polygon. Then, for the two surveyed dates, the average distances between all centroids in a given class and: the catchment boundary, the valley axis (as the opposition to the catchment boundary), the river network, the village centre where the catchment/ part of the catchment is located, and the nearest main/secondary road were determined. The first three features represent the natural properties of the catchment that may affect LULC changes, the next two represent objects related to human activity. In this way the relations between the mean distances of the LULC types to the examined features in the mid-19th century and the directions of changes that took place right up to the beginning of the 21st century were determined. During the analysis of the buildings distribution, we also checked how were changed: the minimum and maximum altitudes (m a. s. l.) slope aspect and slope degree.

Slope gradient and elevation (m a.s.l.) were also selected as natural factors. In mountain areas these two environmental factors strongly affect climate conditions and soil properties, which influence agricultural development and ultimately affect the LULC structure. At the same time, steeper slopes mean that certain areas are less accessible, thereby limiting settlement and thus also influencing the LULC structure. Dependencies between LULC categories and elevation and slope gradient were studied by cross-cover analysis on the basis of a digital elevation model developed from topographic maps 1:10,000 in scale. Based on the same source line layers (e.g. rivers) were digitalized. At the end of the data preparation stage, all vector layers (points, lines and polygons) were transformed to 5 m raster.

The environmental transformations were quantified by: 1) percentage changes - including matrix changes and 2) annual rates of change ($\mathrm{Ann_{ch}}$) calculated for each LULC category. The annual rate of change follows the model of the FAO forest change assessments (Pandey 1995). This measure is based on the following equation (Puyravaud 2003):

$$[\mathrm{Ann_{ch}}=((A_2/A_1)^{1/(t_2-t_1)})-1]$$

where, A_1 and A_2 represent the area of land cover of interest at the times of t_1 and t_2. The $\mathrm{Ann_{ch}}$ index was recalculated and expressed in % terms. Man-made factors including settlement development and socio-economic changes were analysed basing on the literature.

Field work was conducted in order to assess whether and how changes in the LULC structure are visible in the mountain environment. The objective of this research was to detect plot borders marked on the cadastral maps. If the forms were visible (e.g. agricultural terraces, cut roads) the basic parameters of these forms, such as height/ depth, width and length were measured. During field work we identified terrace borders and we marked their upper edge on the maps. This provided a basis for further analyses in which certain aspects of the transformation of the mountain environment were analyzed and discussed.

3 Results

3.1 Changes in the LULC structure

In 1848 in the foothills (the Zalasówka and Pożory catchments) arable lands were dominant in the LULC structure. On average they constituted 55% of the study area. Forests covered 27% and grassland (meadows and pastures) approx. 15%. Buildings and “other” LULC categories (mainly roads) covered 3% of the catchment area (Figure 2). Some differences in the LULC structure between the Zalasówka and the Pożory catchments were observed. In the Zalasówka catchment arable lands prevailed (72%), whereas forests prevailed in the Pożory catchment (56%). The LULC structure has changed significantly since the 19th century. Currently a significant decrease in arable land (from 55% in the 1848 to 26% in 2009),

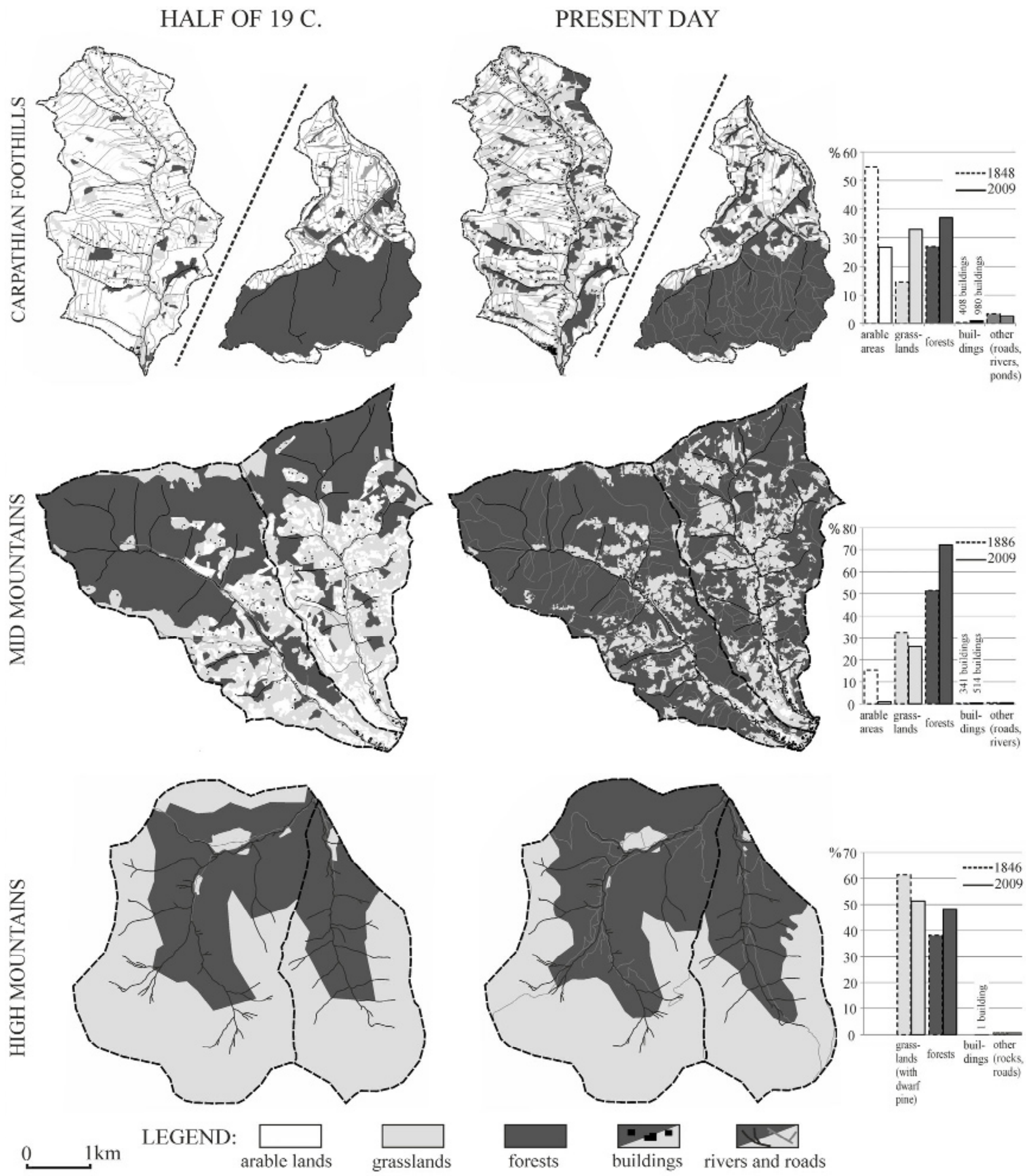

Figure 2 Land use and land cover (LULC) structures in the research catchments in the 19th and 21st centuries.

an increase in grassland (from 15% to 33%) and forest (from 27% to 37%) can be observed. It is worth emphasizing that a large forest complex shown on mid-19th century cadastral maps in the Pożory catchment has not changed. This is due to the fact that the area belonged to one estate, and was therefore not divided or resettled. The increase in forest cover can be explained by the process of natural succession, in which small pieces of forest started to appear along tributaries (Figure 2).

In 1886, in the mid-mountains (the Jaszcze and Jamne catchments) 48% of the catchments were occupied by agricultural land (arable land and grassland) – Figure 2. Arable land occupied 15% of the area and prevailed in the lower and middle parts of the valleys. Almost 52% of the study area was occupied by forest, which usually covered the upper parts of the catchments (here, in contrast to the foothills catchment, forest complexes belong to different owners). The LULC structure has changed significantly since the 19th century. In 2009, arable land decreased from 15% to below 1%, and grassland from 33% to 26%. The consequence of these changes was an increase in forest area – from 52% in 1886 to 72% in 2009.

In the high-mountains (the Chochołowska and Starorobociańska catchments), cadastral maps show only forest and grassland structures. Figure 2 shows a significant increase of the forest – from 38% to 48% and a decrease of the grasslands from 61% to 51% between 1846 and 2009. There is, however, a problem with detailed LULC studies, because the cadastral maps include both mountain pine and natural grasslands in one category. In 2009, mountain pine constituted 21% of the grasslands category, but it is difficult to assess the mountain pine content in the 19th century. The literature reports that in the 19th century grazing led to the destruction of 30% of the mountain pine throughout the Tatra Mts. (Antoniewicz et al. 1959; Mirek 1992). Based on this information we can assume that mountain pine covered only a small part of the catchments studied.

The mean annual rate of change, as explained by the Ann_{ch} index, is a secondary measure which enables an averaged quantitative analysis of LULC changes (Table 1). This index cannot be identified as the average change year-to-year but as a general trend of environmental transformations. According to Muntenau et al. (2014) the change rates between ± 0.1% change/year were defined as stable land use. Higher values denote changes in the LULC structure.

The most significant LULC changes were related to arable land. The largest decrease in this LULC structure occurred in the mid-mountain areas and amounted to −2.28%. Similar relationships, though smaller in scale, can be seen in the foothills and reached −0.45%. Forest content increased in all studied areas. The average increase was comparable in the foothills and mid-mountains, reaching +0.20% and +0.27%, respectively. This increase was slightly lower (+0.12%) in the high-mountains. Changes in grasslands were moderate in the mid- (−0.18%) and high-mountains (−0.09%), unlike the foothills, where a significant increase (+0.51%) was observed.

The significant changes in the distribution of buildings are also worth noting. Despite the fact that this LULC structure covered only a small percentage of the catchment area (Figure 2), the dynamic changes occurred in the analysed time-span (+0.81% in the foothills; +0.74% the mid-mountains).

After determining the scale of changes within the analysed catchments we have indicated the directions of changes (Table 2). In the agricultural landscape of the foothills only 45% of arable lands from the mid-19th century were used in the same way as today. The remaining arable lands are currently used as grasslands (36%) and forests (10%) (Table 2). More significant changes have taken place in the mid-mountains, where only 4% of arable lands from the 19th century have survived to this day. 58% of them are now grasslands and 37% are forests. The main changes in this area are connected with grasslands transformations into forests. In the Jaszcze and Jamne catchments as

Table 1 Land use and land cover (LULC) changes in the research catchments quantified by the mean annual rate of change (Ann_{ch}) (Source: author's elaboration)

Study area (catchment)	Arable lands	Grasslands	Forests	Buildings
	(% per year)			
Foothills (Zalasówka, Pożory)	−0.45	0.51	0.20	0.81
Mid-Mountains (Jamne, Jaszcze)	−2.28	−0.18	0.27	0.74
High Mountains (Chochołowska, Starorobociańska)	-	−0.09	0.12	-

Table 2 Matrix of changes in the land use and land cover (LULC) structure (%) (Source: author's elaboration)

Half of 19 century	Present day					
	Foothills					
	Arable lands	Grasslands		Forests	Buildings	Other
Arable lands	44.6	35.8		9.9	1.3	8.4
Grasslands	8.6	44.7		38.2	0.8	7.7
Forests	0.8	2.2		95.1	0.0	1.9
Buildings	8.9	30.5		8.6	18.5	33.5
	Mid-mountains					
	Arable lands	Grasslands		Forests	Buildings	Other
Arable lands	4.2	58.0		36.7	0.5	0.6
Grasslands	0.7	39.3		58.8	0.5	0.7
Forests	0.1	7.8		91.6	0.1	0.4
Buildings	0.5	58.3		14.9	13.7	12.6
	High mountains					
	-	Grasslands	Dwarf pines	Forests	Buildings	Other
Grasslands	-	33.4	50.2	16.2	0.0	0.2
Forests	-	0.3	1.6	98.1	-	0.0

much as 59% of the 19th century grasslands are overgrown with forest today, 38% in the foothills, and 16% in the high mountains. It is important that in the high mountain cadaster maps the grasslands were classified together with dwarf mountain pine. Today half of the historical grasslands are covered with mountain pine, and both forms of land cover occupy 84% of the 19th century grassland area.

Forests are the most stable form of land cover, over 90% of land covered by forests in the studied catchments had no change. The change in LULC from forests into grasslands in the mid-mountains (8%) is related to deforestation, which occurred after the cadastre was made – at the end of the 19th century (Bucała-Hrabia 2017). According to Bucała-Hrabia (2017) in the first half of the 20th century, the forest covered, reached the lowest area in the history of human activity in the Jaszcze and Jamne catchments. At the foothills, a change of 4% in favor of grasslands is the result of planned forest management and forest road construction (Table 2).

Based on specific directions of land cover changes, we can see that arable land is first transformed into grasslands and then into forest. The scale of these changes is connected with altitude - the changes are more significant in the higher part of the catchment.

Significant changes occurred in the distribution of arable lands, grasslands and forests in the analysed period. What is significant is that these changes in agricultural areas, i.e. foothills and mid-mountains, often had opposite tendencies (Table 3). In the foothills, arable lands are currently closer to the border of the catchment (52 m on average), at the same time moving away from the axis of the valley and river network by about 25-30 m. Also, in the mid-mountains, the average distance of arable lands from the catchment boundary decreased (by 34 m) but, unlike in the foothills, this type of land use is now closer to the bottom of the valley (286 m) and the river network (84 m). In both cases this is associated with the retraction of arable land from the slopes, i.e. areas relatively more inclined and less communicated. In the foothills and the mid-mountains, arable land is now much closer to the centre of the village and closer to the roads, i.e. in the more urbanized area. The average change in the distance from arable lands to the centre of the village in the mid-mountains amounted to nearly 800 m, which proves that today many areas used in this way are home gardens. Areas abandoned by arable land are occupied by grasslands and forests, hence in the mid-mountains they are located statistically closer to the catchment boundary and further away from the other analysed catchment features, and are the most distant from the centre of the village (618 m). In the foothills, the grasslands are closer to the centre of the village (380 m) and the roads and the border of the catchment, but further from the axis of the valley and river networks (i.e. on the slopes). This dependence is the result of selective exclusion from the use of highly dispersed small plots. The situation is similar for forests, which, in turn, have mainly entered the areas covered in the 19th century with grassland, which are neglected today and overgrown with forest in 38% (Table 2). On the other hand, a significant increase in forest cover in the catchment in the mid-mountains resulted in a reduction of the distance between forests and all studied catchment features, with the exception of river networks along which are roads and settlements. A separate issue is the changes in the distribution of the LULC categories in the high mountains. Both grasslands and forestry have only reached the border of the catchment, moving away from the other catchment features analysed. It happened because, after grazing was forbidden in

Table 3 Average distance from polygons of LULC structures in the mid-19th century to the five features of the catchments (and its changes to the present day) (Source: author's elaboration)

Average distance (m) from:	Foothills			Mid-Mountains			High Mountains	
	Arable lands	Grasslands	Forests	Arable lands	Grasslands	Forests	Grasslands	Forests
Catchment border	364 (+52)	387 (+70)	344(+15)	464(+34)	392(+38)	442(+7)	689(+129)	882(+166)
Valley axis	461 (–25)	369(–67)	369(–12)	462(+286)	476(–38)	533(+45)	356(–170)	50(–325)
Streams	173 (–31)	138(–45)	136(–28)	201(+84)	194(–21)	209(–23)	169(–3)	30(–130)
Village centre	2119(+158)	2037(+168)	2045(–30)	2649(+785)	2572(–618)	3602(+689)	9260(–423)	9307(–197)
Main/secondary roads	517 (+342)	528(+380)	489(+285)	410(+278)	462(–32)	695(+341)	564(–179)	176(–361)

+ *(plus)* nearer, – *(minus)* further.

the mid-20th century and a national park was established in 1954, re-naturalization took place. The forest returned to its natural upper limit, i.e. areas covered with grass in the mid-19th century.

The changes that have occurred in the distribution of particular types of LULC with respect to the catchment features suggest a significant role of slopes and elevation above sea level. Therefore, in the next step, the changes in the structure of LULC resulting from elevation and slope gradient were checked.

3.2 Changes in the LULC structure versus elevation and slope gradient

The relationship between LULC, elevation (m a.s.l.) and slope gradient (degrees) is presented in Figure 3. At the foothill catchments, areas located up to 400 m a.s.l. were generally covered by arable land and grassland both in 1848 and 2009. The temporal changes in these LULC structures, were more noticeable in grassland (locally also small forested areas), and are related to the abandonment of arable lands by farmers. Areas located above 400 m a.s.l were covered by forest, and the higher content in this LULC category is connected with the fact, that large forest complex covers a local ridge in the Pożory catchment.

The relationship between LULC structures and slope gradient in relation to forest content revealed a general rule – the higher the slope gradient, the greater the increase in forest cover (Figure 3). Flat floodplains and gentle slopes (up to 5°) were generally covered by grasslands and arable lands (valley bottoms), and this relationship is typical for mountain areas. The general tendency in LULC changes in the range up to 400 m a.s.l. – this deserves a special emphasis. There is a proportionate decrease in arable land and increase in other types of LULC (grassland, forests) regardless of slope gradient.

Significant changes have also occurred in the

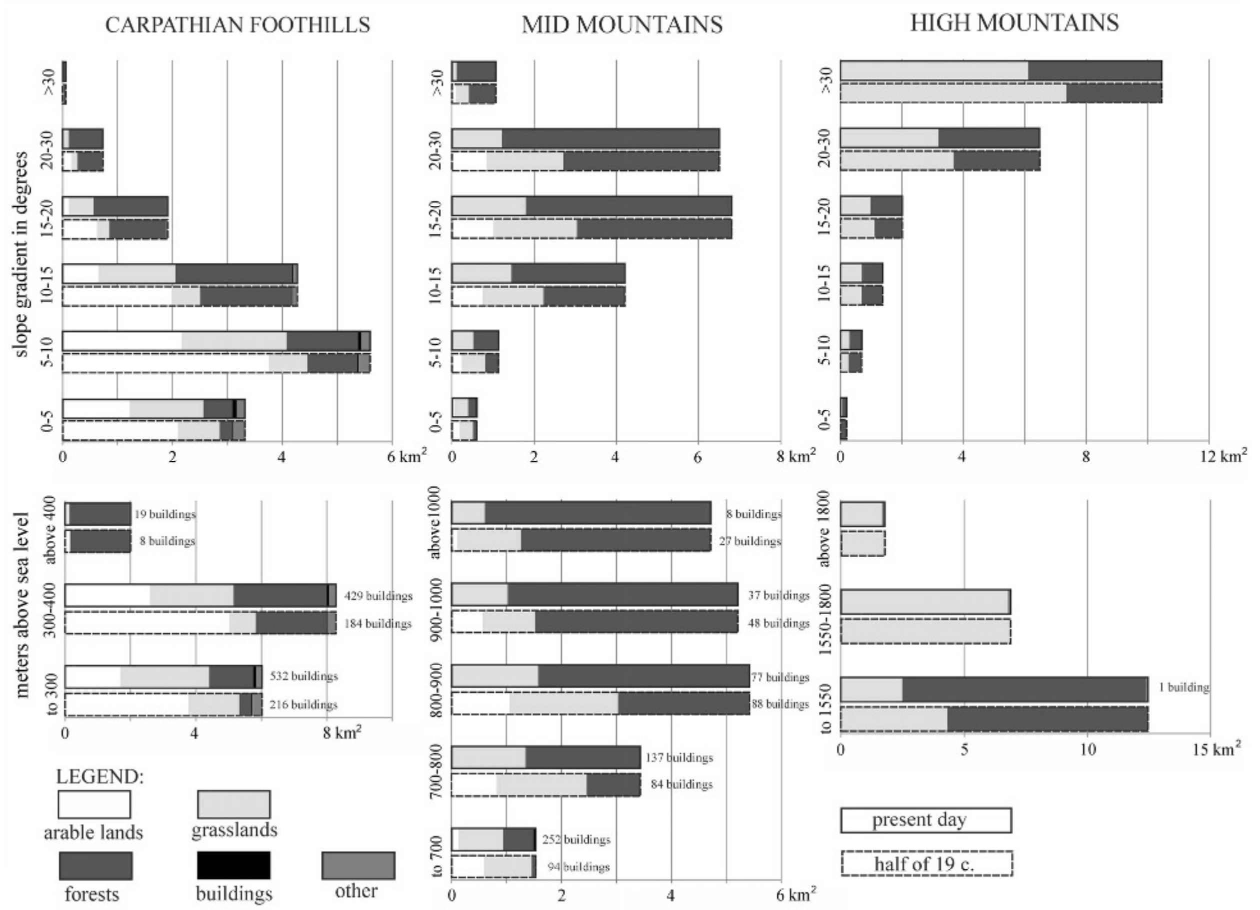

Figure 3 Land use and land cover (LULC) structures in the research catchments versus elevation and slope gradient in the 19th and 21st centuries.

Table 4 Changes in the building distribution in the studied catchments in the 1st half of 19 century and present (Source: author's elaboration)

	Foothills		Mid-Mountains		High Mountains
	1st half of 19 c.	Present day	1st half of 19 c.	Present day	
Number of buildings	408	980	341	514	Area without settlements
Minimum elevation (m a.s.l.)	239	239	605	605	
Maximum elevation (m a.s.l.)	483	480	1155	1060	
Slope aspect of buildings location (%)	N9, NE13, E14, SE19, S17, SW16, W8, NW4	N7, NE16, E21, SE19, S14, SW14, W6, NW3	N6, NE12, E14, SE19, S17, SW21, W7, NW4	N1, NE8, E17, SE16, S27, SW24, W6, NW1	
Average:					
Altitude (m a.s.l.)	304	301	802	730	
Slope degree (°) *	7.8	6.3	14.7	13.1	
Distance from the catchment border (m)	393	341	452	517	
Distance from the valleys axis(m)	311	381	390	299	
Distance from the streams (m)	145	175	153	135	
Distance from the village center (m)	1884	1742	2627	2210	
Distance from main/secondary roads (m)	502	130	334	236	

*) calculated based on rectangular 50 m buffer.

mid-mountain catchments. In 1886, arable land and grassland dominated in areas with an elevation lower than 900 m a.s.l. Higher elevations were generally covered by forest (>70%), and arable land content was lower than 11%. In 2009 a significant increase in forest cover occurred regardless of elevation. Arable land disappeared almost completely above 800 and 900 m a.s.l., resulting in a shift of the upper boundary of arable land by about 200 m down the hillslopes. Forest cover above 900 m a.s.l. reached 87% (the remaining parts are natural grasslands). Significant shifts occurred in the spatial distribution of arable land, which in 2009 was located on the valley bottoms and dominated mainly on the slopes up to 5° (near the buildings). The largest decrease in arable land (in %) occurred on slopes steeper than 10°. Slopes above 10° were mostly covered by forest.

In the high-mountains, methodological difficulties hampered a detailed historical analysis in areas above 1550 m a.s.l. There are no changes in the grasslands category between 1846 and 2009. In 1846, 65% of areas up to 1550 m a.s.l. were covered by forests, the rest (35%) were covered by natural grasslands and mountain pine combined into a single grasslands category. In 2009, forests occupied 80%, the remaining 20% constituted natural grasslands without mountain pine, as the upper boundary of the timberline is located between 1500-1550 m a.s.l. The LULC structure changes slightly on hillslopes with a slope gradient up to 15°, with a successive increase in forest cover on steeper slopes.

3.3 Changes in building distribution

Temporal and spatial analysis of buildings distribution is rarely presented in the literature, but can be a valuable indicator in LULC change analyses. Out of the three analysed regions, only two have a settlement network and in both cases the number of buildings (including: residential and farming buildings) in the analysed time interval increased (Table 4). In the foothills, this increase was 140% (from 408 in the mid-19th century) and 50% (from 341 in the mid-19th century) in the mid-mountains. In the studied high-mountain catchments, there is only one building. On the Chochołowska Polana clearing there is one shelter, built in 1932, and some sheds which were built when intensive sheep grazing was allowed – they are now considered protected historical buildings.

In both regional catchments, the lower settlement elevation did not change, but the upper elevation in the mid-mountains decreased by nearly 100 meters. This trend is confirmed by the average altitude for all buildings. In the mid-mountains, this value decreased by 70 meters while in the foothills, it remained unchanged. In both regions, it is clearly visible that settlements move to areas with lower inclinations, but there is no significant location preferences in respect to the slope direction. An important factor in determining the development of the settlement network is the distance from roads. We checked how the distance from the main (regional) and secondary (local) roads changed. In both regions, the settlements have approached both the main and secondary roads, much more in the foothills. An important reason for this change, in the foothills, is that in the middle of the 19th century the main roads were mainly located on ridges and now the roads are in the bottoms of the valleys. Therefore the average distance from a house to the centre of the village, in which the house is administratively located, is a more reliable indicator. Both in the foothills and in the mid-mountains, the settlements are approaching the village centre, although the clearest trend is seen in the second case. While the centre of the village is subject to administrative changes, the distance from the border of the catchment (tops and ridges), river networks and the axis of the valley (i.e. the bottom of the main river) are purely natural conditions. In the foothills, the settlement clearly moves away from the axis of the valley and the rivers, approaching the border of the catchment (top, ridge). In the mid-19th century, major communication routes were located on the catchment boundaries, but a significant distance from rivers excluded the settlement. Nowadays, easier access to the infrastructure (water, electricity, gas, etc.) has led to the development of settlement areas on the hilltops. An important current factor determining the development of settlement on the tops is the fact that they are very visually attractive areas. A reverse tendency was recorded in the mid-mountains, where the settlements are clearly redistributed closer to the axis of the valleys (main/secondary roads), closer to the rivers, at the same time moving away from the tops, which in this region are practically without infrastructure. Agriculture including pastoralism in the mid-mountains (which until the mid-20th century was one of the main sources of income for locals) had a significant impact. In the 19th century, the total number of buildings (including residential and farming buildings) was 341. In up to half of 20th century, permanent settlement occurred mostly in the lower parts of the valley, whereas shepherd's shacks and huts (that only served as farming buildings during the grazing period) were located higher on the hillslopes. Currently, historical pastoral buildings are no longer functioning and are very often demolished.

3.4 LULC changes and their records in a mountain environment

Field studies were carried out in all 6 catchments, during which all roads were inventoried and agricultural terraces were identified. Our fieldwork revealed that changes in the LULC structures are predominantly reflected in the geomorphological transformation of hillslopes. The geomorphological transformations predominantly include the development of a dense network of unpaved roads and the development of agricultural terraces (Table 5, Figures 4-5). The unpaved road network system, developed in the 19th century, triggered the geomorphological transformation of hillslopes leading to the development of deep road cuts and gorges, finally resulting in the fragmentation of hillslopes (Figure 5). These landforms, which indirectly resulted from LULC changes, are well preserved in the mountain environment today. We have determined that many roads that cut into hillslopes were abandoned (Table 5, Figure 5). Preserved road cuts of ancient old major routes in the foothills can be up to 4 m deep, and more than 2 m deep in the mid-mountains. In the Jaszcze and Jamne catchments the total length of abandoned road cuts reaches approx. 10.2 km, giving a density of 0.5 km·km^{-2}. A similar density was noted in the foothills.

Table 5 Road network and agricultural terrace densities, resulting from land use and land cover changes between the 19th and 21st centuries (Source: author's elaboration)

	Foothills		Mid-Mountains		High Mountains	
	1848	2009	1886	2009	1846	2009
Road density (km·km^{-2})	8.2	8.4	1.75	6.7	0.3	2.5
Abandoned cut roads density (km·km^{-2})	0.2*	0.5	No data	0.5	No data	0.0
Agricultural terrace density (km·km^{-2})	No data	0.8	No data	0.3	No data	0.0

*) estimated value based on the cadastral map view, Source: this study.

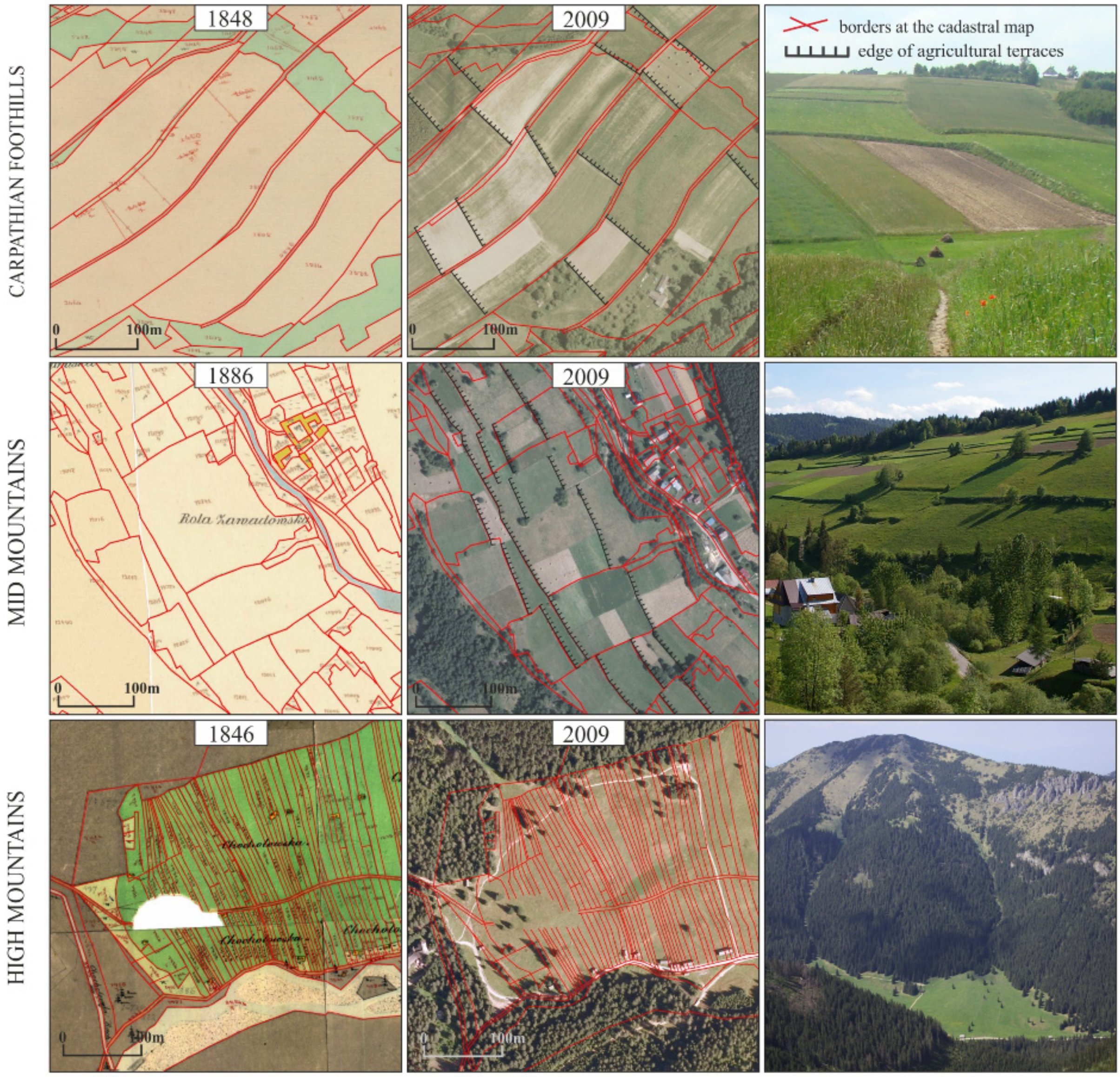

Figure 4 Present-day agricultural terraces in the background of historical field borders (foothills, mid-mountains) and historical pasture borders in high-mountains.

Apart from roads, agricultural terraces are the most visible geomorphological forms of LULC structure alteration (Figure 4). They are situated crosswise to the slope gradient, and they modify slope geometry.

The terraces are very well preserved, especially in the foothills, and their density reaches up to 0.8 km·km^{-2}. The elevation of agricultural terraces is usually up to 2 m in the foothills, but in the mid-mountains elevation is between 0.5 and 2 m. Despite a large fragmentation of plots in area in the 19th century, agricultural terraces were not identified in the high-mountains catchment. There are, however, numerous micro terraces, which are connected with pastoralism but not the boundaries of plots/owners.

4 Discussion

4.1 LULC structure – changes and driving factors

Changes in the LULC in the Carpathians result from environmental (e.g. elevation n, slope gradient, soil type) and human-related conditions including: a) institutional (e.g. national and regional policy, political systems, institutional changes), b)

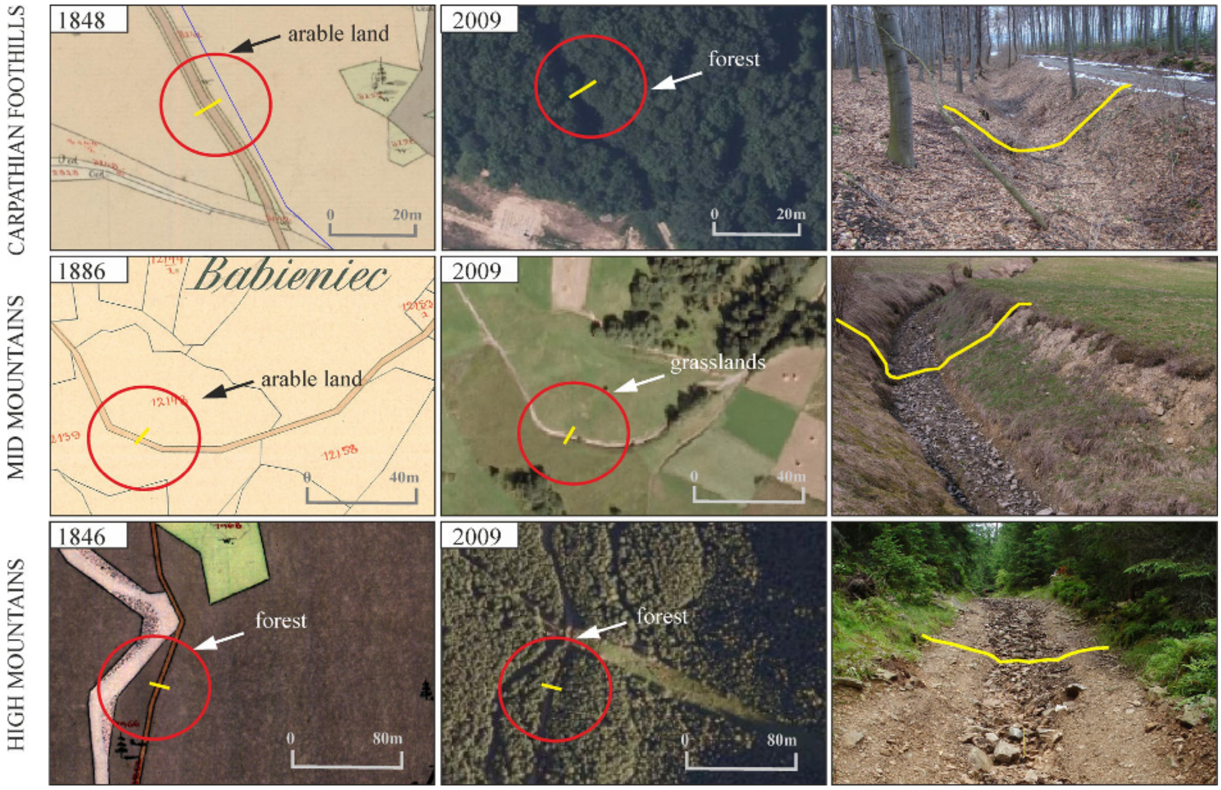

Figure 5 Land use and land cover (LULC) structure preserved in the mountain environment based on changes on the unpaved roads.

economic (e.g. market access and commercialization, urbanization and industrialization, technical development and innovations) and c) socio-demographic changes (e.g. colonization, migrations and displacement) (Kozak et. al. 2007; Munteanu et al. 2014; Bičík et al. 2015; Cabral and Costa 2017; Xystrakis et al. 2017). In the areas studied, the formation of the LULC structure was preceded by a long period of deforestation that was accelerated by a rapid population growth in the 19th century in the foothills and mid-mountains (Soja 2008; Bucała-Hrabia 2017), and the development of ore mining and grazing in the high-mountains (Podolak 1982). In the foothills, favourable conditions for agricultural development meant that deforestation began as soon as the area was first settled in the 14th century (Solarz 2016) and peaked during the early 19th century (Kroczak 2010). The mid-mountains (the Gorce Mts.) were first settled by Wallachian shepherds at the turn of the 14th and 15th centuries. This gave rise to permanent settlement and deforestation of this part of the Polish Carpathians (Bucała et al. 2014). Cadastral maps, which show the spatial distribution of the LULC structure in the 19th century, indicate that agricultural land (arable land and grasslands) covered a significant part of the catchments located in the foothills (>55%) and mid-mountains (>48%) catchments. It can be concluded that the scarcity of land available for use, which resulted in the overpopulation of these areas, was one of the main driving factors contributing to the LULC structure formation in the first half of 19th century. Until World War II (WWII) agriculture was the main source of income for up to 98% of the residents of the Jaszcze and Jamne catchments. In the absence of other sources of income (outside agriculture), there was a close relationship between the population increase and deforestation even in the first half of the 20th century (Bucała-Hrabia 2017). The low contribution of forest area was noted in many regions of the Polish Carpathians at that time. For example, in Orava and the Pieniny regions located on the border with Slovakia, forest cover reached the lowest contribution of 36% and 23% in 1931 and 1936 respectively (Kozak 2003; Kaim 2009). As a consequence of WWII, the eastern part of the Polish Carpathians experienced population displacement in 1947 (Soja 2008) and then rapid

LULC changes, in contrast to study areas located in the western part of the Polish Carpathians. At the end of WWII, with the establishment of a centrally planned socialist economy agriculture was still the main source of income in the studied mid-mountains and this was result of the peripheral location of large urban centres and weakly developed communications networks. The foothills present the opposite situation, where, under a centrally planned economy, a gradual transition from agriculture to heavy industry was observed.

The fall of the Iron Curtain in 1989 caused reforms in farming sectors, individualised land use and privatised farmland (Kuemmerle et al. 2008). The lack of agricultural subsidies and the corresponding decreasing profitability led to the bankruptcy of most agricultural enterprises (Müller et al. 2013). This transition from a centrally planned system to a free-market economy brought the development of other than agricultural activities (e.g., construction, services, agritourism). As a result of these changes, most residents in the studied foothills and mid-mountains sought employment outside agriculture. For this reason, less than half (45%) of the arable lands from the mid-19th century survived in the foothills, and only 4% in the mid-mountains (c.f. Table 2). Arable lands have largely been converted to grasslands and forest areas have increased, which is a process of natural succession. The decline of arable lands, (especially in the foothills) regardless of good or bad conditions for agricultural development (evaluated here by slope gradient, elevation), suggests that the influence of natural factors on LULC changes is nowadays less significant than the human-related factor.

The clear withdrawal of agriculture does not mean a reduction in the number of buildings. The withdrawal of the population from agriculture did not cause a mass depopulation. Nowadays, there are more buildings in both the foothills and the mid-mountains, and the larger increase in their number in the foothills can be associated with the proximity of industrial centres (Tarnów, Dębica). During our field studies, we confirmed that the vast majority of the inhabitants of the foothills are descendants of the former inhabitants of this region and that the overwhelming majority of existing homes are occupied throughout the year (we estimate over 95%). Due to the attractive region for tourists that is the Gorce Mts. (Jaszcze and Jamne catchments), the construction of holiday houses took place alongside the permanent rural houses. Also, many old houses are now being purchased by city dwellers as second residences. About 20% of existing buildings are occupied, mainly in the summer (Bucała 2014).

Contemporary settlement has moved to more convenient areas, i.e. with a smaller inclination and closer to the centre of the village. Today, houses are usually concentrated along major roads, which in the mid-mountains are located only within the valleys, whereas in the foothills both within valleys and on hilltops. This leads to an increase in the average distance between buildings and the rivers and axis of the catchment (consequently decreasing the distance between the buildings and the border of the catchment). Today, in the mid-mountains, buildings are located on average 70 m lower (changes weren't noted in the foothills), while the upper limit of arable land decreased by as much as 200 meters.

In the high mountains (the Tatra Mts.), the results of intense human activity can be observed from the 18th century to the first half of the 20th century. While ore mining had a moderate impact on changes in the environment (significant only in certain locations), the process of iron smelting required large quantities of wood. This led to massive deforestation which was reflected in the LULC structure. Intensive sheep grazing also caused the transition of large areas of natural forests to grasslands (Kolowca 1957). The ore mining ended in 1876 and grazing was prohibited in the mid-20th century (Mirek 1992), which made the natural succession of forest complexes possible. This is reflected in the increase in forest cover evident today in the LULC structure, which nowadays tends to be preserved in the Tatra National Park.

4.2 LULC change and its influence on the transformation and functioning of a mountain environment

The influence of the LULC structure on the environment has frequently been discussed in literature and general rules relating to water chemistry, geomorphological changes, soil properties and vegetation (e.g. Benjamin et al.

2005; Nunes et al. 2011; Bucała et al. 2015; Wiejaczka et al. 2017; Holthusen et al. 2018). One of the most important dependencies is the relationship between the changes in the LULC and runoff formations. Changes in land use in the catchment cause a number of processes in river beds. In the Carpathians, these processes are particularly noticeable in the mountains, where grasslands and forests entering abandoned arable land stabilize the slopes and limit the supply of sediments to rivers (Korpak 2007; Zawiejska et al. 2015). This is also confirmed by observations in the Carpathian permanently controlled catchment of the Jasiołka River (513 km^2), which in the upper part flows through the mid-mountains and in the lower part flows by the foothills (Ortyl et al. 2018). Just after the WWII, at the upper part (mid-mountains) of this catchment, the area covered by arable land decreased, as a result of depopulation (from 45% in 1938 to 24% in 1975 and 19% in 2000). In the abandoned arable lands were replaced by grasslands, shrubs and finally forests. In the foothills part, the changes were analogous, but on a smaller scale (arable lands decreased from 55% in 1938 to 45% in 1975 and 43% in 2000). The response in the river flow to the changes in land use (in the mid-mountains part of the catchment) was visible almost immediately: a decrease in the mean water level. These changes resulted in the river channel deepening. This incision of river into the substrate was correlated with an increase in grassland, shrub areas and paved roads. In the mouth of the river closing the foothills and the mid-mountains parts of the catchment, these processes occurred over a different period of time. The river incision was not so intensive and ended nearly 30 years later (Ortyl et. al. 2018). Changes in water level were also observed in another mid-mountain Carpathians catchment (the Ochotnica river). The average rate of incision was 3.2 cm year^{-1} in the period characterized by a rapid decrease of arable land (Kijowska-Strugała, Bucała-Hrabia 2019). Other research conducted by Boongaling et al. (2018) showed a strong relationship between LULC changes and the intensity of hydrologic processes. Furthermore changes in the LULC in small catchments have an important role in relation to soil erosion (Kijowska-Strugała, Demczuk 2015) and their boundary conditions in flash flood context (Hegedüs et al. 2013).

Abandonment of agricultural land and forest expansion are correlated with elevation and slope gradients, which was identified, similarly to our research, among others in the Swiss mountains (Gellrich et al. 2007) and in the mountain areas of Greece (Xystrakis et al. 2017). Areas at high altitudes and on steeper slopes are more prone to abandonment followed by forest succession.

LULC changes in the study areas caused progressive fragmentation and dispersion of agricultural land (arable land, grassland). The main reason for this was constant overpopulation in the Polish Carpathians, which resulted in the division of the land between successive owners (descendants). Cadastral maps of the foothills (the Zalasówka and Pożory catchments) show 1350 arable fields with a total area of 1110 ha, yielding individual plots of on average 0.8 ha. In 2009, an individual arable plot was about 0.3 ha. Since each agricultural plot had to be accessible for agricultural work a dense road network was developed. It is worth noting that the unpaved road network density in the mountain areas is among the highest in the world (Kroczak et al. 2016) and several times higher than the density of the natural valley system, which is estimated at 3.5 km·km^{-2} (Soja 2002). This fact has a significant impact on the hydrological response of a catchment. An analysis of the influence of the road network on the hydrological response of the Zalasówka catchment (Kroczak and Bryndal 2015) reveals that road networks contribute to flood wave parameters, resulting in a maximum flow increase of approx. 15%, predisposing them to flash flood formation (Bryndal 2014). Currently, the decline of agriculture has resulted in successive abandonment of sections of roads. However, we observed that approx. 70% of the roads are still being transformed, especially during rainstorms, when a road may be deepened up to several tens of centimeters during one event. In this way, the roads are one of the main sources of suspended material, and may contribute up to 70% of the mean total annual suspended load (Froehlich and Walling 1997). For example, in the Pyrenees, this value is several times lower and amounts to 10% (Batalla et al. 1995), but in the Winooski River catchment (USA) 53% of the road network is hydrologically integrated with streams and the unpaved roads contribute up to 31% of the annual suspended sediment load (Wemple et al. 2017). Similarly, in the Carpathian catchments, the dense unpaved road system, which resulted from LULC alterations during the 19th century, has a negative impact on the environment, because it accelerates water circulation in catchments and makes them prone to flash flood formation.

Apart from roads, agricultural terraces are the most visible geomorphological forms of the LULC structure changes. It should be emphasized that agricultural terraces are preserved in the landscape for many years. An analysis of cadastral maps reveals that in the mid-mountains (the Jaszcze and Jamne catchments) almost 50% of all observed agricultural terraces were developed before the mid-19th century. In the foothills study area, most terraces were created after 1848. The agricultural terraces function as a local base for denudation processes and in the Carpathians may accumulate up to 40% of the mineral material washed out from the slope surface (Gerlach 1966). In this context, these landforms are currently desirable, because they reduce surface erosion on hillslopes in mountain environments. The LULC structure changes recorded in the high mountain environment of the Tatra Mts. differ somewhat from the foothills and mid-mountains. Exploration of the study area, particularly from the beginning of 19th century to the first half of the 20th century, led to large-scale deforestation connected, among others, with sheep grazing (Mirek 1992). The results of grazing are most visible in the numerous micro terraces, especially on clearings on steep slopes.

5 Conclusion

Knowledge of LULC changes and the driving factors that affect these changes is fundamental to understanding the present, and predicting the directions of changes in the LULC structure that will be expected in the three main regions of the Carpathians. The main results of our study can be concluded as follows:

1. There was an overall increase in forest, and a decrease in arable lands in all areas analysed. The changes in forest cover, quantified by an annual change index (Ann_{ch}), amounted: +0.20% (foothills), +0.27% (mid-mountains) and +0.12% (high-mountains). For arable land the index reached: −0.45% (foothills) and −2.28% (mid-mountains). We anticipate that similar trends in LULC changes are expected in the future. Changes in the LULC structure, detected in this study, are favourable, taking into account the functioning of the mountain environment e.g. the natural succession of primary vegetation (renaturalization), reduction of soil erosion, increases in small retention etc.

2. The scarcity of land available for settlement, which resulted in the overpopulation of these areas, was one of the main driving factors contributing to the LULC structure formation in the 19th century. Since that time, changes in the LULC are the results of a combination of many man-related factors, which include and socio- economic changes. A decrease in arable land, regardless of natural conditions for agricultural development, indicates that natural factors (slope gradient, elevation) are less important than the human-related ones. This dependence has been clearly demonstrated, especially in the foothills

3. Our study also focused on the changes in the settlement areas, which are rarely analysed in literature focusing on historical analyses of the LULC structure. There was a significant increase in the number of buildings, both in the foothills and in the mid-mountains study areas, as well as significant changes related to their spatial distribution. Today, settlements in the foothill areas are located on hilltops and gentle hillslopes. In the mid-mountains the number of farming buildings related to pastoralism has fallen and settlement areas are located lower, along streams in valley bottoms and on terrain with the lowest inclination. In the immediate neighborhood of modern settlement in the bottom of the valley about 4% of arable lands is preserved as home gardens. Both, in foothills and mid-mountains, currently houses are located closer to the village centre and main roads.

4. Changes in LULC structures are well preserved in a mountain environment. The LULC changes are reflected in the geomorphological transformation of hillslopes, which predominantly includes the development of a dense network of unpaved roads, their transformation to road cuts and gorges and the fragmentation of hillslopes, as well as the development of agricultural terraces.

These geomorphological forms, mainly resulting from the fragmentation of the agricultural area, affect the functioning of the environment in the present.

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