THE LANDSCAPE FRAGMENTATION: ANALYSIS OF LAND COVER TRANSFORMATION IN HIGH MOUNTAINS ENVIRONMENT ON THE EXAMPLE OF TATRA REGION (SOUTHERN POLAND)

Piotr Pyryt, Katarzyna Pukowiec-Kurda

Faculty of Natural Sciences, University of Silesia, Sosnowiec, Poland

Manuscript received: March 21, 2023
Revised version: December 5, 2023

Pyryt P., Pukowiec-Kurda K. 2024. The landscape fragmentation: analysis of land cover transformation in high mountains environment on the example of Tatra region (southern Poland). *Quaestiones Geographicae* 43(1), Bogucki Wydawnictwo Naukowe, Poznan, pp. 111–126. 5 figs, 5 tables.

Abstract: Changes in land cover (LC) are continuously growing due to natural and human factors, and they are even occurring within protected areas. In Europe, one such place is the Tatra region (southern Poland), which is the area of the presented research. Dynamic landscape transformation in a valuable natural area can negatively affect both environmental quality and sustainable land use planning. Appropriate recommendations and treatments can be introduced to prevent negative effects. To do this, it is necessary to understand the dynamics and character of these transformations. Therefore, the purpose of the article is to analyse changes in LC, its causes and their spatiotemporal dynamics, as well as the resulting landscape fragmentation. For this purpose, a set of landscape metrics and GIS (Geographic Information System) tools were used. The main data source in the study was the CORINE Land Cover (CLC) database. The results indicate a significant landscape transformation with a negative impact on the region's environment, even in protected areas. Landscape fragmentation, which causes disturbances in ecosystems, increased across the entire study area. In turn, in the spatial development, it can introduce chaos and spatial disorder, and lead to the phenomenon of urban sprawl.

Key words: ecological informatics, landscape metrics, protected areas, natural hazard, anthropogenic changes, Tatra region

Corresponding author: Katarzyna Pukowiec-Kurda; katarzyna.pukowiec@us.edu.pl

Introduction

The latest findings of scientists on land cover (LC) change are startling in their magnitude. Winkler et al. (2021) found that global LC change (LCC) is four times greater than previously estimated. They found that over the past 60 years, the area of land change has affected a third of global land. Similar values of the world's land area undergoing change were estimated by Ellis et al. (2010). As a consequence of being aware of the magnitude of these changes and how they will continue, researchers are attempting to establish predictions for them (Popp et al. 2017). A great deal of research is also underway into their consequences for both humans (Young et al. 2006) and the environment (Prestele et al. 2017). Changes in LC bring with them changes in ecosystems, including ecosystem services (Fu et al. 2015, Gomes et al. 2021) and therefore have a significant impact on the human habitat and an even greater impact occurs in protected areas. It

https://doi.org/10.14746/quageo-2024-0007
ISSN 2082-2103, eISSN 2081-6383

is then necessary to carefully plan their further management so that the values for which they are protected are not lost (DeFries et al. 2007, Martinuzzi et al. 2015, Hersperger et al. 2018).

Areas close to or within protected areas should be subject to special development plans (Vukomanovic et al. 2020). Changes in LC within them should be continuously monitored and must not affect their conservation status. Unfortunately, these are only the theoretical assumptions of those who developed the concept. In reality, many protected areas are subject to intensive LCC (Fuller et al. 2019, Asamoah et al. 2021). These are caused by both human factors (urbanisation, agricultural development and tourism development) and natural ones (natural disasters, climate change, etc.) (Rodríguez-Rodríguez et al. 2019). In addition, an important aspect is their geographical location and degree of uniqueness. If they are rare areas, e.g. high mountains, wetlands with Natura 2000 habitats or UNESCO biosphere areas, the degree of conservation should be even stronger (Alphan 2017). Nevertheless, even in areas such as these, there are changes in LC, if not for human reasons, then for natural ones, and the consequences for these pristine environments are clear to see.

Information about LC and the dynamics of its changes are crucial for landscape research and spatial management (Solon et al. 2018, Ledda et al. 2019). They are the aim of study for many researchers (Lu et al. 2003, Long et al. 2007, Jjumba, Dragićević 2012). Very often, a LC database, such as CORINE Land Cover (CLC), or other similar data sources are used as material (Gimona et al. 2009, Cieślak et al. 2020, Naranjo Gómez et al. 2020, Śleszyński et al. 2020). The application of quantitative and qualitative analyses, as well as statistical landscape metrics, allows for better monitoring of the landscape and the entire environment, which many researchers have paid attention to in their studies (Solon 2002, Zhang, Wang 2006, Richling, Solon 2011, Sobala, Pukowiec-Kurda 2016, Pukowiec-Kurda, Vavrouchová 2020). One very important phenomenon of land change is landscape fragmentation, which has been studied in many works (Atasoy 2018, Lam et al. 2018, Zambrano et al. 2019). In recent years, the importance of such analyses concerning Central Europe as well as Poland has grown, along with an increased pace of LC dynamics connected with the political and economic transformations in 1989 and later in 2004, after Poland acceded to the European Union (Kijowska et al. 2010, Sikora 2012, Wężyk et al. 2013, Krajewski et al. 2017b). Research on LCC has therefore been carried out in the Czech Republic (Bičík, Kupkova 2007, Van Rompaey et al. 2007, Vavrouchová, Toman 2013), Slovakia (Šveda 2010, Vojtek, Vojteková 2018) and Hungary (Cegielska et al. 2018, Németh et al. 2021). Similar research has also been conducted in the Baltic Countries (Jõgiste et al. 2015) and Eastern Germany (Pleninger, Schaich 2014).

Of course, the most important from the point of view of this study is the work on land use changes in protected areas. Protected areas in the United States from this perspective were studied by the team of Martinuzzi et al. (2015). European national parks and their surroundings were studied by Mingarro and Lobo (2023). On the other hand, the theoretical approach of studying land use change in protected areas and surroundings is presented by the work of DeFries et al. (2007). A paper on spatial changes due to tourism in the study area was presented by Hełdak and Szczepanski (2011). An important work on land use changes in the Western Carpathians was many times presented by Bucała-Hrabia (2017, 2018).

The aim of this article is to analyse changes in LC, its causes and their dynamics in the Tatra region (southern Poland). The selected area includes the Tatra National Park (Tatra NP) and the surroundings and the selected period for analysis is 2000–2018. The Tatra NP is strictly protected and is home to rare species, as well as those protected by international law (Kubak et al. 2020). For this reason, the area of the national park, as well as the neighbouring areas, should have relative stability in the processes of land change. However, a popular mountain resort—Zakopane—is located in the immediate vicinity of the park. In recent years, the phenomenon of overtourism has been diagnosed there (Murzyn-Kupisz, Hołuj 2020), and consequently, the expansion of tourist infrastructure has occurred. Unfortunately, these activities are not without impact on the adjacent protected area (Senetra et al. 2020, Fidelus-Orzechowska et al. 2021). So, what are the LCC in this area, and do they significantly affect the national park? Are they a threat to it? In need of answers to these questions, a study of LCC in the Tatra region was designed.

Materials and methods

Study area

The research area is the Tatra and its northern foreland in the article, for easier understanding, referred to as Tatra region, which is located in the southernmost part of the Małopolskie Voivodeship in Poland (Fig. 1). The area of the Tatra region is 471.6 km^2, and the population is 67,719 people (Bank Danych Lokalnych 2020). The largest city and the only urban municipality in the region is Zakopane. In terms of the region's geographic location, it is divided into six sections: Wysokie Tatry, Tatry Zachodnie, Tatry Reglowe, Bruzda Podtatrzańska, Magura Spiska and Pogórze Przedtatrzańskie (Solon et al. 2018).

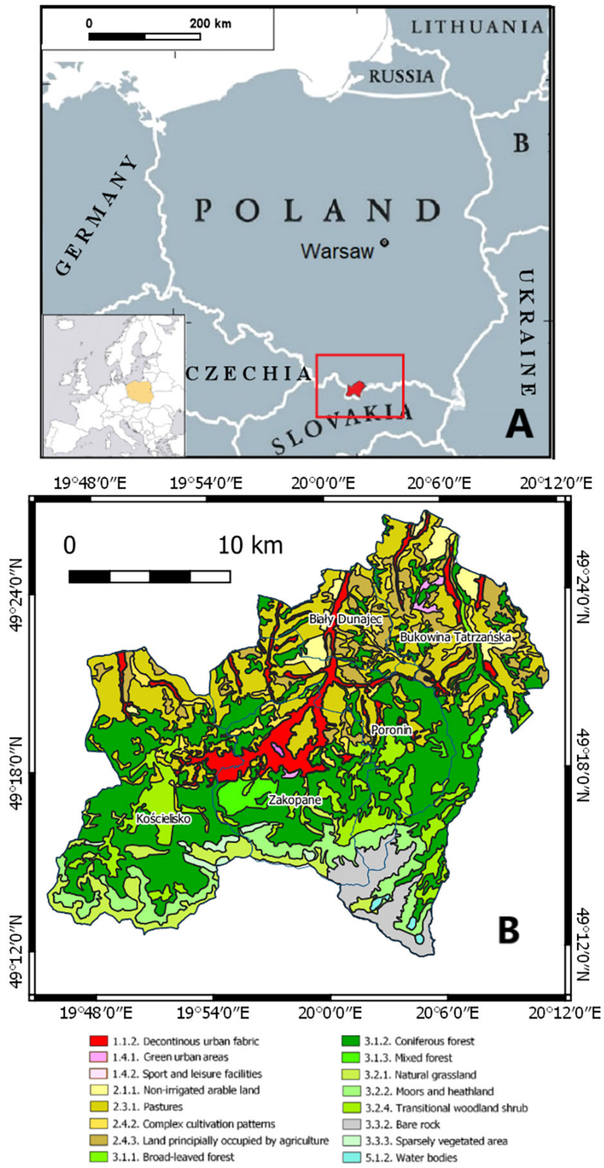

Fig. 1. Location of the Tatra region in Poland (A) with information about its CORINE Land Cover classes (B).

With the inclusion of five different mesoregions, there is a great variety of terrain relief, which is a factor that makes the area exceptionally attractive for tourists and settlement. The region of Wysokie Tatry (High Tatras) in particular is characterised by unique natural values, and it is one of the best examples of glacial relief in the entire country. The region's landscape has several glacial landforms, like U-shaped valleys, middle, side and bottom moraines, and glacier cirques. Most of the lakes are tarns located in the cavities of cirques (Klimaszewski 1988). The biggest and most recognisable ones are Morskie Oko and Wielki Staw, both located in the High Tatras.

In the southernmost point of the area, there is the highest mountain peak in Poland, Rysy (2499 m a.s.l.). The lowest point of the area is the valley of Dunajec by Nowy Targ, where the absolute height is 641 m a.s.l. As a result, the study area is subject to altitudinal zonation of its climate and flora (Hess 1965). This is the most important condition shaping LC in the Tatra region. It creates six vegetation layers: the foothills zone, lower montane zone, higher montane zone, subalpine zone, alpine zone and crag zone (Fabijanowski 1962). The research area is located in the mixed temperate climate zone but belongs to the alpine climatic region (Woś 2008). A characteristic feature of the regional climate is the so-called *halny*, which is a type of foehn wind. It is a dry and gusty wind that causes windfall and damage to forests.

The outstanding natural beauty of the High Tatras and their importance for the whole ecosystem resulted in the creation of the Tatra NP in 1955. Its area is 21,164 ha. Both the Tatra NP and the neighbouring Slovak national park, TANAP, have had the status of international UNESCO biosphere reserves since 1993 (UNESCO 2022).

Data sources

The primary data source is the CLC database, which is a part of the European programme Coordination of Information on the Environment (CORINE), which is led by the European Environment Agency. It was mainly created through the use of a semi-automatic method of visual interpretation of high-quality satellite images (Landsat, RapidEye, IRS, SPOT-4). The CLC database is available for the years 1990, 2000, 2006, 2012 and 2018. Currently, the CLC programme covers most European countries, including Poland. The data used in the study was downloaded through the website of the Inspectorate of Environmental Protection (pol. *Inspektorat Ochrony Środowiska*) (CORINE Land Cover 2022).

As auxiliary research material, the authors used the current orthophoto map obtained from the National Geoportal (geoportal.gov.pl). It allowed the results to be verified, thus facilitating a more reliable analysis. Apart from the above, the study used plans and sketches made during the field study, as well as acquired photographic documentation.

The software used for the spatial analyses is the licensed geoinformation programme ArcGIS v.10.7.1. Landscape fragmentation metrics were calculated using a free V-late plug-in (Vector-based Landscape Analysis Tools, v.2.0) for ArcGIS software. Calculations of the indicators of landscape changes were done in Microsoft Excel software.

Research procedure

For the purpose of analysing LCC and landscape fragmentation, the research procedure was divided into three stages (Fig. 2). The spatial phenomena were quantified with the use of landscape metrics based on measurements of the homogeneous elements of the landscape (patches).

The first stage of the research was a statistical analysis of the increases and decreases of the identified LC forms in the entire period of study covering the years 2000–2018. For this purpose, the authors used the index of landscape change (ICh), which expresses the percentage value of changes in a given LC form (Vavrouchová, Toman 2013). The greater it is, the greater the change of a given LC form is. A value of 0 means that no change occurred. The index was calculated for each of the LC forms, for the entire period of 2000–2018, as well as for the three sub-periods: 2000–2006, 2006–2012 and 2012–2018. The index of landscape change is expressed using the following formula:

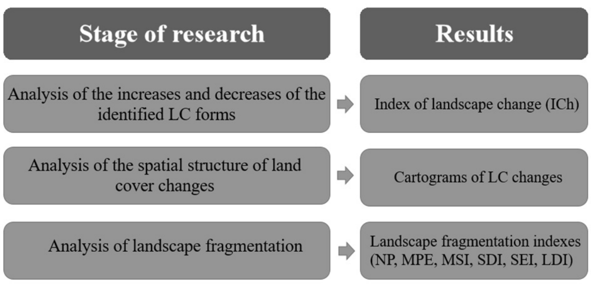

Fig. 2. Methodology workflow.

$$ICh_{(XY)} = \frac{\sum_{i=1}^{n} |\mathrm{r}_{ax} - \mathrm{r}_{ay}|}{2c} \times 100$$

where:
- *ICh* – Index of landscape change (%); for the same LC form in the period between years X and Y,
- r_{ax} – area occupied by LC type A in year X,
- r_{ay} – area occupied by LC type A in year Y,
- *c* – total area of the Tatra region.

In the second part of the research, the authors analysed the spatial structure of LCC. For this purpose, a cartogram presenting the percentage share of LCC was created for each sub-period. The class intervals for the cartogram were based on relative data (area of changes in ha km^{-2}) and a square was chosen as the base field. Thanks to cartographic representations of the phenomena, it was possible to indicate where the most changes in the form of LC took place.

The third research stage was dedicated to the analysis of landscape fragmentation in the years 2000–2018. To do this, the authors computed a set of six simple landscape fragmentation metrics. The metrics, along with their mathematical formulas and abbreviated forms used in the following chapters, are presented in Table 1. Apart from the metrics-based analysis, this stage was extended using a graphical representation of the Landscape Division Index (LDI) for each of the LC forms in the study area. The results obtained from the analysis and the available published works will allow the last phase of research to formulate regularities about the causes of the ongoing fragmentation of the landscape.

Results

Analysis of the share and dynamics of particular LC forms

When comparing the values of the landscape change index of individual LC forms, it can be concluded that both urban and agricultural

Table 1. Landscape fragmentation indexes.

Index	Name	Formula	Notes	Level of operation*	Source
NP	Number of Patches	–	–	Landscape level	
MPE	Mean Patch Edge	$MPE = (e_1 + e_2 + ... + e_n) \div n$	e – edge of the patch (m) n – the number of patches in the selected LC class	Class level	McGarigal and Marks (1995), Zhang and Wang (2006)
MSI	Mean Shape Index	$MSI = (e \div A)$	e – edge of the patch (m) A – total area of landscape	Class level	McGarigal and Marks (1995), Zhang and Wang (2006),
SDI	Shannon's Diversity Index	$SDI = (-\sum_{i=1}^{R} p_i \ln p_i)$	p_i – proportion of individuals belonging to the ith LC class in the landscape	Landscape level	Urbański (2008), Sobala and Pukowiec-Kurda (2016)
SEI	Shannon's Evenness Index	$SEI = (SDI \div \max(SDI))$	SDI – actual value of Shannon's Diversity Index max (SDI) – maximal possible SDI value	Landscape level	Urbański (2008)
DIVISION	Landscape Division Index	$DIVISION = (1 - \sum_{i=1}^{m}\sum_{j=1}^{n}(\frac{a_{ij}2}{A}))$	i – LC class a_{ij} – area (m^2) of the patch A – total area of landscape	Class level	Urbański (2008)

* Landscape level – the index is calculated for the entire landscape as one value; class level – the index is calculated for each LC class.

areas, as well as forest and semi-natural areas, have been subject to significant changes. It is possible to observe a wide range in the value of this indicator (Table 2). The overall ICh was 13.16%, which points to high dynamics of LCC in the research area.

In the category of urban areas (CLC level I), each of the LC classes has increased its share of the area. One of the strongest increases in the share of the area occurred in urban fabric (112). An increase was observed in the case of sports facilities (142). Over time, green urban areas (141)

Table 2. Values of index of landscape change for particular land cover forms according to the CORINE Land Cover classification in the Tatra region (ICh value—green colour when the share of a given LC form has increased and red colour when the share of a given LC has decreased).

CLC code	Area [ha]				ICh [%]			
	2000	2006	2012	2018	ICh_{00-06}	ICh_{06-12}	ICh_{12-18}	ICh_{00-18}
112	1735.21	1839.39	2399.88	2972.04	0.11	0.59	0.61	1.31
141	0.00	18.78	17.05	18.18	0.02	0.00	0.00	0.02
142	23.10	22.95	21.24	129.36	0.00	0.00	0.11	0.11
211	2634.21	2687.80	16258.58	4626.12	0.06	14.39	12.33	2.11
231	14225.05	14317.34	4284.58	12295.75	0.10	10.64	8.49	2.05
242	2079.09	1904.76	982.94	910.70	0.18	0.98	0.08	1.24
243	3136.02	3035.51	2387.99	2341.27	0.11	0.69	0.05	0.84
311	97.59	458.98	113.98	121.66	0.38	0.37	0.01	0.03
312	14856.89	14811.78	13638.78	13243.95	0.05	1.24	0.42	1.71
313	679.73	388.05	451.19	582.83	0.31	0.07	0.14	0.10
321	2406.07	2403.38	2074.84	2697.85	0.00	0.35	0.66	0.31
322	2159.93	2151.63	2057.61	2033.98	0.01	0.10	0.03	0.13
324	410.64	429.77	456.00	2874.62	0.02	0.03	2.56	2.61
332	2348.89	2322.01	1646.70	1783.19	0.03	0.72	0.14	0.60
333	291.07	291.38	279.61	436.38	0.00	0.01	0.17	0.15
511	0.00	0.00	18.88	20.04	0.00	0.02	0.00	0.02
512	76.53	76.50	70.15	72.06	0.00	0.01	0.00	0.00
Overall ICh					1.38	30.19	25.81	13.36

have appeared, but the share of the area occupied by this LC form remains insignificant.

In the category of agricultural areas (CLC level II), an increase was only observed in the case of arable land (211). On the other hand, there was a notable shrinkage in pastures (231). A more significant decrease occurred in the case of complex cultivation (242) and land principally occupied by agriculture (243).

When it comes to the category of forest and semi-natural areas (CLC level III), a slight increase in its share was observed in broad-leaved forests (311) and grasslands (321), as well as sparsely vegetated areas (333). The class which increased its area the most is the transitional woodland shrub (324). It has enlarged its share several times (ICh = 2.61%). However, this goes together with a decline in the area occupied by coniferous forests (312) and rocks (332). Shrinking of mixed forests (313) and moors (322) was also observed, but to a smaller extent.

In terms of LC dynamics in the three sub-periods, the results point to a significant disparity in the values of overall ICh. In the first sub-period, the changes remained insignificant (ICh_{06-12} = 1.38%), while in the second and third sub-period, they were much greater (ICh_{12-18} = 30.19%; ICh_{12-18} = 25.81%). Thus, LCC are becoming more and more rapid in the Tatra region. However, this is mainly caused by extraordinarily high dynamics in only three categories: arable land (211), pastures (231) and woodland shrub (324).

Analysis of the spatial structure of dynamics of LCC

The elaborated cartograms presenting the spatial distribution of changes confirm the tendency described in the previous sub-chapter (Fig. 4), and the graph shows the ICh values for the sub-periods studied (Fig. 3).

In the area of the Tatra National Park, although the landscape is changing, they are twice as weak as in the surrounding area. This regularity applies to both the second and third periods of analysis. This means that the high value of the indicator for the entire research area results mainly from changes taking place in the surroundings of the national park, not the park itself.

In the first period, the total area of LCC is relatively small, amounting to 622.45 ha (Fig. 4), and

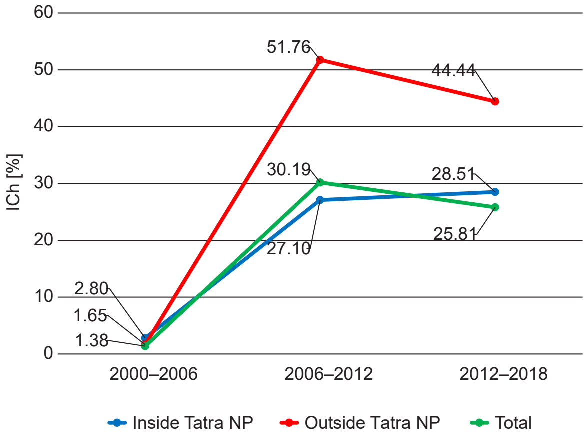

Fig. 3. Index of landscape change (ICh) inside and outside Tatra NP in the period of 2000–2018.

it is mainly concentrated in the central part of the area, in Zakopane and Poronin. Some changes also occurred in the Tatra NP. In the eastern and northern parts, the LCC are negligible, and in most of the areas, there are no changes recorded.

In the next sub-period, the changes amount to 8214.52 ha, so they are several times larger. In this case, LCC are concentrated mainly in the north-western part of the area, in the municipalities of Biały Dunajec and Poronin (Fig. 4). Referring the figures of the LC structure, it is possible to observe that some significant changes (1961 ha) are due to the transformation of pastures into arable land.

The third period (2012–2018) is also characterised by a very large total area of LCC (10,417.52 ha). The most important similarity to the previous period is the concentration of changes in the north-western part of the area and reoccurring transformation of arable land into pastures (Fig. 4). However, unlike the previous period, in the years 2012–2018, there were also radical landscape transformations within the Tatra NP caused by the transformation of coniferous forests into woodland shrubs.

Analysis of landscape fragmentation

The major finding in the analysis of landscape fragmentation was a significant increase in the number of patches, 259 in 2000 and 268 in 2018. On a landscape level, the calculation of Shannon Diversity Index (SDI) indicated a growing diversity of LC forms in the district's landscape over the years (from 1.869 to 2.070), which was caused

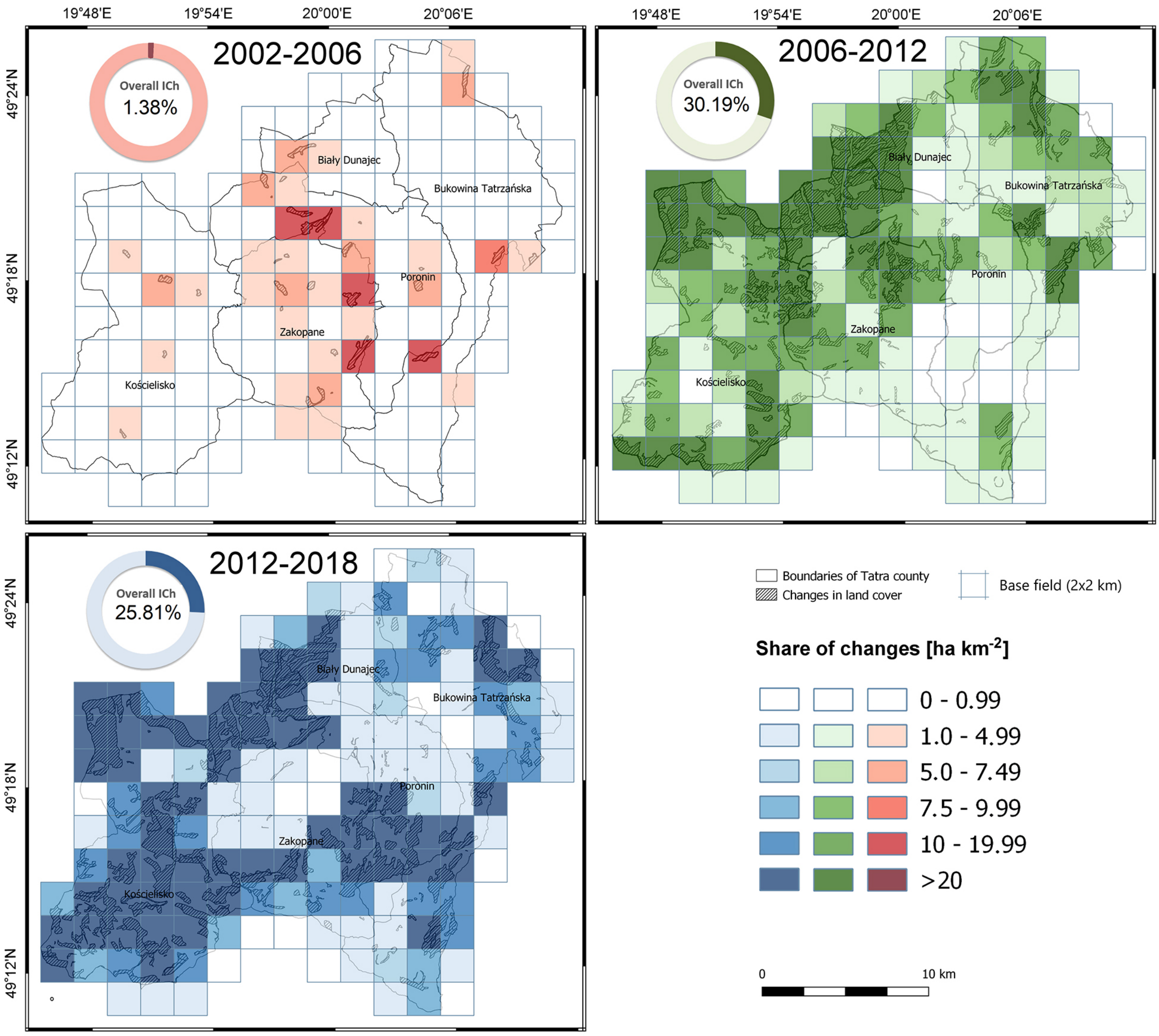

Fig. 4. Land cover changes in the Tatra region in the 2000–2006–2012–2018 periods.

by the appearance of green urban areas, sports facilities and water courses. Simultaneously, the change in Shannon Evenness Index (SEI) (from 0.690 to 0.731) showed that relative proportions of the various LC forms have become slightly more even.

On a class level, the analysis of Mean Patch Edge (MPE), Mean Shape Index (MSI) and DIVISION indexes draws attention to their high dynamics in several classes. In terms of the MPE values, the LC forms that increased their MPE are urban fabric (112), moors (322), grassland (321), woodland shrub (324), rock (332), sparsely veg. (333) and water courses (511, Table 3). At the same time, three forms of LC decreased their MPE in 2000–2018: arable land (211), coniferous forests (312) and mixed forests (313). There are also many LC forms that are not very dynamic: green urban areas (141), pastures (231), complex cultivation (242), land principally occupied by agriculture (243) and broad-leaved forests (311).

Analysing the MSI, the decreasing values of which indicate the simplification of geometry, there are also five forms of LC with a downward tendency: urban fabric (112), arable land (211), complex cultivation (242), grassland (321) and sparsely veg. (333, Table 4). There are seven LC forms with the opposite tendency: sports facilities (142), pastures (231), coniferous forests (312), mixed forests (313), moors (322), woodland shrubs (324) and rock (332). Their areas are getting more and more complex and fragmented. These are mostly forest and semi-natural areas, which are mainly present in the national park.

The most spectacular results concerned the changes in the LDI in the different LC forms (Table 5). First of all, the LC categories can be divided into three groups. The first are those characterised by constantly low fragmentation: green urban areas (141) and sports facilities (142). The second is those with constantly high fragmentation: pastures (231), complex cultivation (242), land principally occupied by agriculture (243) and woodland shrubs (324). There are also those whose degree of fragmentation has changed significantly: urban fabric (112), arable land (211), broad-leaved forests (311), coniferous forests (312), mixed forests (313), grassland (321), rock (332) and sparsely veg. (333). The spatiotemporal differentiation of LDI has been visualised in Figure 5. It is significant that agricultural LC forms, like arable land (211), pastures (231), complex cultivation (242) and land principally occupied by agriculture (243), had LDI values that were clearly higher than others. Most of them had very slight fluctuations in LDI in the following years. The complete opposite are those LC forms belonging to the category of forests and semi-natural ecosystems. Their fluctuations between 2000 and 2018 reached as much as several dozen per cent in both directions.

When analysing the cartograms showing the LDI for each of the studied years, completely different directions can be observed in the northern and southern parts. First of all, the southern part of the Tatra region, located within the park and dominated by forests, has much lower LDI values than the northern part for the first analysed years (2000; 2006). This regularity is not so distinct in the case of the last two analysed years (2012; 2018). Moreover, during this time, the

Table 3. Mean Patch Edge (MPE) in the Tatra region in the 2000-2018 period for selected LC forms.

CLC code		MPE [m]			
		2000	2006	2012	2018
112		14 367.00	12 397.14	15 228.02	15 063.99
141		0.00	2 557.64	2 557.64	2 557.64
142		3 109.36	3 109.36	3 109.36	8 495.38
211		12 735.41	12 735.33	26 570.53	4 144.60
231		12 429.33	12 495.35	9 969.87	11 031.61
242		5 588.21	5 506.85	5 453.74	4 733.83
243		5 265.41	5 393.80	5 577.05	5 478.32
311		3 824.21	3 934.29	3 804.81	3 784.66
312		18 097.87	17 500.69	15 868.58	17 768.00
313		9 271.88	10 256.72	10 259.33	7 865.39
321		7 880.22	7 945.46	10 764.73	12 471.43
322		14 040.35	14 004.48	14 659.31	22 307.29
324		4 266.16	4 284.40	3 943.19	6 878.49
332		13 777.95	13 595.98	10 604.71	54 742.03
333		1 229.49	1 229.49	3 191.27	3 698.45
511		0.00	2 623.02	3 690.03	3 533.54
512		2 623.03	12 397.14	2 620.30	2 616.70
Overall MPE		9451.12	9413.86	9964.18	9822.28

Table 4. Mean Shape Index (MSI) in the Tatra region in the 2000–2018 period for selected land cover forms.

LC class		MSI [m]			
		2000	2006	2012	2018
112		2.991	2.767	2.816	2.736
141		–	1.398	1.398	1.398
142		1.523	1.523	1.523	2.342
211		2.688	2.688	2.835	1.672
231		2.244	2.212	2.332	2.291
242		2.019	2.010	1.997	1.886
243		1.877	1.894	1.904	1.884
311		1.785	1.822	1.807	1.776
312		2.488	2.468	2.430	2.515
313		2.152	2.400	2.294	3.117
321		2.815	2.819	2.575	2.319
322		2.441	2.436	2.378	2.722
324		2.267	2.041	1.918	2.418
332		2.586	2.570	2.097	3.499
333		3.986	3.986	2.592	2.018
511		–	–	2.696	2.840
512		1.209	1.209	1.210	1.227
Overall MSI		2.276	2.259	2.238	2.228

Table 5. Landscape Division Index (LDI) in the Tatra region in the 2000–2018 period for selected land cover forms.

LC form		LDI			
		2000	2006	2012	2018
112		71.76	73.94	50.33	57.49
141		–	0.00	0.00	0.00
142		0.00	0.00	0.00	30.58
211		34.04	34.04	56.92	82.11
231		90.60	90.44	87.08	94.10
242		95.09	95.31	94.59	94.93
243		96.87	96.76	96.36	96.17
311		44.77	63.08	60.24	60.85
312		20.28	21.11	60.88	67.30
313		30.45	34.55	28.36	47.02
321		80.29	79.67	73.01	67.98
322		77.17	77.10	77.61	65.80
324		90.17	89.94	80.62	88.58
332		42.58	41.15	25.74	0.00
333		44.23	44.23	62.15	77.02
511		–	0.00	0.00	0.00
512		62.71	62.71	62.61	64.07

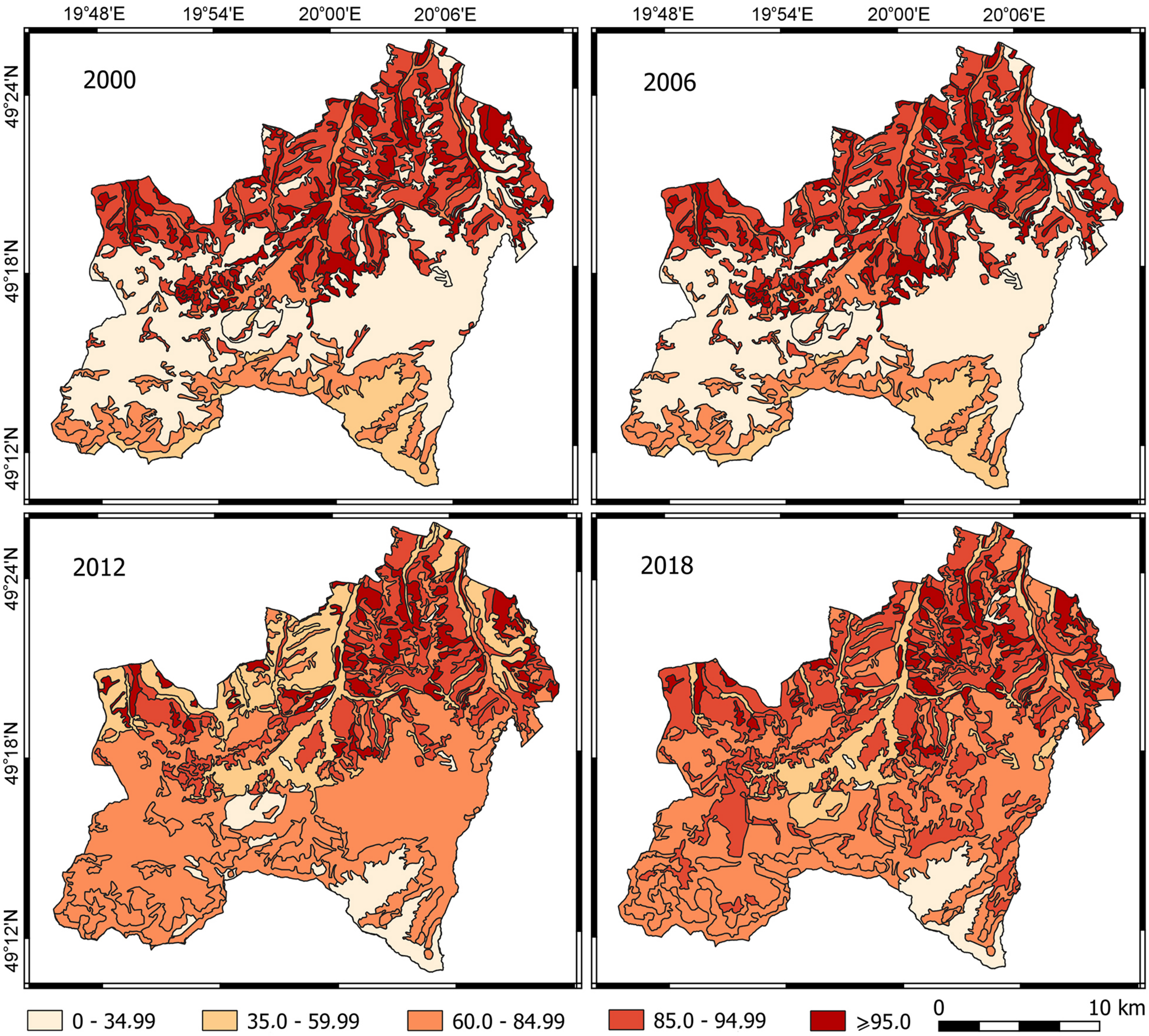

Fig. 5. Landscape Division Index values in the Tatra region in the 2000–2018 period for each patch of landscape.

fragmentation of this part increased dramatically. This is related to the influx of new LC forms into previously homogeneous areas, especially in the Tatra NP.

The northern part of the area is characterised by completely opposite values, and it is dominated by highly fragmented agricultural areas. The year 2012 stands out from the rest of the analysed years. Referring to the CLC maps, a large area in the northwest was briefly reclassified from complex cultivation (242) to arable land (211), and consequently, the LDI decreased temporarily. In the last year, the share of land with an average LDI value also increased in the north. Taking this into account, it can be concluded that the degree of LDI contrast between the areas in the south (protected) and the north (urbanised) decreased over the years 2000–2018, with a simultaneous increase in the share of areas with high LDI values.

Discussion

Landscape dynamics

The latest research on landscape transformation has indicated in recent years that the speed of these changes is accelerating. They are being carried out at global as well as national and even regional scales. Such studies have also been conducted in Poland, in various regions of the country, both in rural areas (Krajewski et al. 2017a, Krajewski 2019) and in metropolitan ones (Pukowiec-Kurda, Vavrouchova 2020).

Landscape changes in these areas were in the range of a few to several per cent of the ICh. This means that a percentage of the area changed from one type of cover to another over the time period studied. The results of this index obtained in the Tatra region indicate an extremely high degree of spatial change, which is several times higher than in other regions of Poland (Łowicki 2008, Krajewski 2019, Pukowiec-Kurda, Vavrouchová 2020). This indicates the existence of large causal forces responsible for land transformation. It also indicates the dynamics of these transformations. In the first studied period, 2000–2006, the rate of change was small. However, in the second period, 2006–2012, it underwent dynamic growth. This means that during this period, one-third of the area of the entire region changed from one type of LC to another. Comparing the results of this study with those of other authors (Krajewski et al. 2018), one can speak of the uniqueness of this area in terms of the strength and speed of landscape transformation. Moreover, the considerable variation in relief, and thus in climatic conditions, vegetation types, etc., in the study area is the natural basis for the functioning of different landscape processes. Thus, the same phenomenon operates with different dynamics in the foothills and high mountains, for example, overgrowth of fields in the foothills and natural succession of the forests after windthrow in the Tatras.

The reasons for these transformations can be traced back to a variety of sources. The first is the socio-economic and political transformation in Central Europe in the period after 2004 (Deslatte et al. 2022). The period studied, 2006–2012, is characterised by the highest transformation rate in any area studied in Poland. This period follows shortly after the accession of Poland and neighbouring Central European countries to the European Union (Bucała-Hrabia 2018). During this period, there was an economic acceleration, with many investments in both housing and services, the development of road networks and the creation of new industrial and technological spaces. It was also a period of increased work in the field of nature protection, e.g. the establishment of Natura 2000 areas. All this has influenced changes in LC. As a result of increasing urbanisation, new residential areas have been created, especially on the urban periphery, road density has increased, and shopping centres, service and storage areas have been created. These human-influenced transformations have also occurred in Zakopane and neighbouring tourist destinations. These changes have been particularly evident in this region due to the investment and rapid development of tourism. Large hotel complexes, restaurants, ski resorts and additional tourist attractions such as aquaparks have been built (Fidelus-Orzechowska et al. 2021), as well as second houses (Mika, Faracik 2008). At the same time, the local population began to change their lifestyle and shift their work from farming to tourism. This is evident in the conversion of agricultural land (arable fields, pastures, etc.) into wasteland or development for tourism and residential purposes. The role of tourism in the contemporary transformation of space in the Tatra Mountains is also highlighted by Rączkowska (2021). In turn, Bucała-Hrabia (2018) writes about the abandonment of agriculture in the Polish Carpathians after the fall of communism in 1989, which is evidence of the prevalence of this phenomenon in the study area.

The rapid changes in the Tatra region can also be attributed to the attractiveness of its location. It attracts those investing in the tourist industry on the one hand, and people wanting to live in beautiful surroundings in the neighbourhood of protected areas on the other (Zbierska 2022). Hence, the rapid development and building up of plots of land. The district's attractiveness comes from its geographical location in a valley at the foot of the highest mountains in Central Europe, the closeness of the Tatra National Park, the possibility of living with a beautiful view of the Tatras, the clean environment and the close proximity of good tourist infrastructure, especially for skiing.

The above-described causes are mainly man-made. However, a large part of the region is under strict legal protection in the national park area. By analysing the transformation maps, it can be seen that these areas have also been subject to rapid transformation (Zbierska 2022). It is known that the cause of such large changes in the nature protection area could not be man-made. In the study period, 2000–2018, several extreme windfall events occurred in the Tatra area (Falt'an et al. 2020). Significant forested areas were devastated, transforming spruce forests into treeless areas. This change was recorded in the LC database and detected in the applied landscape change index. The force of this windthrow was so great that it is possible to speak of significant land transformation in the Tatra NP (Bodziarczyk et al. 2019). Moreover, in addition to the windthrow, there were other natural forces that also affected land use in the Tatras. These included debris flow or snow avalanches, as pointed out by Spyt et al. (2020) in their study. Thus, the second cause of change is the forces of nature. It is interesting to note that both factors responsible for the transformation of the landscape—humans and nature—interacted with great force at the same time. This combination of these two forces has resulted in spectacularly huge changes in the study area over the analysed time period.

Landscape fragmentation

Rapid changes in LC were reflected in the occurrence of landscape fragmentation in the studied area. Its appearance was influenced by another factor, which is the lack of spatial planning and chaotic land development (Duarte et al. 2018). At the investment planning stage, no analyses of spatial design were carried out. New buildings were built chaotically, sometimes on random plots of land (Ćwik, Hrehorowich-Gaber 2021). This resulted in the fragmentation of landscape patches (LC patches) revealed in the research. The area of individual patches decreased, while their number and the length of their borders increased. In the case of the action of the second driving force—nature—it is difficult to talk about planning. Due to their nature, extreme events produce chaotic and unplanned consequences. Therefore, the fragmentation phenomenon also applies to the area of the national park (Kubacka et al. 2022) with the area of the forest felled by winds. The shapes of the windfall areas are also irregular; they occur in several places and are random and incidental in space.

The phenomenon of landscape fragmentation is common and characteristic in urbanised areas, as well as being subject to mainly human influence and its constant investment (Jaeger et al. 2016). In the case of the development of agricultural areas or naturally valuable areas, e.g. forests, meadows and wetlands, we can talk about the loss of ecosystems or at least disturbances in their existence. The development of such types of cover also involves the loss of the ecosystem services they provide (Zambrano et al. 2019). Another effect of anthropogenic changes is the creation of new barriers in space, e.g. in the form of fences, transmission lines, roads and large concrete areas. These are often an insurmountable barrier for animals. In this case, ecological corridors can also be threatened, both as a result of the fragmentation of the landscape (fragmentation, separation of patches into smaller ones) and the formation of barriers. All these ecological effects are detrimental to nature in urbanised areas (Atasoy 2018). However, their effects are much more visible in naturally valuable areas. The fall of tree cover disrupts the operation of the forest ecosystem. It breaks the continuity of the ecological corridor that the forest offers or causes perforations in it. As a result of windfall, valuable forest ecosystems, along with all their functions, such as water retention, slope stabilisation and habitat for plants and animals, are lost (Jaworek-Jakubska et al. 2020). This is particularly significant in the Tatra NP area since it is inhabited by rare and protected species, such as the brown bear. Once again, the action of a double changing force, in this case, fragmenting the landscape of the Tatra region, is revealed—man and nature. Man, mainly changes the areas of the city and its surroundings, and the forces of nature destroy the areas of the national park.

Landscape metrics as a tool for landscape change identification

Landscape metrics have been used for years to determine various landscape parameters (McGarigal, Marks 1995, Urbański 2008). Some of the most common are analyses of landscape change, including landscape fragmentation, both using the landscape change index and other more sophisticated mathematical and statistical tools. One of the most substantial advantages of using landscape metrics is that the landscape can be monitored by determining a set of indices in successive years (Peano, Cassatella 2011). They give measurable and comparable results revealing changes in the landscape. Furthermore, using statistical models, predictions of future landscape changes can be made. Measurability, ease of use and universality are among the greatest advantages of landscape indices.

Another remarkable advantage of using landscape indicators as tools to determine its changes is their universality. They are used by researchers from many disciplines on examples from different regions (Cassatella, Peano 2011, Li et al. 2021). Therefore, it is possible to compare results, even on a global scale. Reference can be made to indicator values obtained in geographically similar areas and areas that are quite different.

However, the use of landscape indicators, like any method based on the use of a cartographic database, has its limitations. Some of these relate to the materials used and others to the metrics themselves. In order to avoid errors of interpretation, the set of indicators should be appropriately selected for the purpose and the scale of the study. Depending on the degree of precision of the research, different metrics can be used as they relate to different degrees of detail, e.g. some only to patches of a landscape, others to the entire landscape (Inkoom et al. 2018). The results of indicators are often dependent on the size of the study area and its landscape diversity. The best results are given by large-scale analyses at a smaller scale, e.g. regional, than by small-scale analyses, e.g. within a municipality or parcels. Limitations relating to the materials used most often relate to their validity and the degree of accuracy, generalisation and the way in which the satellite image was processed into a vector model (Śleszyński et al. 2020). In the latter, interpretation errors often occur, resulting, for example, from automation of the process. One of these is the misreading of satellite images and the incorrect classification of areas. Such an error is unfortunately present in the CLC database, which is revealed in the classification of the same area into two different types in successive analysed years. Nevertheless, the database is still useful due to its undergoing regular updates, its coverage of the entire study area and its universality and accessibility for the whole of Europe (Cieślak et al. 2020).

Conclusions

The article identifies the dynamics of landscape transformation and the most important landscape processes in the Tatra region. Particular attention was paid to landscape fragmentation, which is of key importance in shaping the space in the research area, and its consequences relate to spatial planning and the quality of the natural environment. The main directions of LCC to be determined are increase in urbanised areas, shrinkage of agricultural areas with simultaneous agricultural internal conversions and appearance of large-scale tourism investments. The changes mentioned above take place in the surroundings of the national park, not within it. However, some of them are located close to the border of the park (e.g. construction of hotels) and may indirectly affect the park's ecosystem. However, it certainly disturbs the landscape surrounding the national park. The environment in the national park is directly affected by the loss of compact forest area in the Tatra NP as a result of natural incidents. These cannot be predicted, but are incidental and spatially limited. The ongoing changes are taking place in the very sensitive environment of the national park and its immediate surroundings. Unfortunately, we cannot predict or influence violent natural phenomena. However, when it comes to the transformation of the landscape surrounding the park, special attention should be paid to spatial planning, as the negative effects of fragmentation are a threat to the traditional Tatra landscape.

On the basis of the current landscape transformation that occurs in the Tatra region, the authors make a prediction that further increases in the share of urban areas will go together with a continuous decline in the role of agriculture and the appearance of tourist investments. Moreover, uncontrolled sprawl of the built-up fabric will lead to spatial chaos. Many localities will lose their compact development character and thus their traditional spatial layout. The phenomenon of urban sprawl will begin to appear around urban areas, which generates a number of spatial consequences: the need to bring in infrastructure, longer commuting times and increased distances to urban services (schools, hospitals and cultural facilities). This will increase the cost of maintaining such neighbourhoods. In addition, through dispersed settlement, spatial order will be disrupted, which will visually affect the local landscape, currently very valuable. In order to reduce the fragmentation that is already occurring, it would be advisable to introduce sustainable spatial planning principles in the built-up areas surrounding the national park. Fragmentation can be reduced by introducing the principle of compact construction, not building in scenic axes, foregrounds and on slopes outside existing buildings. Spatial order is also positively influenced by the cultivation of agricultural traditions and preventing the creation of wastelands.

The landscape fragmentation caused by natural incidents will probably continue, but it will never be permanent due to natural succession. Directly, fragmentation affects forest loss. In addition, the areas of individual ecosystems are reduced and ecological corridors are interrupted. Indirectly, fragmentation has a negative impact on the habitats of protected species. The decreasing acreage of habitats in which they occur leads to their withdrawal from the area. An example in the Tatra Mountains is the brown bear population, for which forests in Tatra NP are a refuge. Unfortunately, we are unable to influence fragmentation that occurs due to natural causes, e.g. within forests. However, its effects can be minimised, for example, by planting in areas of loss or allowing rapid natural succession in these places.

The use of the ICh and landscape fragmentation indexes allows for the assessment of landscape changes and their dynamics. However, it should be emphasised that the results obtained are strictly dependent on the quality of the materials used. Landscape indicators, although they have certain limitations, such as dependence on input data, mathematical nature and measurability of selected phenomena, still remain a good tool for quantifying landscape changes. However, landscape interpretation should be supplemented with qualitative information, for example, regarding local spatial development or spatial policy.

Acknowledgements

The authors would like to thank two anonymous reviewers for their valuable suggestions on the article.

Author's contribution

Conceptualisation; PP, KPK, Data curation; PP, Formal analysis; KPK, Funding acquisition; KPK, Investigation; PP, Methodology; PP, KPK, Project administration; PP, KPK, Resources; PP, KPK, Software; PP, Supervision; KPK, Validation; KPK, Visualisation; PP, Roles/Writing – original draft; PP, KPK, Writing – review & editing: KPK.

References

Alphan H., 2017. Analysis of landscape changes as an indicator for environmental monitoring. *Environmental Monitoring Assessment* 189: 24. DOI 10.1007/s10661-016-5748-7.

Asamoah E.F., Beaumont L.J., Maina J.M., 2021. Climate and land-use changes reduce the benefits of terrestrial protected areas. *Nature Climate Change* 11: 1105–1110. DOI 10.1038/s41558-022-01363-z.

Atasoy M., 2018. Monitoring the urban green spaces and landscape fragmentation using remote sensing: A case study in Osmaniye, Turkey. *Environmental Monitoring and Assessment* 190: 713. DOI 10.1007/s10661-018-7109-1.

Bank Danych Lokalnych, 2020. Online: https://bdl.stat.gov.pl/bdl/start (accessed 22 July 2022).

Bičík I., Kupková L., 2007. Land use development in the Czech Republic and possibilities of generalization and modelling. In: Dostál P. (ed.), *Modellling natural environment and society*. Charles University in Prague, Prague, Czech Republic: 179–203.

Bodziarczyk J., Szwagrzyk J., Zwijacz-Kozica T., Zięba A., Szewczyk J., Gazda A., 2019. The structure of forest stands in the Tatra National Park: The results of 2016–2017 inventory. *Forest Research Papers* 80(1): 13–21. DOI 10.2478/frp-2019-0002.

Bucała-Hrabia A., 2017. Long-term impact of socio-economic changes on agricultural land use in the Polish Carpathians. *Land Use Policy* 64: 391–404. DOI 10.1016/j.landusepol.2017.03.013.

Bucała-Hrabia A., 2018. Land use changes and their catchment-scale environment al impact in the Polish Western Carpathians during transition from centrally planned to free-market economics. *Geographia Polonica* 91(2): 171–196. DOI 10.7163/GPol.0116.

Cassatella C., Peano A., 2011. *Landscape indicators. Assessment and monitoring landscape quality*. 1st Edn. Springer Science+Bussiness Media, Dordrecht, Heidelberg, London, New York. DOI 10.1007/978-94-007-0366-7.

Cegielska K., Noszczyk T., Kukulska A., Szylar M., Hernik J., Dixon-Gough R., Jombach S., Valánszki I., Kovács K.F., 2018. Land use and land cover changes in post-socialist countries: Some observations from Hungary and Poland. *Land Use Policy* 78: 1–18. DOI 10.1016/j.landusepol.2018.06.017.

Cieślak I., Biłozor A., Szuniewicz K., 2020. The use of the CORINE Land Cover (CLC) database for analyzing urban sprawl. *Remote Sensing* 12: 282. DOI 10.3390/rs12020282.

CORINE Land Cover (CLC) European Environment Agency (EEA). Online: https://www.eea.europa.eu/publications/COR0-landcover (accessed 22 July 2022).

Ćwik A., Hrehorowicz-Gaber H., 2021. Causes and effects of spatial chaos in the polish Carpathians – A difficult way to sustainable development. *European Countryside* 13(1): 153–174. DOI 10.2478/euco-2021-0009.

DeFries R., Hansen A., Turner B.L., Reid R., Liu J., 2007. Land use change around protected areas: Management to balance human needs and ecological function. Land use change around protected areas. *Ecological Applications* 17(4): 1031–1038.

Deslatte A., Szmigiel-Rawska K., Tavares A.F., Ślawska J., Karsznia I., Łukomska J., 2022. Land use institutions and social-ecological systems: A spatial analysis of local landscape changes in Poland. *Land Use Policy* 114: 105937. DOI 10.1016/j.landusepol.2021.105937.

Duarte G.T., Santos P.M., Cornelissen T.G., Ribeiro M.C., Paglia A.P., 2018. The effects of landscape patterns on ecosystem services: Meta-analyses of landscape services. *Landscape Ecology* 33: 1247–1257. DOI 10.1007/s10980-018-0673-5.

Ellis E.C., Goldewijk K.K., Siebert S., Lightman D., Ramankutty N., 2010. Anthropogenic transformation of thebiomes, 1700 to 2000. *Global Ecology and Biogeography* 19: 589–606. DOI 10.1111/j.1466-8238.2010.00540.x.

Fabijanowski J., 1962. Lasy tatrzańskie. In: Szafer W. (ed.), *Tatrzański Park Narodowy*. Zakład Ochrony Przyrody PAN, Wydawnictwa popularnonaukowe, Kraków 21: 240−304.

Falťan V., Katina S., Minár J., Polčák N., Bánovský M., Maretta M., Zámečník S., Petrovič F., 2020. Evaluation of abiotic controls on windthrow disturbance using a generalized additive model: A case study of the Tatra National Park, Slovakia. *Forests* 11: 1259. DOI 10.3390/f11121259.

Fidelus-Orzechowska J., Gorczyca E., Bukowski M., Krzemień K., 2021. Degradation of a protected mountain area by tourist traffic: Case study of the Tatra National Park, Poland. *Journal of Mountain Science* 18: 2503–2519. DOI 10.1007/s11629-020-6611-4.

Fu B., Zhang L., Xu Z., Zhao Y., Wei Y., Skinner D., 2015. Ecosystem services in changing land use. *Journal Soils Sediments* 15: 833–843. DOI 10.1007/s11368-015-1082-x.

Fuller C., Ondei S., Brook B.W., Buettel J.C., 2019. First, do no harm: A systematic review of deforestation spillovers from protected areas. *Global Ecology and Conservation* 18: 00591. DOI 10.1016/j.gecco.2019.e00591.

Gimona A., Messager P., Occhi M., 2009. CORINE-based landscape indices weakly correlate with plant species richness in a northern European landscape transept. *Landscape Ecology* 24: 53–64. DOI 10.1007/s10980-008-9279-7.

Gomes E., Inácio M., Bogdzevič K., Kalinauskas M., Karnauskaitė D., Pereira P., 2021. Future land-use changes and its impacts on terrestrial ecosystem services: A review. *Science of the Total Environment* 781: 146716. DOI 10.1016/j.scitotenv.2021.146716.

Hełdak M., Szczepanski J., 2011. Changes of the landscape village of Bialka Tatrzanska from the development tourism. *Infrastructure and Ecology of Rural Areas* 1: 151–161.

Hersperger A., Oliveira E., Pagliarin S., Palka G., Verburg P., Bolliger J., Grădinaru S., 2018. Urban land-use change: The role of strategic spatial planning. *Global Environmental Change* 51: 32–42. DOI 10.1016/j.gloenvcha.2018.05.001.

Hess M., 1965. Piętra klimatyczne w polskich Karpatach Zachodnich. *Zeszyty Naukowe UJ, Prace Geograficzne* 11, Nakładem Uniwersytetu Jagiellońskiego, Kraków.

Inkoom J.N., Frank S., Greve K., Walz U., Fürst C., 2018. Suitability of different landscape metrics for the assessments of patchy landscapes in West Africa. *Ecological Indicators* 85: 117–127. DOI 10.1016/j.ecolind.2017.10.031.

Jaeger J.A.G., Soukup T., Schwick Ch., Madriñán L.F., Kienast F., 2016. Landscape fragmentation in Europe. In: Feranec J., Soukup T., Hazeu G., Jaffrain G. (eds), *European landscape dynamics*. 1st Edn. CRC Press

Jaworek-Jakubska J., Filipiak M., Napierała-Filipiak A., 2020. Understanding of forest cover dynamics in traditional landscapes: Mapping trajectories of changes in mountain territories (1824–2016), on the example of Jeleniogórska Basin, Poland. *Forests* 11: 867. DOI 10.3390/f11080867.

Jjumba A., Dragićević S., 2012. High resolution urban land-use change modeling: Agent iCity approach. *Applied Spatial Analysis and Policy* 5: 291–315. DOI 10.1007/s12061-011-9071-y.

Jõgiste K., Metslaid M., Uri V., 2015. Afforestation and land use dynamics in the Baltic States. In: Stanturf J.A. (ed.), *Restoration of boreal and temperate forests*, 2nd edn. CRC Press, Boca Rayton. DOI 10.1201/b18809.

Kijowska J., Kijowski A., Rączkowski W., 2010. Politics and landscape change in Poland: c. 1940–2000. In: Cowley D.C., Standring R.A., Abicht M.J. (eds), *Landscapes through the lens: Aerial photographs and historic environment*. 1st Edn. Oxbow Books Editors: 155–166.

Klimaszewski M., 1988. *Rzeźba Tatr Polskich*. PWN, Warszawa: 668.

Krajewski P., 2019. Monitoring of landscape transformations within landscape parks in Poland in the 21st century. *Sustainability* 11: 2410. DOI 10.3390/su11082410.

Krajewski P., Solecka I., Mastalska-Cetera B., 2017a. Landscape change index as a tool for spatial analysis. *IOP Conference Series: Materials Science and Engineering* 245: 072014. DOI 10.1088/1757-899X/245/7/072014.

Krajewski P., Solecka I., Mrozik K. 2018. Forest Landscape Change and Preliminary Study on Its Driving Forces in Ślęża Landscape Park (Southwestern Poland) in 1883–2013. *Sustainability* 10(12): 4526. DOI 10.3390/su10124526.

Krajewski P., Solecka I., Mrozik K., 2017b. Experience in identification of landscape background for rural landscapes in the suburban area of Wrocław. *Dissertations of Cultural Landscape Commission* 37: 117–125.

Kubacka M., Żywica P., Subirós J.V., Bródka S., Macias A., 2022. How do the surrounding areas of national parks work in the context of landscape fragmentation? A case study of 159 protected areas selected in 11 EU countries. *Land Use Policy* 113: 105910. DOI 10.1016/j.landusepol.2021.105910.

Kubak M., Gavurova B., Legutka K., 2020. Economic value estimation of the natural heritage of the Tatra National Park. *International Journal of Environmental Research and Public Health* 17(9): 3032. DOI 10.3390/ijerph17093032.

Lam N.S.-N., Cheng W., Zou L., Cai H., 2018. Effects of landscape fragmentation on land loss. *Remote Sensing of Environment* 209: 253–262. DOI 10.1016/j.rse.2017.12.034.

Ledda A., Serra V., De Montis A., 2019. The effect of rural buildings on landscape fragmentation in Natura 2000 sites: A case study in Sardinia. *Sustainability* 11(17): 4695. DOI 10.3390/su11174695.

Li X., Li S., Zhang Y., O'Connor P.J., Zhang L., Yan J., 2021. Landscape ecological risk assessment under multiple indicators. *Land* 10(7): 739. DOI 10.3390/land10070739.

Long H., Heilig G.K., Li X., Zhang M., 2007. Socio-economic development and land-use change: Analysis of rural housing land transition in the Transect of the Yangtse River, China. *Land Use Policy* 24: 141–153. DOI 10.1016/j.landusepol.2005.11.003.

Łowicki D., 2008. Land use changes in Poland during transformation: Case study of Wielkopolska region. *Landscape and Urban Planning* 87: 279–288. DOI 10.1016/j.landurbplan.2008.06.010.

Lu L., Li X., Cheng G., 2003. Landscape evolution in the middle Heihe River Basin of north-west China during the last decade. *Journal of Arid Environments* 53: 395–408. DOI 10.1006/jare.2002.1032.

Martinuzzi S., Radeloff V.C., Joppa L.N., Hamilton C.M., Helmers D.P., Plantinga A.J., Lewis D.J., 2015. Scenarios of future land use change around United States' protected Areas. *Biological Conservation* 184: 446–455. DOI 10.1016/j.biocon.2015.02.015.

McGarigal K., Marks B.J., 1995. FRAGSTATS: *Spatial pattern analysis program for quantifying landscape structure*. USDA Forest Service General Technical Report PNW-351, Portland.

Mika M., Faracik R., 2008. Second homes as a factor of the transformation of rural areas in the Polish Carpathians. *Folia Geographica* 12: 245–255.

Mingarro M., Lobo J.M., 2023. European National Parks protect their surroundings but not everywhere: A study using land use/land cover dynamics derived from CORINE Land Cover data. *Land Use Policy* 124: 106434. DOI 10.1016/j.landusepol.2022.106434.

Murzyn-Kupisz M., Hołuj D., 2020. Museums and coping with overtourism. *Sustainability* 12(5): 2054. DOI 10.3390/su12052054.

Naranjo Gómez J.M., Lousada S., Velarde J.G., Castanho R.A., Loures L., 2020. Land-use changes in the canary archipelago using the CORINE data: A retrospective analysis. *Land* 9: 232. DOI 10.3390/land9070232.

National Geoportal. Online: https://geoportal.gov.pl/ (accessed 20 July 2022).

Németh G., Lóczy D., Gyenizse P., 2021. Long-term land use and landscape pattern changes in a Marshland of Hungary. *Sustainability* 13: 12664. DOI 10.3390/su132212664.

Peano A., Cassatella C., 2011. Landscape assessment and monitoring. In: Cassatella C., Peano A. (eds), *Landscape indicators. Assessment and monitoring landscape quality*, 1st Edn. Springer Science+Bussiness Media, Dordrecht, Heidelberg, London, New York. DOI 10.1007/978-94-007-0366-7.

Pleninger T., Schaich H., 2014. Socialist and postsocialist land-use legacies determine farm woodland composition and structure: Lessons from Eastern Germany. *European Journal of Forest Research* 133: 597–610. DOI 10.1007/s10342-014-0788-4.

Popp A., Calvin K., Fujimori S., Havlik P., Humpenöder F., Stehfest E., Bodirsky B.L., Dietrich J.P., Doelmann J.C., Gusti M., Hasegawa T., Kyle P., Obersteiner M., Tabeau A., Takahashi K., Valin H., Waldhoff S., Weindl I., Wise M., Kriegler E., Lotze-Campen H., Fricko O., Riahi K., van Vuuren D.P., 2017. Land-use futures in the shared socio-economic pathways. *Global Environmental Change* 42: 331–345. DOI 10.1016/j.gloenvcha.2016.10.002.

Prestele R., Arneth A., Bondeau A., de Noblet-Ducoudré N., Pugh T.A.M., Sitch S., Stehfest E., Verburg P.H., 2017. Current challenges of implementing anthropogenic land-use and land-cover change in models contributing to climate change assessments. *Earth System Dynamics* 8: 369–386. DOI 10.5194/esd-8-369-2017.

Pukowiec-Kurda K., Vavrouchová H., 2020. Land cover change and landscape transformations (2000–2018) in the rural municipalities of the upper Silesia-Zagłębie Metropolis. *Sustainability* 12(23): 9911. DOI 10.3390/su12239911.

Rączkowska Z., 2021. Współczesna ewolucja rzeźby Tatr. In: Kostrzewski et al. (eds), *Współczesne przemiany rzeźby Polski*, pp. 59–94. DOI 10.12657/9788379863822-00.

Richling A., Solon J., 2011. *Ekologia krajobrazu*. Wydawnictwo PWN, Warszawa: 464.

Rodríguez-Rodríguez D., Martínez-Vega J., Echavarría P., 2019. A twenty year GIS-based assessment of environmental sustainability of land use changes in and around protected areas of a fast developing country: Spain. *International Journal of Applied Earth Observation and Geoinformation* 74: 169–179. DOI 10.1016/j.jag.2018.08.006.

Senetra A., Dynowski P., Cieślak I., Źróbek-Sokolnik A., 2020. An evaluation of the impact of hiking tourism on the ecological status of Alpine Lakes – a case study of the valley of Dolina Pięciu Stawów Polskich in the Tatra Mountains. *Sustainability* 12: 2963. DOI 10.3390/su12072963.

Sikora J., 2012. Analiza zmian struktury użytkowania gruntów w gminach o charakterze turystycznym województwa małopolskiego. *Infrastruktura i Ekologia Terenów Wiejskich* 3(4): 99–108.

Śleszyński P., Gibas P., Sudra P., 2020. The problem of mismatch between the CORINE land cover data classification and the development of settlement in Poland. *Remote Sensing* 12: 2253. DOI 10.3390/rs12142253.

Sobala M., Pukowiec-Kurda K., 2016. The new method of evaluating the degree of anthropogenic landscape transformation based on landscape metrics. *Dissertations of Cultural Landscape Commission* 31: 71–84.

Solon J., 2002. Ocena różnorodności krajobrazu na podstawie analizy struktury przestrzennej roślinności. *Prace Geograficzne* 185: 1– 233.

Solon J., Borzyszkowski J., Bidłasik M., Richling A., Badora K., Balon J., Brzezińska-Wójcik T., Chabudziński Ł., Dobrowolski R., Grzegorczyk I., Jodłowski M., Kistowski M., Kot R., Krąż P., Lechnio J., Macias A., Majchrowska A., Malinowska E., Migoń P., Myga-Piątek U., Nita J., Papińska E., Rodzik J., Strzyż M., Terpiłowski S., Ziaja W., 2018. Physico-geographical mesoregions of Poland: Verification and adjustment of boundaries on the basis of contemporary spatial data. *Geographia Polonica* 91(2): 143–170. DOI 10.7163/GPol.0115.

Spyt B., Kaczka R., Lempa M., Zajączkowska Z., 2020. Application of timberline morphometric. Analysis for detecting snow avalanche paths: A case study of the Tatra Mountains. *Gegraphia Polonica* 89(1): 91–111. DOI 10.7163/GPol.0048.

Šveda M., 2010. Zmeny v ovyužitízemevo funkcnom mestskom regióne Bratislava. *Acta Geographica Universitatis Comenianae* 54: 137–155.

UNESCO Convention Concerning the Protection of the World Cultural and Natural Heritage. Online: https://whc.unesco.org/en/convention/ (accessed 21 July 2022).

Urbański J., 2008. *GIS w badaniach przyrodniczych*. Centrum GIS Uniwersytet Gdański, Gdańsk: 266.

Van Rompaey A., Krasa J., Dostal T., 2007. Modelling the impact of land cover changes in the Czech Republicon sediment delivery. *Land Use Policy* 24: 576–583. DOI 10.1016/j.landusepol.2005.10.003.

Vavrouchová H., Toman F., 2013. Landscape dynamics in the Brno's surrounding between 2001 and 2011. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis* 61: 1451–1457. DOI 10.11118/actaun201361051451.

Vojtek M., Vojteková D., 2018. Mapping and assessment of land changes in coal mining area: A case studyfrom Slovakia. 5th International Multidisciplinary Scientific Conference on Social Sciences and Arts. *Conference Proceedings, Urban Planning Architecture Design* 5: 439–446. DOI 10.5593/sgemsocial2018/5.2.

Vukomanovic J., Singh K.K., Vogler J.B., Meentemeyer R.K., 2020. Protection status and proximity to public-private boundaries influence land use intensification near U.S.

parks and protected areas. *Conservation Science and Practice* 2: 190. DOI 10.1111/csp2.190.

Wężyk P., Wójtowicz-Nowakowska A., Pierzchalski M., Mlost J., Szafrańska B., 2013. Map of land use changes in malopolska voivodeship in 1986–2010 created by object based image analysis of Landsat and RapidEye satellite images. *Archiwum Fotogrametrii, Kartografii i Teledetekcji* 25: 273–284.

Winkler K., Fuchs R., Rounsevell M., Herold M., 2021. Global land use changes are four times greater than previously estimated. *Nature* 12: 2501. DOI 10.1038/s41467-021-22702-2.

Woś A., 2008. *Klimat Polski*. Wydawnictwo Naukowe PWN, Warszawa: 301

Young O.R., Lambin E.F., Alcock F., Haberl H., Karlsson S.I., McConnell W.J., Myint T., PahlWostl C., Polsky C., Ramakrishnan P., Schroeder H., Scouvart M., Verburg P.H., 2006. A port folio approach to analyzing complex human-environment interactions: Institutions and land change. *Ecology and Society* 11(2): 31.

Zambrano L., Aronson M.F.J., Fernandez T., 2019. The consequences of landscape fragmentation on socio-ecological patterns in a rapidly developing urban area: A case study of the National Autonomous University of Mexico. *Frontiers in Environmental Science* 7: 152. DOI 10.3389/fenvs.2019.00152.

Zbierska A., 2022. Landscape changes in protected areas in Poland. *Sustainability* 14: 753. DOI 10.3390/su14020753.

Zhang L., Wang H., 2006. Planning an ecological network of Xiamen Island (China) using landscape metrics and network analysis. *Landscape and Urban Planning* 78(4): 449–456. DOI 10.1016/j.landurbplan.2005.12.004.