

LAND-USE CHANGES AND THEIR IMPACT ON LAND DEGRADATION IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT OF THE POLISH WESTERN CARPATHIANS DURING THE TRANSITION TO FREE-MARKET ECONOMICS (1986-2019)

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Abstract

The objective of this study was to analyse land use and land cover in three catchments of the Polish Western Carpathians, using good practice guidance for estimating land degradation in the context of the United Nations' Sustainable Development Goals. Orthophotomap analysis indicates that the vast majority of changes, especially those related to the withdrawal of agriculture, have resulted in land improvement. Relatively minor changes leading to land degradation were associated with pressure from increasing population due to settlement development as well as the conversion of forested areas into grassland. The latter was dominant in the higher mountain catchments.

Key words

SDG Indicator 15.3.1 • sustainable development • land degradation • land use • Polish Carpathians

Introduction

The transformation of socio-economic systems has caused intensive changes in the physical environment, whose evolution was, for most of the Earth's history, conditioned by natural factors such as climate, geology, relief, soils and vegetation (Bellwood, 2005; Petraglia & Allchin, 2007). Regardless of the type and duration of human activity in the physical

environment, anthropogenic impacts usually first appear in the form of changes in land use and land cover (LULC) (Geist & Lambin, 2002; Rączkowska et al., 2018; Davidar et al., 2010). In particular, vegetation changes may generate landscape fragmentation (Bennett & Saunders, 2010), soil erosion on slopes (Zorn & Komac, 2009) and affect river flows (Lasanta-Martínez et al., 2015). These processes influence forest stands, as well

as biomass and carbon sequestration in soils (Guo & Gifford, 2002; Gellrich et al., 2007), with significant climate impacts (Bonan, 2008; Brahma et al., 2018).

In Central Europe, population increases have led to the expansion of agricultural land and forced farmers to move to higher parts of the mountains (Soja, 2008). Extensive deforestation for agriculture purposes has caused land degradation; in particular, soil erosion increased drastically between the second half of the 18th and 19th century when root crops were introduced (Klimek, 1987; Dotterweich, 2008).

During the 20th century, the progressive abandonment of cropland has occurred across most of Central Europe following intensive urbanisation and industrialisation (Skokanowa et al., 2016; Kupková et al., 2021). In addition, low soil productivity, unfavourable climatic conditions, steep slopes and high elevations are the main natural constraints to agriculture in mountainous areas; these factors could, therefore, increase the risk of farmland abandonment (Gellrich et al., 2007; Pointereau et al., 2008; Baumann et al., 2011).

Since 1989, the transformation from a communist system to a free-market economy has decreased the profitability of agricultural production in Central and Eastern European countries (Kanińska et al., 2014; Munteanu et al., 2014). The effects of economic changes are clearly visible in the Polish Western Carpathians, where LULC changes have probably occurred fastest in the last 200 years, with most cropland transformed into grassland and forest (Kaim et al., 2016; Kolečka et al., 2017). However, in contrast to mountainous areas in other countries, the cessation of traditional farming and increased forest cover in the Polish Western Carpathians have been accompanied by a general increase in population density (Soja, 2008).

Analysis of vegetation cover dynamics is commonly applied in LULC studies and is often used as a proxy for land degradation (Metternicht et al., 2010; Easdale

et al., 2019; Kertesz & Křeček, 2019; Prokop, 2020). In the Polish Carpathians, Kędra and Szczepanek (2019) analysed the direction and magnitude of LULC changes since 1990 to determine the current status of land degradation and future degradation risk. Their study found that in mountainous regions, there is a need to apply sustainable management practices that can avoid or reduce degradation in the involved catchments due to the effects of ongoing intensive urbanization. Ćwik and Hrehorowicz-Gaber (2021) demonstrated that mountainous rural areas are vulnerable to inappropriate land management, especially due to poorly planned and unstructured increases in buildings, which is incompatible with the concept of sustainable development.

LULC changes and class trends are one of the measures (sub-indicators) of indicator 15.3.1. required for the implementation of the United Nations' Sustainable Development Goals (SDGs) (Sims et al., 2017, 2019). SDG indicator 15.3.1 is defined as the proportion of land that is degraded over the total land area. SDG 15 aims 'to protect, restore and promote sustainable use of terrestrial ecosystems, to sustainably manage forests and combat desertification, as well as to halt and reverse land degradation and halt biodiversity loss' (United Nations, 2022).

The objective of this study was to analyse LULC changes in the context of land degradation and SDGs in three catchments in the central part of the Polish Western Carpathians from 1986 to 2019. The investigated period covers the transition from centrally planned to free-market economics after the collapse of communism in 1989. More specifically, this study aimed to: (i) analyse general spatio-temporal LULC changes in two sub-periods: 1986-2003(04) and 2003(04)-2019 (i.e. before and after the accession of Poland to the European Union in 2004), and (ii) recognise whether LULC changes have led to the improvement, stabilisation or further degradation of the land in the context of the SDGs.

Materials and methods

Study area

The three catchments analysed in this study are located in the Polish Western Carpathians: the Uswicza (22.7 km²) in the Wiśnickie foothills, the Homerka (19.3 km²) in the Beskid Sądecki mountains and the Jaszcze-Jamne (20.3 km²) in the Gorce mountains (Fig. 1). The study area is underlain by flysch sediments. The Uswicza catchment is dominated by gentle topography, with broad hills rising mainly to 300-500 m a.s.l. (Starkel, 1972). Only 21% of slopes in the area are classified as steep, i.e. above 15°. The lower part of the Homerka catchment is characterised by foothill topography with ridges up to 600 m a.s.l. The main landforms of the upper Homerka and Jaszcze-Jamne catchments are rounded ridges (1,000-1,250 m a.s.l.) built of resistant sandstone and deep, narrow V-shaped valleys (Niedziałkowska, 1981). In these catchments, about 71% of slopes are steeper than 15°.

The whole Uswicza catchment is situated in the temperate warm zone, with a mean annual temperature of 6-8°C at elevations of up to 600-650 m a.s.l. (Hess, 1965). The mean annual precipitation was 750 mm between 1996 and 2015. The Homerka catchment is situated in the temperate warm zone at heights of up to 650 m a.s.l. and the temperate cold zone (4-6 °C) above this elevation. In the Homerka catchment, the mean annual precipitation was around 960 mm in the period 1971-2011. The lower part of the Jaszcze-Jamne catchment is situated in the temperate cold zone between 650 and 1,100 m a.s.l., while the upper part of the catchment occupies the cold zone (2-4°C). The mean annual precipitation was 840 mm between 1971 and 2011.

In the Uswicza catchment, loess-like silt deposits support the formation of Luvisols, while Cambisols occur in the Homerka and Jaszcze-Jamne catchments (IUSS Working Group WRB, 2015). The foothill zone mainly comprises deciduous forests, while the lower

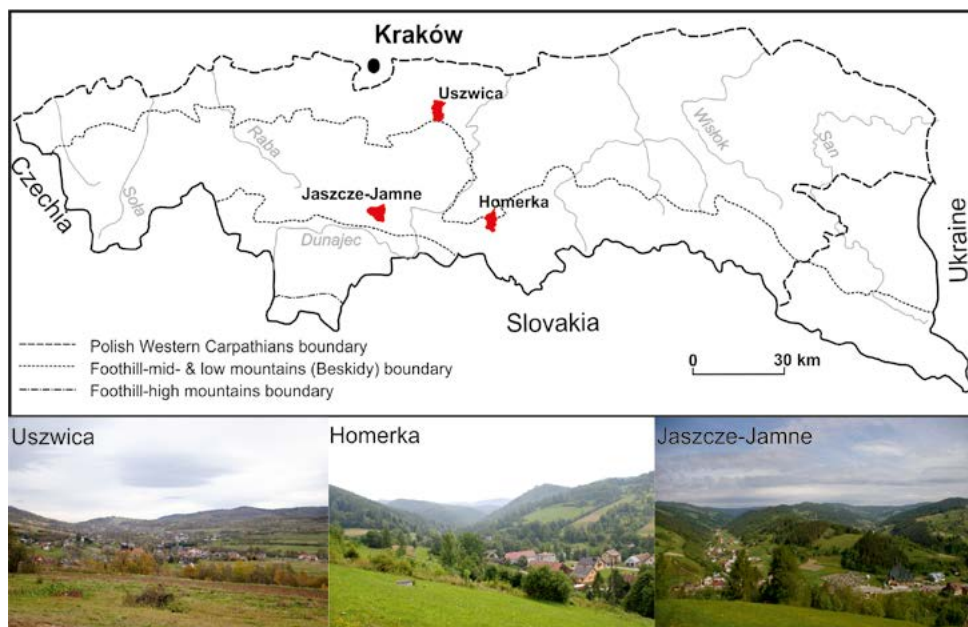


Figure 1. Location of the three catchments in the Polish Carpathians

Source: author's elaboration based on Starkel (1972)

mountain zone is covered by mixed forests. Coniferous forest is found at elevations above 1,100 m a.s.l. (i.e. only the highest part of the Jaszcz-Jamne catchment) (Grodzińska & Szarek-Łukaszewska, 1997).

The Uszwica catchment, in the foothills of the Polish Carpathians, was more deforested before the 1980s compared to mountainous areas of the Homerka and Jaszcz-Jamne catchments; the higher proportion of cultivated land in the Uszwica catchment is due to the area's favourable natural conditions, such as a benign climate, gentle topography and fertile soils. In 2019, the population density values were 113, 81 and 24 people per km² in the Uszwica, Homerka and Jaszcz-Jamne catchments, respectively.

Database development and analysis

In this study, changes in LULC were determined from aerial photographs at scales of 1:25,000 for 1986-1987, as well as orthophotomaps at scales of 1:5,000-1:13,000 for 2003-2004 and 2019, which were obtained from the Centre for Geodetic and Cartographic Documentation in Poland. Manual vectorisation was conducted in detail at a scale of ~1:2,000 using GIS software. The resulting vector data were then rasterised at a 5 m spatial resolution. Four LULC categories were defined: forest, grassland (meadow and pasture), cropland (arable land) and settlements (built-up areas), following the Good Practice Guidance for SDGs Indicator 15.3.1 (Sims et al., 2017, 2019). In this approach, the LULC data is divided into six classes: forest, grassland, cropland, wetlands, settlements and other land. However, the wetlands and other land classes were not identified in the study area and were thus excluded from the study.

SDG indicator 15.3.1 was applied to evaluate whether a given area remained in the same LULC type or changed over the studied period. The resulting map and matrix represented a three-class LULC change indicator, involving degradation, improvement and neutral or no change in the context of sustainable development. Degradation is interpreted

as the transformation of forest areas into any other LULC class, conversion of grassland and cropland into settlements as well as conversion of cropland into grassland (Sims et al., 2017). Expansion of forest through natural succession or afforestation and withdrawal of settlements indicated improvement, while areas with the same land use in two intervals are treated as stable with no change. However, the final interpretation should always be based on local knowledge of the conditions in the study area. Therefore, in the case of mountain areas with steep slopes, such as the Polish Carpathians, conversion of cropland into grassland was treated in this study as an improvement in land quality due to the reduction of soil erosion.

Results

LULC dynamics in 1986-2019

In general, an increase in forest cover was observed throughout the whole period, in parallel with a rapid decrease in cropland in all three catchments (Fig. 2, Tab. 1). The annual rate of increase of the forest area was up to 0.87%, while the annual rate of cropland decrease reached almost 14%. These changes were accompanied by a marked increase in settlement area, with an annual growth rate of up to 4.17%. Complex changes were observed in the grasslands due to their decrease parallel to increases in forest area, or their increase due to cropland abandonment – these LULC changes, however, were uneven in space and time.

In the early years of the first sub-period (1986(87)-2003(04)), forests dominated the upper part of the Uszwica catchment, as well as the middle and upper parts of the Homerka and Jaszcz-Jamne catchments, respectively (Fig. 2, Tab. 1). Cropland occurred in the lower parts of each catchment, however, isolated arable fields reached even their upper parts. Settlements were concentrated along the main watercourses in the middle and lower parts of all three catchments, with single buildings also present in the upper part of the Jaszcz-Jamne catchment. In this sub-period,

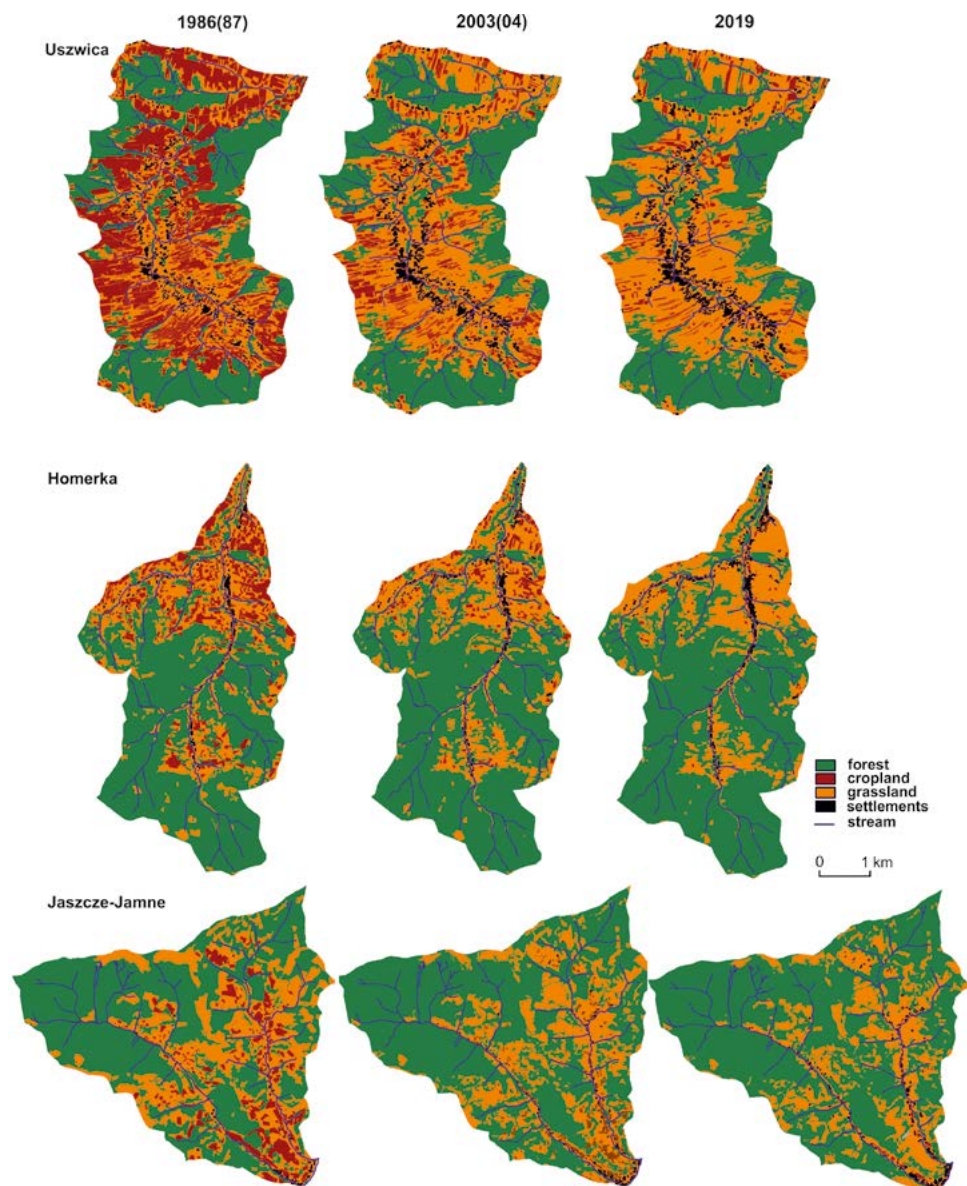


Figure 2. Spatial distribution of LULC in the Uswica, Homerka and Jaszcz-Jamne catchments for the periods 1986(87), 2003(04) and 2019

the most significant changes in the LULC classes were recorded in the foothill Uswica catchment.

In the second sub-period (2003(04)-2019), the fastest increase of forest area was continued in the Uswica catchment located in the foothills (Fig. 2, Tab. 1). In contrast, in both

mountainous catchments, cropland decreases and settlement increases were faster than those in foothills, and also faster than those recorded in the previous sub-period. In effect, in 2019, the area of forest glades was reduced in the upper parts of the catchments, with grassland areas decreasing at the expense

Table 1. LULC and the average annual rate of change in three catchments (1986(87)– 2019)

LULC [%]				Annual rate of change [%]	
	1986(87)	2003(04)	2019	1986(87)-2003(04)	2003(04)-2019
Uszwica					
Forest	34.88	40.08	44.21	0.87	0.62
Cropland	31.30	9.90	4.67	-6.94	-4.59
Grassland	31.72	46.46	46.72	2.41	0.04
Settlements	2.10	3.56	4.40	3.32	1.33
Homerka					
Forest	61.43	66.83	69.52	0.53	0.25
Cropland	10.22	3.57	0.53	-6.38	-11.37
Grassland	27.37	28.26	28.04	0.21	-0.05
Settlements	0.98	1.34	1.91	1.98	2.30
Jaszcze-Jamne					
Forest	58.66	67.35	72.21	0.77	0.47
Cropland	7.71	2.32	0.25	-6.48	-13.88
Grassland	33.14	29.66	26.35	-0.61	-0.79
Settlements	0.49	0.67	1.19	1.47	4.17

of forest in the middle parts of the catchments. Croplands were converted to grasslands, with only single cultivated fields restricted to the lower parts of the catchments. Settlements dominated in the lower part of catchments and along the main watercourses.

LULC changes and their impact on sustainable development in 1986-2019

The LULC transition map illustrates changes associated with land degradation, land improvement or which were neutral in terms of the land degradation (Fig. 3). Of the 12 transitions identified in the studied catchments, six indicated land degradation and six indicated land improvement (Tab. 2). During the 1986-2019 period, 62.72%, 78.03% and 73.53% of the land in the Uszwica, Homerka and Jaszcze-Jamne catchments, respectively, was neutral or experienced no change. The neutral land-use area mainly comprised large blocks of forest at the highest elevations and on less accessible steep slopes, core areas of large grasslands and settlements mainly located in the lower parts of the catchments.

The LULC changes associated with improvement covered 33.59%, 18.78% and 22.72% of land in the Uszwica, Homerka and Jaszcze-Jamne catchments. The main trends in land improvement were transitions from cropland into grassland and from grassland into forest. A much smaller contribution to the improvement was the conversion of settlements to other LULC classes. Among the land degradation trends, the most important were the expansion of settlements and deforestation; however, the area subject to degradation did not exceed 3.75% in any catchment.

Analysis of changes in LULC with altitude shows an increase in the proportion of neutral (i.e. stable) land in terms of land degradation with a decreasing proportion of land improvement and degradation with elevation in all three catchments (Fig. 4). The largest fraction of land improvement was recorded at up to 300 m a.s.l. (41.37%), up to 400 m a.s.l. (30.23%) and up to 700 m a.s.l. (41.07%) in the Uszwica, Homerka and Jaszcze-Jamne catchments, respectively. These areas of the catchments were subject to the abandonment of croplands.

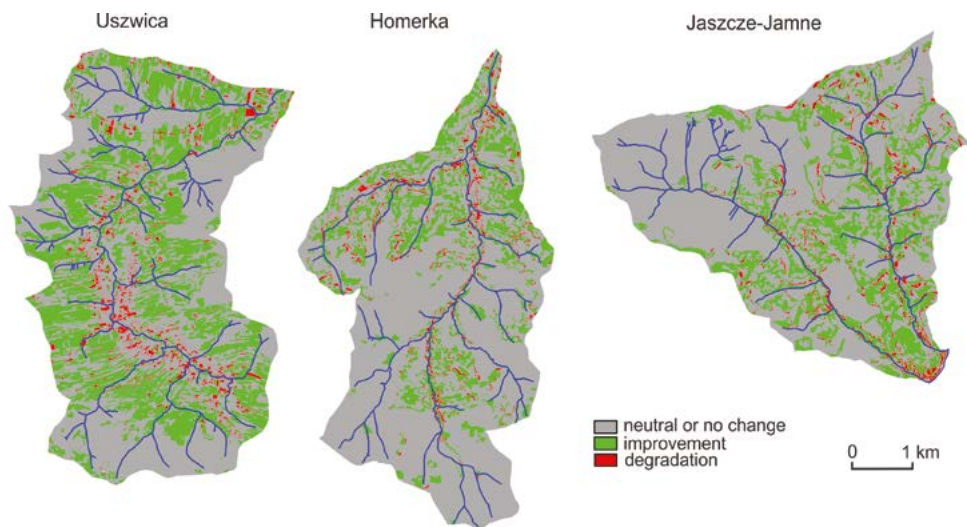


Figure 3. Spatial distribution of LULC changes in 1986(87)–2019. Three-class LULC change indicators of land degradation are based on Table 2

Table 2. LULC change matrix (%) for the three catchments in 1986(87)–2019. The transition scheme and colours are as follows: red – degradation, grey – neutral or no change, green – improvement, according to Sims et al. (2017, 2019)

LULC in target 2019 year					
LULC in baseline 1986 year	Uswzica (1987-2019)				
		forest	grassland	cropland	settlements
	forest		0.29	-	0.01
	grassland	6.39		1.07	1.80
	cropland	3.25	23.94		0.52
	settlements	-	0.01	-	
	Homerka (1987-2019)				
		forest	grassland	cropland	settlements
	forest		1.75	-	0.10
	grassland	8.69		0.25	0.94
	cropland	1.19	8.64		0.15
	settlements	0.05	0.20	0.01	
	Jaszcz-Jamne (1986-2019)				
		forest	grassland	cropland	settlements
	forest		2.63	0.01	0.10
	grassland	15.06		0.08	0.68
	cropland	1.28	6.06		0.25
	settlements	0.10	0.22	-	

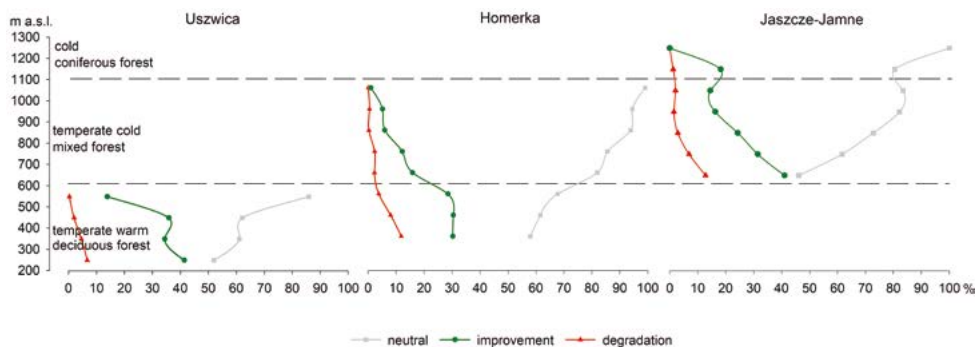


Figure 4. The improvement, stabilisation and degradation of the lands along an altitudinal gradient in the three catchments (1986/87-2019)

The most land degradation was recorded at up to 300 m a.s.l. (6.68%), up to 400 m a.s.l. (11.81%) and up to 700 m a.s.l. (12.82%) in the Uszwica, Homerka and Jaszcze-Jamne catchments, respectively. In the Uszwica catchment, the land degradation mainly comprised the transition from grassland into cropland and an increase in settlements. In both mountainous catchments, the most significant land degradation transition was the conversion of forest to grassland, as well as the conversion of different LULC classes to settlements. With increasing altitude, the proportion of land degradation almost disappears (0.27%) in the upper part of the Uszwica catchment and does not occur in the upper parts of either mountainous catchment.

Discussion

Analysis of aerial photographs and orthophotomaps allowed general trends and dynamics of LULC change to be assessed in the context of land degradation and sustainable development in three catchments situated in the central part of the Polish Western Carpathians. In all three catchments, there has been a persistent trend towards the reduction of cropland area, forest succession and expansion of settlements, both before and after accession to the European Union. These general trends in LULC change are similar to those recorded in the Polish Western Carpathians after the collapse of communism in 1989 (Kaim, 2009;

Kolecka et al., 2017; Bucala-Hrabia, 2017; Kijowska-Strugała, 2019). Similar observations have also been made in mountainous regions of most Central and Eastern European countries after the collapse of centrally planned economics (Kummerle et al., 2008; Baumann et al., 2011; Munteanu et al., 2014).

The final assessment of LULC changes using the SDG 15.3.1 sub-indicator was modified and adopted to knowledge of the conditions in the study area (Sims et al., 2017). In contrast to the original framework, the transition from cropland to grassland was recognised as land improvement, involving a lower level of intensity in land use. The withdrawal of cropland occurred as a result of the low economic viability of agricultural production in the mountains after the transition from centrally planned economics to a free market economy (Górz, 2002, 2003). Despite the continuous increase in population density in all three catchments, the number of people dependent only on agriculture has decreased to less than 5% (Bucala-Hrabia, 2018); thus, farmland abandonment was the result of finding work in other sectors of the economy. Such LULC changes are positive with respect to erosion and flood control (Tasser et al., 2003; Boardman & Poesen, 2006) and agree with the concept of sustainable management devised for the Polish Carpathians (Starkel, 1990; Starkel et al., 2007). The withdrawal of cropland triggers vegetation succession processes that limit soil erosion on slopes

and unused roads (Świąchowicz, 2012; Kijowska-Strugała, 2019), thus limiting potential sources of material and water transfer in the slope-channel system (Gil et al., 2021).

At present, settlements in the Polish Carpathians are increasingly recognised as a major driver of land degradation due to their contributions to changes in catchment microclimate, hydro-geomorphological processes and soils (Krocak et al., 2018; Kędra & Szczepanek, 2019; Ćwik & Hrehorowicz-Gaber, 2021). The expansion of housing developments onto steeper slopes and slope-cutting for transport networks have affected the intensity of geomorphic processes (e.g. linear erosion and landslides) (Starkel et al., 2007). The replacement of plant cover with impervious surfaces reduces the catchment's natural infiltration capacity and ability to store water. Changes in a watershed's hydrological characteristics caused by built-up areas can also significantly affect the peak discharge, volume and frequency of floods (Mitsova, 2014). The development of settlements was related to a continuous increase in population density in all three catchments (Bucala-Hrabia, 2018). This process is typical in the valley bottoms, with broader areas in the foothills and narrower areas in both mountainous catchments; however, such development is also currently spreading to higher slopes and ridges. In the Polish Carpathians, between 1990 and 2012, the main changes involving the conversion of farmland to settlements or forested land occurred principally at altitudes of 200-400 m a.s.l. (Kędra & Szczepanek, 2019). This pattern was observed in both mountainous catchments, with an increase in individual buildings in their highest parts. This change is related to increased tourist activity, especially in Jaszczke-Jamne, where agritourism has become an important source of income (Bucala-Hrabia, 2018).

The transition of forest into grassland which was recorded locally in both mountainous catchments was mainly associated with forest clearing due to windthrow and bark beetle infestation (Czajka, 1987; Grodzki et al., 2006). In recent decades, large areas

of forest in Europe, including the Carpathians, have been affected by windthrow and bark beetle infestation (Potterf & Bone, 2017). These are natural phenomena that shape forest ecosystems; however, in the past 50-60 years, their frequency in European forests has significantly increased. This change is the result of improper forest management in the past; in addition, climate change has caused prolonged summer droughts, leading to the weakening of trees, and increased the frequency of extreme weather phenomena such as strong winds (Seidl et al., 2014). Griffiths et al. (2014) found that almost 20% of the Carpathian forests experienced stand-replacing disturbances between 1985 and 2010. The second reason for the decrease in some forested areas is the removal of natural forest successions from grasslands within the Common Agricultural Policy (CAP) that was implemented after joining the European Union in 2004 (Keenleyside & Tucker, 2010). The subsidies for mowing grasslands were used by twice as many people in both mountain catchments (12%) relative to the foothill catchment (6%) in 2016 (Bucala-Hrabia, 2018).

Conclusions

An analysis of LULC in the Polish Western Carpathians showed highly dynamic changes over the last 30 years. Both the LULC structure and changes therein resulted from a combination of environmental conditions and the emergence of new driving forces of LULC change during the transformation to a free-market economic system. From the point of view of the SDGs, the vast majority of changes, especially those related to the withdrawal of agriculture, resulted in land improvement. Increase area of forest and grassland in the upper and middle part of catchments, respectively are in accordance with the model of sustainable management devised for the Polish Carpathians in 1970s., which recommended reducing cultivation, especially of root crops on steep slopes and replacing them with grasslands and forests.

Relatively minor changes leading to land degradation were associated with pressure from increasing population in the form of the spreading settlements. The latter process was dominant in the higher mountain catchments.

For sustainable development, the progressing forest disturbances due to windthrow and bark beetle infestation are alarming, with an increasing trend recorded in the first decades of the 21st century. Climatic scenarios suggest that these trends will continue to increase in the future. Facing this environmental threat, it is recommended the urgent implementation of solutions to fight land degradation by afforestation, rational management and the conservation of water resources, as well as the limited logging activities on bark beetle control in neighbouring areas.

As a component of sustainable development, spatial management plans should

be developed for the Polish Western Carpathians that can protect them from issues such as chaotic building on the mountain slopes, especially in places of particular scenic value, or the establishment of new roads and trails which can accelerate runoff during heavy rainfall. The proposed solutions should ensure ecological restoration of degraded lands and this study can serve as starting point for a landscape management forecast for the next decade. Furthermore, it should help to implement a sustainable model in land-use planning.

Editors' note:

Unless otherwise stated, the sources of tables and figures are the authors', on the basis of their own research.

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