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LAND COVER CHANGES OVER THE PAST 30 YEARS IN THE DEMÄNOVKA RIVER CATCHMENT

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Land cover changes over the past 30 years in the Demänovka river catchment

Many protected areas in Slovakia are under increasing pressure of deforestation and urbanisation. The Demänovka river catchment is one of the most affected. The river valley is famous for its largest cave system in the Carpathians, as a critical drinking water resource and nature values of international significance. In the past 30 years, the catchment's land cover has changed significantly, which has resulted in instability, habitat fragmentation, and biodiversity loss. In this study, we evaluated land cover changes for the periods 1992, 2003, and 2021 using visual interpretation from orthophoto maps to 18 CORINE Land Cover (CLC) standard classes. Area metrics such as class area (CA), number of patches (NP) and mean patch size (MPS) were employed in the analysis. Additionally, coefficients of anthropic impact (CAI) and ecological stability (CES) were computed to further evaluate the changes. The most significant change was related to deforestation. In 1992, coniferous forests represented 53.02% of the study area, but in 2021, it was 39.94%. It is related mainly to the increase of a transitional woodland/shrub class (change from 1.18% in 1992 to 14.08% in 2021). In addition, the area of new construction sites, sports, and leisure facilities was increased. Other changes concerned the decrease in alpine meadows or pastures were observed. Our results propose further trends and underpin the utmost importance for the sustainable management and protection of this unique catchment.

Key words: CORINE Land Cover, nature protection, habitat fragmentation, deforestation, tourism development, Demänovka river catchment

INTRODUCTION

Anthropic impact on the landscape has increased significantly in recent decades (Schneider 2012), including protected areas (Getzner and Švajda 2015 and Žoncová 2020). In Slovakia, this was a result of changes in political, economic, and land ownership structures (Krtička et al. 2018). Accurate knowledge about the size and type of changes in the land cover and its resources and their impact on natural processes is essential for the proper planning, management, and regulation of anthropogenic impacts (Anderson 1977, Sterling et al. 2012 and Yang et al. 2014). Land cover changes have already been associated by many authors with the growth of environmental problems (Turner et al. 2007), and with their manifestations such as soil degradation (Bakker et al. 2005), deteriorated water quality (Bolstad and Swank 1997 and Giri and Qiu 2016), loss and fragmentation of habitats (Foster et al. 2003, Fardila et al. 2017 and Li et al. 2018), or loss of biodiversity (Kopecká 2011 and Fardila et al. 2017). These facts are particularly important in protected areas (DeFries et al. 2007, Nagendra 2008 and Švajda et al. 2020).

Human-lead land cover transformations (especially deforestation or urbanisation causing soil sealing) are the subject of many scientific studies on a global scale (Hasan et al. 2020). Changes in the land cover in our territory were comprehensively evaluated in several studies (e. g. Feranec and Oťahel 2001, Feranec et al. 2006,

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Feranec and Nováček 2009, Feranec et al. 2010, Solín et al. 2011 and Feranec et al. 2017). Forest cover changes in protected areas in Slovakia were dealt with, for example, by Boltižiar et al. (2006), Boltižiar (2007), Falťan and Bánovský (2008), Hlásny et al. (2015), Bucha and Koreň (2017), Žoncová et al. (2020), including the territory of the Low Tatras (e. g. Čerňanský and Kožuch 2000, Stanková 2002, Krtička et al. 2018 and Hladký et al. 2020).

Demänovská dolina, legislatively recognized as one of the most valuable territories in Slovakia, has been facing the pressure of human activities for a long time (Hilbert 1982). Especially in recent years, this has been manifested by the unprecedented devastation of the territory, and many of its natural components and systems have been threatened or irreversibly damaged (Herich 2022).

This study aims to follow previous works in this area (Stanková 2002, Rakytová et al. 2015, Rakytová and Tomčíková 2017 and Krtička et al. 2018) and evaluate the most recent changes in land cover in the context of rapid developing tourism infrastructure, which began to manifest intensively, especially after the end of socialist era in the 1990s. The results of this work are critical for further geographical and environmental studies but also are useful for nature protection and sustainable management of this catchment.

STUDY AREA

The investigated territory of the Demänovka river catchment (Fig. 1) represents an extremely rare and irreplaceable natural heritage with rich fauna and flora and a unique cave system located in its central part. Most of the watershed lies within the Nízke Tatry National Park, and a significant part also in the 5th level of protection (National Nature Reserve Demänovská dolina, National Natural Monument Demänovská jaskyne and National Natural Monument Vrbické Pleso). Along its eastern edge, it borders the National Nature Reserve Jánska dolina and National Nature Reserve Ďumbier. In the northern part are Natural Reserve Jelšie, Natural Monument Demänovská Slatina, and Protected Site Bodický Rybník. The area is internationally protected as a part of the Natura 2000 network. It is represented by two Special Protection Areas (SPA). Area designated as SKUEV0302 Ďumbierske Tatry is protected under the Habitats Directive and area designated as SKCHVU018 Nízke Tatry is protected under the Birds Directive. Since 2006, the caves of Demänovská dolina valley have been included in the Ramsar sites. They are supraregional biocenters and biocorridors of regional importance. From the point of view of water resources, they belong to the Protected Water Management Area of the Low Tatras. In the upper and middle parts of the catchment, protective zones of water resources also occur. The karst spring in the lower part of the Demänovská dolina valley represents the most important source of drinking water (uptake of min. 150 l/s) for the Liptovská kotlina basin.

In terms of geology and geomorphology, the Demänovská dolina valley is divided into two parts, namely the northern and southern parts. The geological base of the area is formed by the Mesozoic rocks of the Inner Carpathians, such as local limestones, slates, and dolomites (Mazúr and Jákal 1969). The southern part of the valley is built with crystalline rocks, crystalline slates, and granites. Quaternary glaciation created cauldrons and extensive moraines. The northern part of the valley is made up of a massive complex of carbonate rocks of the Krížna mantle. The valley is shaped into a deep canyon, which was created at the confluence of Zadná voda and Demänovka streams.

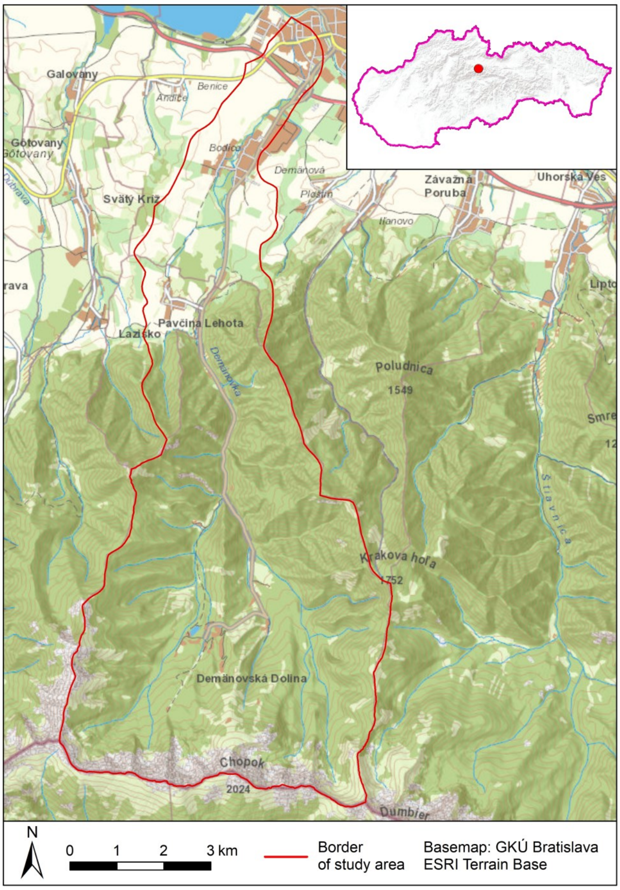

Fig. 1. The location of the studied catchment of the Demänovka river in the Low Tatras Mts. in Slovakia

Source: Basemap: GKÚ (2023) and ESRI (2023).

The highest peak is Chopok on the south (2,024 m a. s. l.) and the lowest is the confluence of Demänovka with the River Váh (562 m a. s. l.). Demänovka flows underground on the river-glacial plateau of Lúčky, where it creates the system of caves, shaping them by mechanical and chemical processes. The process of karstification of Triassic limestones created the Demänovský Kras (karst), which is expected to be the longest in the Carpathians (Herich 2022). From a recreational point of view, the most important are caves.

The area of Demänovská dolina valley belongs to the cold climate zone. The average annual air temperature is in the range of 6 to 7 °C. In the highest locations, the mean annual air temperature is around 0 °C and in the valleys, it is 0 to 4 °C

(Lapin et al. 2002). The temperature is influenced by the slope exposure in the valley and the forested area (Šavrnoch 1978) and inversions are typical here. Snow cover lasts on average between 140 to 160 days per year, but at the highest places, it can last more than 200 days per year. In Jasná, the height of the snow cover is on average 44 cm, in Chopok it is often over 200 cm (Lapin et al. 2002). The airflow in the valley refers to the orographic weakening or strengthening of the wind. This mainly concerns the falling winds that are present on the northern and southern sides of the Low Tatras ridge. The average wind speed is directly proportional to the increasing altitude, where the north-south air flow mainly prevails on the ridges (Šavrnoch 1978). Altitude also affects the amount of precipitation. The long-term mean annual rainfall in the period from 1951 to 1980 was 1,327 mm in Jasná, 1,158 mm in the Luková station, and 1,139 mm in the Chopok station.

Hydrologically, the Demänovka basin belongs to the region of the mantle of the northeastern slopes of the Low Tatras Mts., which is made up of limestones (Malík and Švasta 2002). Drainage of surface water is carried out on an impermeable base made of granitoid rocks and Werfen layers. The drainage streams Demänovka, Zadná voda, and Priečny potok originate in the crystalline granite core (Droppa 1976). The headwaters' part is divided into two branches, namely the eastern Široká dolina valley, where the Demänovka flows, and the western Zadná voda valley. In the valley of Zadná voda, there is Vrbické pleso lake, which, with its an area of 0.69 ha. Vrbické pleso lake was formed on the frontal moraine as a remnant of the glaciation period. Demänovka springs at an altitude of 1,570 m a. s. l. in one of the three glacial cauldrons located under the main ridge between mountains Chopok and Krúpova hoľa. The long-term mean annual flow of the Demänovka at the valley entrance was 1.3 m^3/s. This runoff regime is characterized by the maximum mean monthly flow in May and the minimum in January and February (Šimo and Zaťko 2002).

The flora of the catchment can be considered a characteristic of the Low Tatras Mts. and important plant species are represented here. According to the phytogeographic classification of Slovakia, the area belongs to the Central Carpathian flora (Futák 1980) and the coniferous district. The northern part of the valley, located on carbonate rocks, belongs to the Demänovské Hills subdistrict. The southern part of the valley, located on the crystalline rocks, belongs to the Kráľohoľský subdistrict (Plesník 2002). In the lower-lying area of the valley, fir and fir-spruce forests occur as potentially natural vegetation. On the dolomites and limestones, spruce-pine forests occur together with deciduous larch. The higher areas of the valley with silicate subsoil up to the upper border of the forest are covered with spruce blueberry forests. The higher positions of the main backbone of the Low Tatras Mts. and the adjacent side mountain ridges above the upper forest line on acidic substrates are covered with subalpine dwarf pine communities. At an altitude above 1,800 m a. s. l. alpine grass communities prevail. Along the upper forest line, communities with *Sorbus aucuparia* and *Picea abies* occur (Cvachová 1975). Original vegetation with some rare species is preserved only in remote and inaccessible places that were not affected by anthropogenic activity (Turis 2007).

The limestone cliffs of the Demänovská dolina valley are home to protected and endemic species of plants such as the bellflower *Campanula cochleariifolia*, pasqueflower *Pulsailla slavica*, snowbell *Soldanella carpatica* or grass *Kernera saxatilis*. Saxifrage *Saxifraga caesia*, avens *Dryas octopetala*, and sedge *Carex firma* grow in high mountain areas. Saxifrage *Saxifraga bryoides*, stonecrop *Sedum* *alpestre*, *Veronica alpina* or groundsel *Senecio abrotanifolius subsp. Carpathicus* can be found here on the crystalline rocks (Plesník 1995). The ecosystems of the studied area provide valuable habitat to endangered animal species of international significance such as golden eagle (*Aquila chrysaetos*), Eurasian eagle-owl (*Bubo bubo*), brown bear (*Ursus arctos*), grey wolf (*Canis lupus*), Eurasian lynx (*Lynx lynx*), Tatra chamois (*Rupicapra rupicapra tatrica*) or alpine marmot (*Marmota marmota*).

TOURISM DEVELOPMENT

The most important impetus for tourism in Demänovská dolina came in 1921 when Alois Král discovered the Demänovská Cave of Liberty. The first opening of the cave took place three years later, a road was built from Liptovský Mikuláš to the cave, and the first plans for further development of the valley were created (Herich 2022). Fast development of tourism in the Demänovská dolina valley began after the Second World War with the construction of the cable car from Jasná to Chopok in 1949 (Rakytová et al. 2015) and Jasná became the first planned tourist center in Low Tatras. In 1964 the independent municipality of Demänovská dolina valley was formed. In 1975, the northern and southern sides of Chopok mountain were connected by cable car, and this connection operated until 1988. Several hotels were built during the socialist era, however, the uncontrolled build-up was restricted by a construction closure (Herich 2022). In 1992, the company Ski Jasná (Inc.) was established. In 1994, the government approved the bid for downhill skiing during the 2002 Olympic Games, but it was withdrawn (Janiga et al. 1993). The candidacy was repeated in 2014, together with Krakow in Poland, but this was also canceled (Rakytová et al. 2015).

In the past 30 years, Demänovská dolina valley has seen significant tourist infrastructure growth, and the landscape of the entire catchment has changed rapidly, including the most protected areas. The development of accommodation capacities and the construction of new ski slopes are significantly reflected in the major changes in the landscape character of this valley (Krtička et al. 2018). The situation continues to worsen in many aspects, and the past 17 years have been unprecedented in terms of the devastation of the environment (Herich 2022).

In 2009, the company that owned the Jasná resort, the Tatry Mountain Resort (TMR), began large investments in the modernization of the ski infrastructure. In 2012, an unpaved road was built up to Chopok mountain. Since 2014, new cable cars and five new hotels have been added, and the Jasná Nízke Tatry resort has become the largest ski resort in Slovakia (Rakytová and Tomčíková 2015). However, the construction in the catchment is not even half of what was approved and there is still the threat of the construction of large multi-story buildings (Herich 2022).

In 2021 there were 5,375 beds in 151 accommodation facilities available. Facilities with a further 1,958 beds were under construction and other facilities with 582 beds have already the land permit. This makes 7,915 beds in 209 facilities (hotels, chalets, apartments for rent, etc.), with the biggest being the Damian Hotel by Vrbické Pleso with 1,000 beds (Herich 2022). It should be pointed out that there is a considerable discrepancy with the proposed maximal capacity in 1996 which accounted only for 3,450 beds at maximum (this data only concerns the Demänovská dolina valley area). According to the Demänovská Dolina municipal office (written communication in 2023), the mean number of overnight stays between 2013 and 2022 was 380,375 per year, which comes to 1,042 stays per day on average. At the peak of the winter holiday season, this number could be many times higher.

METHODS

The catchment border was obtained from the Slovak Hydrometeorological Institute (SHMI) and corrected using a digital elevation model (DEM). An area of 6,141.28 ha was defined in this way. Objects and segments of the land cover types were identified from orthophoto maps and assigned to one of the 18 third-level classes (out of 44) based on the Copernicus Programme CORINE Land Cover (CLC) nomenclature (EEA 1994). Digitization of land cover classes was performed by the manual "on-screen" method (Vojteková 2013 and Lillesand et al. 2015) in the ArcGIS 10.5 software environment (ESRI). For establishing the individual polygons, the interpretation rules according to Gerard et al. (2006) were used. The delineation of land cover objects was carried out on a scale of 1:10,000, but in case of ambiguities or the need to improve the identification of the class definition of individual polygons, a scale of 1:6,000 was used. The minimum size of the polygon was set at 0.5 ha and the minimum width of the linear element was 20 m. Land cover polygons smaller than 0.5 ha or line elements narrower than 20 m were not considered as a change. Each land cover class was designated by a three-digit code corresponding to the CORINE nomenclature. Land cover changes were only valid if the resulting polygons exceeded a minimum size of 0.5 ha or a minimum width of 20 m.

The first step was the creation of the starting map for 2021 based on the WMS orthophoto provided by the Geodetic and Cartographic Institute in Bratislava. For 2003, aerial images from GEODIS Slovakia, s. r. o. and for 1992 images from the Topographic Institute of Banská Bystrica were used. These aerial survey images had to be manually georeferenced. In this step, a georeferencing tool in the ArcGIS software was used. Orthophotos were registered in the coordinate system S-JTSK (Krovak's projection). The probability of introducing inaccuracies during the delineation of individual polygons and their determination from the point of view of the type of land cover was minimised by the retro-dating approach (Gerard et al. 2006). The resulting database displays the study area as a 1:10,000 map, divided into polygons, each displaying land cover information for 2021, 2003, and 1992.

For describing the land cover structure of the study area, the most appropriate landscape metrics were chosen. Metrics were calculated at the class level. Principles of landscape metrics were defined in several relevant works (Forman and Godron 1981, Gustafson and Parker 1992, McGarigal and Marks 1995, McGarigal and Cushman 2002 and Cushman et al. 2008) and applied in many studies of different regions. For this study, three indexes (area metrics) have been chosen: 1) class area (CA) – a measure of landscape composition (in hectares); 2) number of patches (NP) – a measure of landscape configuration that represents the number of individual patches (polygons) of landscape elements and 3) mean patch size (MPS) – represents average patch size (in hectares) and it is a measure of landscape subdivision. For calculating the chosen landscape metrics, the Patch Analyst extension for ArcGIS (Centre for Northern Forest Ecosystem Research) was used.

To reflect on the intensity of man-made land cover changes, the coefficient of the rate of anthropogenic impact (CAI) was applied (Kupková 2001). It is expressed as the ratio of areas with high land-use intensity (e.g. fields, built-up areas) to the areas with low intensity (forests, meadows and lakes). If the coefficient is equal to one, it means that both variables are in balance with each other. In general, the larger the share of intensively used areas, the higher the value of the coefficient (Kupková 2001).

Finally, the coefficient of ecological stability (CES) for each period was calculated (Löw 1987). The degree of ecological stability represents a level of current ecosystem deviation from the natural state. The ecological stability coefficient is determined according to the equation that is put into the proportion of stable (e. g. forests) and less stable classes (e.g. urban areas). CES was calculated according to the equation:

$$CES = \frac{D_5 + D_4 + D_3}{D_2 + D_1 + D_0} \; .$$

D_5 represents a landscape with natural and close-to-nature vegetation – natural forests, natural grass-herb communities, wetlands, peatlands, waterways, and areas with natural channels and banks and with characteristic water and coastal communities, etc.; D_4 represents a landscape with semi-natural and close-to-nature vegetation, forests, meadows with a predominance of naturally growing species, natural water bodies, etc.; D_3 represents a landscape with anthropogenically conditioned vegetation with natural elements, e.g. grassed and extensively used orchards, etc.; D_2 represents a landscape with anthropogenically conditioned vegetation of a synanthropic character, e.g. intensively used orchards, vineyards, reclaimed meadows, etc.; D_1 are for example intensively used and area-wide blocks of arable land, etc. and D_0 are built-up areas, roads, and associated land. CES by Löw (1987) proved to be the most suitable for the study of this type because it includes in its formula all land cover classes and types of landscape and classifies them according to the degree of ecological stability (Vojteková and Vojtek 2016).

RESULTS AND DISCUSSION

The most dominant class of all analysed periods by the CAI were coniferous forests (Tab. 1). Coniferous forests (312) were also the most dynamic class, with a more than 13% decrease in total area participation from 1992 to 2021. The noticeable decrease in class 312 is related to the increase in the transitional woodland/shrub class (324). It is mainly a result of timber logging, some of which came from wind storms that occurred in the Low Tatras Mts. in 2002, 2004, 2007, and 2014 (Žoncová et al. 2020). Several wind throw calamities have severely affected Slovak forests within the last 20 years. The second biggest wind throw calamity occurred on May 15, 2014, and the study area was one of the most affected (Kunca et al. 2014).

Tab. 1. CLC classes evaluated in the study and the class area (CA) in hectares and % of the total area

Code	Class	CA 1992		CA 2003		CA 2021		CA 1992-2021	
		ha	%	ha	%	ha	%	ha	%
112	Discontinuous urban fabric	157.45	2.56	165.75	2.70	184.78	3.01	**+27.33**	**0.45**
121	Industrial or commercial units	28.92	0.47	36.56	0.60	44.67	0.73	**+15.75**	**0.26**
122	Road and rail networks and associated land	13.89	0.23	13.89	0.23	13.89	0.23	0.00	0.00
133	Construction sites	0.00	0.00	1.45	0.02	23.46	0.38	**+23.46**	**+0.38**
141	Green urban areas	6.83	0.11	6.83	0.11	4.50	0.07	-2.34	-0.04
142	Sport and leisure facilities	199.94	3.26	202.18	3.29	252.98	4.12	**+53.04**	**+0.86**
211	Non-irrigated arable land	597.58	9.73	537.43	8.75	566.68	9.23	**-30.90**	**-0.50**
231	Pastures	193.59	3.15	246.72	4.02	181.80	2.96	**-11.79**	**-0.19**
242	Complex cultivation patterns	32.08	0.52	27.21	0.44	6.44	0.10	**-25.64**	**-0.42**
243	Land principally occupied by agriculture with significant areas of natural vegetation (244 Agro-forestry areas)	74.56	1.21	53.81	0.88	48.14	0.78	**-26.43**	**-0.43**
311	Broad-leaved forest	89.68	1.46	100.68	1.64	137.35	2.24	**+47.68**	**+0.78**
312	Coniferous forest	3256.23	53.02	3270.70	53.26	2453.09	39.94	**-803.14**	**-13.08**
313	Mixed forest	290.19	4.73	296.43	4.83	291.50	4.75	+1.31	+0.02
321	Naturalgrasslands	45.46	0.74	36.22	0.59	35.46	0.58	**-10.00**	**-0.16**
322	Moors and heathland	507.02	8.26	543.99	8.86	570.99	9.30	**+63.97**	**+1.04**
324	Transitional woodland-shrub	72.67	1.18	92.45	1.51	864.72	14.08	**+792.04**	**+12.90**
333	Sparsely vegetated areas	572.66	9.32	506.46	8.25	456.88	7.44	**-115.79**	**-1.89**
512	Water bodies	2.52	0.04	2.52	0.04	3.96	0.06	+1.44	+0.02

Note: The last two columns indicate the overall change and highlighted in bold are values with more than 10 hectares change.

Tab. 2. Indexes NP (number of patches) and MPS (mean patch size in hectares) during the evaluated periods

Code	Class	1992		2003		2021		1992-2021	
		NP	MPS	NP	MPS	NP	MPS	NP	MPS
112	Discontinuous urban fabric	3.00	52.48	3.00	55.25	3.00	61.59	0	+9.11
121	Industrial or commercial units	5.00	5.78	5.00	7.31	7.00	6.38	+2	+0.60
122	Road and rail networks and associated land	1.00	13.89	1.00	13.89	1.00	13.89	0	0.00
133	Construction sites	0.00	0.00	1.00	1.45	4.00	5.87	+4	+5.87
141	Green urban areas	3.00	2.28	3.00	2.28	3.00	1.50	0	-0.78
142	Sport and leisure facilities	10,00	19,99	8.00	25.27	8.00	31.62	-2	+11.63
211	Non-irrigated arable land	4.00	149.40	6.00	89.57	6.00	94.45	+2	-54.95
231	Pastures	27.00	7.17	31.00	7.96	20.00	9.09	-7	+1.92
242	Complex cultivation patterns	6.00	5.35	7.00	3.89	3.00	2.15	-3	-3.20
243	Land principally occupied by agriculture with significant areas of natural vegetation (244 Agro-forestry areas)	2.00	37.28	2.00	26.91	2.00	24.07	0	-13.21
311	Broad-leaved forest	2.00	44.84	4.00	25.17	6.00	22.89	+4	-21.95
312	Coniferous forest	11.00	296.02	12.00	272.56	32.00	76.66	+21	-219.36
313	Mixed forest	2.00	145.10	2.00	148.22	2.00	145.75	0	+0.65
321	Naturalgrasslands	7.00	6.49	8.00	4.53	8.00	4.43	+1	-2.06
322	Moors and heathland	8.00	63.38	6.00	90.67	7.00	81.57	-1	+18.19
324	Transitional woodland-shrub	19.00	3.82	15.00	6.16	34.00	25.43	+15	+21.61
333	Sparsely vegetated areas	4.00	143.17	4.00	126.61	4.00	114.22	0	-28.95
512	Water bodies	2.00	1.26	2.00	1.26	3.00	1.32	+1	+0.06
	Total	116.00	-	120.00	-	153.00	-	-	-

Spatial changes are also visible in classes of discontinuous urban fabric (112), industrial or commercial units, public facilities (121), construction sites (133), and sports and leisure facilities (142). The spatial impact on the total area is not too intense (less than 1% for each of these classes), however, the ecological impacts of these increasing sites are relatively considerable. It is especially relevant to the class of sports and leisure facilities (142). Changes in agricultural areas (classes 211, 231, and 242) point to a slight abandonment of farming activities, successive growth, and urbanisation. In the alpine part of the study area, an increase in the class of moors and heathland (322) was observed replacing the alpine meadows class (333).

Class 312 is also the most dynamic by the NP and MPS indexes (Tab. 2). Coniferous forests achieved significant decreases in mean patch size with an increasing number of patches (by 21). On the other hand, significant increases in NP and MPS indexes were observed in class 324. An increase in the MPS for built-up and sports areas (classes 112, 121, 133 and 142) was observed alongside the appearance of some new patches. In general, the evolution of the NP index in total pointed to the fragmentation of the natural habitats of the study area, mainly due to coniferous forest fragmentation. Fragmentation is mainly the result of logging and created areas of transitional woodland/shrub class (324) representing clearings. However, the spatial impact of the expansion of sport and leisure facilities (142) cannot be neglected (Fig. 2). New development of anthropogenic activities is affecting ecologically stable and valuable parts of the mountain landscape.

Taking into account the different lengths of the compared periods, the land cover change in the first period (1992 – 2003) was not as significant as in the second one (2003 – 2021). If the recent trend continues, subject to forest availability, the MPS would decrease by 9.8 ha/year on average, which may result in MPS decreasing to 27.7 ha in the next 5 years, creating many areas of forest too small to sustain wildlife and another ecosystem services (Vatseva et al. 2016). In terms of the total 312 class area, this would mean a possible loss of 40.9 ha/year.

CAI reflects the level of anthropic activity by relating the areas with high impact to areas with low impact intensity (Kupková 2001). During the evaluated periods the trend of CAI was observed to be increasing (Tab. 3). It points to expanding anthropic impact in the study area. The significant increase in CAI from 0.21 in 1992 to 0.47 in 2021 was caused mainly by changes in class 324. Many areas of transitional woodland/shrub (324) are a result of logging; therefore, these were classified as areas with high land-use intensity. However, the influence of the increase in artificial surfaces 112, 121, 133, and 142 cannot be neglected despite making up only a small proportion of the total catchment area.

In general, the ecological stability coefficient, which represents the ratio of natural and semi-natural ecosystems to fully synanthropic habitats and built-up areas, was high during all the evaluated periods (Tab. 3). According to Kopp (2004), the ecological stability of the landscape is determined not only by the quality of its ecosystems but also by their functional arrangement. In addition, Lipský (2000) states that when assessing the ecological stability of the landscape using various CES, it is also important to take into account the nature of the study area in which the research is carried out. CES should be above 1.21 to mark areas with a high ecological stability (Löw 1987). Despite achieving high values of this index, there was, similar to the CAI, a considerable drop in its value after 2003. This was caused by the processes mentioned earlier. If the recent anthropic impact continues, the index could drop below 1.21 by 2028. However, this is only a rough estimate of ecological stability and more detailed and targeted approaches would be beneficial to demonstrate the seriousness of the situation in the study area with regards to ecological stability.

Tab. 3. Coefficient of anthropogenic influence (CAI) and ecological stability (CES)

Code	Coefficient	1992	2003	2021
CAI	Coefficient of anthropogenic influence	0.21	0.21	0.47
CES	Coefficient of ecological stability	4.70	4.81	2.14

The main land cover change identified in this study lies within deforestation but new artificial areas such as sport and leisure facilities and construction sites are also seen on the interpretation maps (Fig. 2). The major transition from class 312 (coniferous forest) to 324 (transitional woodland scrub) was the most spatially significant as mentioned earlier. Also the transition from coniferous forests (312) to sport and leisure facilities (142) and on the territory of Demänová, also agricultural land (243) to discontinued urban fabric (112) occurred. Comparing our data to the CLC change layers (5 ha minimal mapping unit), the results were very similar. In the period 1990 – 2018, the CLC changes were identified for a class shift from 312 to 142 worth 220.82 ha and 312 to 324 of 586.61 ha. Together this comes to 807.43 ha which is very close to our estimate of 803.14 ha of coniferous forest loss. A small change in the 312 class of up to 5% occurred in 1990 – 2000, no change was recorded in the 2000 – 2006 period, about 30% of the 312 change occurred in the 2006 – 2012 period and most of it, about 65% happened in the last evaluated period 2012 – 2018. Much of the forest affected was concentrated in the upper parts of the valley with some patches in the foothill areas around Pavčina Lehota village and Demänovská hora (1,304 m a. s. l.).

According to a study by Herich (2022), the speed of wood extraction in the upper part of the catchment, especially since 2006, can be regarded as the most severe. Several other studies (e. g. Čerňanský and Kožuch 2000 and Stanková 2002) pointed out deforestation, an increase of built-up areas, and the spread of dwarf pine on alpine meadows as the main land-cover changes in this area. A recent study by Krtička et al. (2018) analysed the area of Demänovská dolina valley for 1949, 2007, and 2013 time horizons in detail (minimal map unit 625 m^2). The authors pointed out significant loss and fragmentation of forests and estimated, considering the local land use plan, further growth of disturbed areas is likely to occur. The largest decline of coniferous forests was observed after 2007, with the growing number of fragmented patches, from 27 to 58 in 2013. In our study, this was only 32 in 2021 which was caused by a larger mapping size (0.5 ha) and some fragmented patches of forest being below this size. Krtička et al. (2018) attributed the habitat fragmentation in the upper (southern) part of the valley to the construction of new cableways and ski slopes, causing further problems such as increased runoff or soil erosion, noise linked to the activity of visitors in the resort or changes in the visual image of the landscape. Another environmental problem can be water availability and high water consumption, especially during the winter season when is necessary to improve snow conditions on ski slopes.

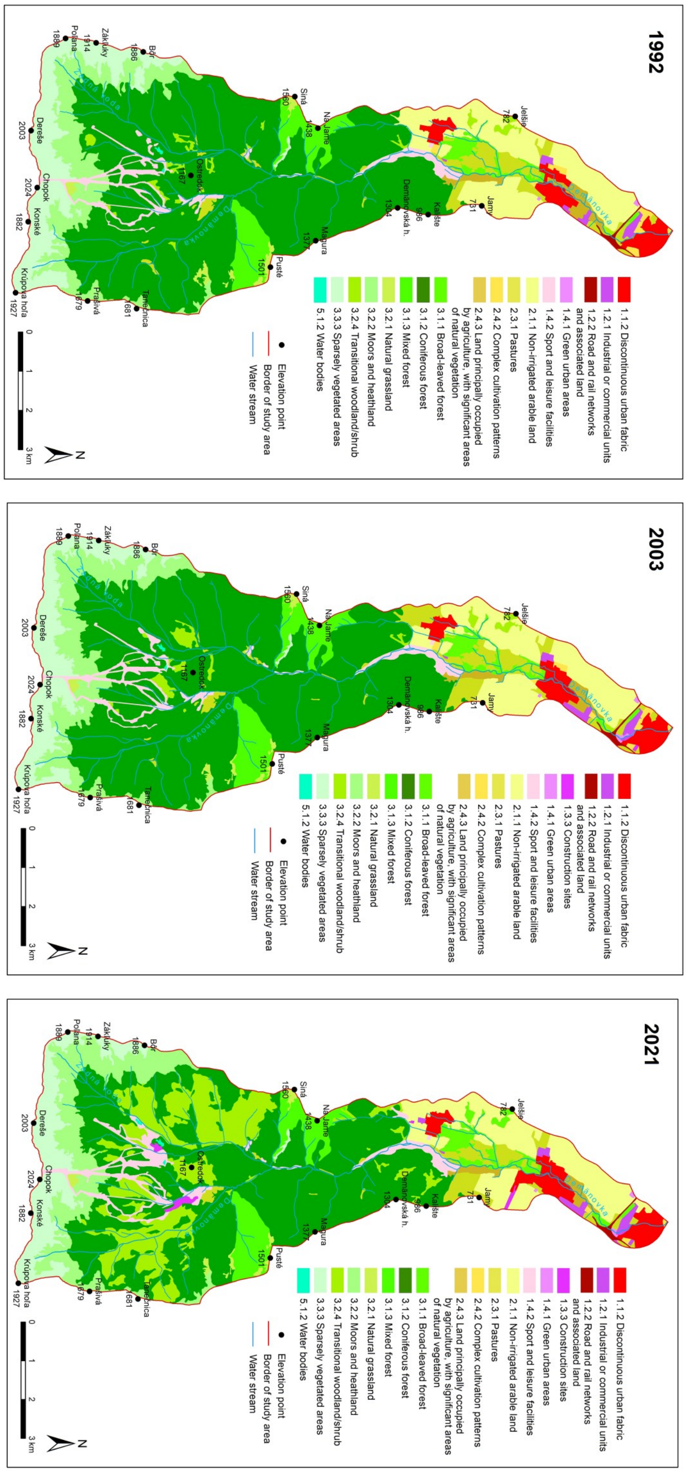

Fig. 2. GIS interpretation of land cover changes of the Demänovská river catchment using the CLC classification in 1992, 2003 and 2021

Significant changes in the study area are also confirmed by works carried out in a wider spatial context. In a study by Považan et al. (2022), the authors identified the frequency and size of changes in the whole of Slovakia based on the 1990, 2000, 2006, 2012, and 2018 CLC data. The growth of urban areas and hotspots was identified and apart from the largest cities, the upper part of the Demänovská dolina valley, the Jasná ski resort, was very significant from the country-wide analysis. The authors expressed concern that the increasing pressure would lead to massive biodiversity reduction and loss in areas where urbanisation enters zones with the highest degree of nature protection.

Oťahel et al. (2011) analysed changes in the Tatra region that occurred after 1990 and studied the effect of the large windstorm event in 2004. The major change was deforestation of the terrace and basin areas, but also the growth of artificial sealed surfaces. Some afforestation occurred due to the abandonment of agricultural fields and a decrease in grazing that was turned into transitional woodland/shrub populated by pioneer species, illustrating that similar trends in land cover changes occur also in other national parks.

Even though tourism can play an important role in the active environmental protection of national parks and other valuable areas, the growing number of tourists and their high demand for more luxurious services can pose a serious threat (Warchalska-Troll 2013). The pressure to develop further sports and accommodation facilities in the Demänovská dolina valley at the local level is higher than the interest in nature protection. In addition to this, other problems are linked to the private (rather than state) land ownership in the protected areas that imposes further pressures for tree harvesting regardless of the level of nature protection. Therefore, the coordination of nature protection, sustainable tourism development, and forestry management are key challenges that occur in the study area and other highly protected areas in Central and Eastern European countries (Puczkó et al. 2016).

CONCLUSION

In protected areas in Slovakia, but also worldwide, we see increasing pressure on the land resulting in land cover changes. Several studies reported significant modifications in the last decades in Slovakia caused by development and deforestation in the post-socialist era. The studies reporting on the exact land cover changes are a cornerstone for proposing their impact on natural processes and for proper sustainable planning and management of the protected areas.

For this study, an area under high pressure undergoing significant changes recently was depicted. It was defined by the orographic boundary of the Demänovka river catchment situated mostly within the Low Tatras National Park. Apart from its unique nature phenomena, it is also a famous ski resort. The expansion of anthropogenic activities represented by logging and the development of tourism infrastructure is the main driving force for the land cover change reported in this study. The expansion of tourist infrastructure has a smaller spatial impact, but its environmental impact can be characterized as greater and long-term.

We have analysed changes for 18 land cover classes using modified CLC methodology and evaluated three area metrics (class area, number of patches, and mean patch size) for 1992, 2003, and 2021. Additionally, the coefficients of anthropogenic impact and ecological stability were computed.

Our results pointed out the most extensive changes in the land cover for the coniferous forests that decreased by 803 ha (mainly since 2003) and these were replaced mostly by transitional woodland/shrub class. This class was mainly represented by clearings. There was a loss of alpine meadows of 115 ha in place of dwarf mountain pine growth and ski slopes, pastures, and agricultural areas were decreased by 120 ha and replaced by transitional vegetation or built-up areas. The developed sites increased the sealed surface by 95 ha. If this trend continues at a recent rate, we may expect 32 ha of newly sealed areas every 10 years. Both coefficients pointed out a significant negative change after 2003 and we expect, if nothing is done, the value of CES to fall below the stability threshold by 2028.

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ZMENY KRAJINNEJ POKRÝVKY ZA POSLEDNÝCH 30 ROKOV V POVODÍ RIEKY DEMÄNOVKA

V chránených územiach na Slovensku, ale aj vo svete, zaznamenávame rastúci tlak na krajinu, ktorý má za následok zmeny krajinnej pokrývky. Množstvo štúdií poukazuje na významné zmeny spôsobené urbanizáciou a odlesňovaním v postsocialistickej ére v posledných desaťročiach.

V tejto práci sme sa zamerali na vyhodnotenie zmien krajinnej štruktúry v území, ktoré sa nachádza pod veľkým tlakom investorov a aktuálne v ňom prebiehajú rozsiahle zmeny, ktoré však zároveň leží v centrálnej zóne národného parku – povodie rieky Demänovka v Nízkych Tatrách. Okrem jedinečných prírodných úkazov, ktoré sa tu nachádzajú (národné prírodné rezervácie, prírodné pamiatky, vzácne druhy rastlín a živočíchov), je toto povodie vo svojej hornej časti aj známym lyžiarskym strediskom Jasná. Rozšírenie infraštruktúry cestovného ruchu je hlavnou hnacou silou zmien krajiny uvedenej v tejto štúdii.

V tejto práci sme vyhodnotili zmeny pre 18 tried krajinnej pokrývky pomocou upravenej metodiky CLC (CORINE Land Cover) a pre ne sme vyčíslili tri plošné metriky (rozloha triedy, počet plôch a priemerná veľkosť plôch) za roky 1992, 2003 a 2021. Okrem toho boli vypočítané aj koeficienty antropogénneho vplyvu a ekologickej stability.

Najväčšie zmeny sme zaznamenali v triede ihličnatých lesov, kde za celé skúmané obdobie došlo k poklesu celkovej rozlohy o 803 ha. Najväčšie zmeny prebehli po roku 2003 (a podľa CLC zmenových vrstiev až po roku (2012). Táto trieda krajinnej pokrývky bola vo väčšej miere nahradená prechodnými lesokrovinami a v menšej, ale stále významnej miere, zjazdovkami a inými športovými areálmi. Ďalej sme zaznamenali úbytok triedy alpínskych lúk, zhruba o 115 ha, ktoré nahradili porasty kosodreviny a pasienky a poľnohospodárske plochy sa vplyvom sukcesie alebo urbanizácie zmenšili o 120 ha. Zastavané plochy celkovo vzrástli o 95 ha, pričom najväčšia zástavba bol koncentrovaná do lyžiarskeho strediska v hornej časti doliny. Ak by súčasný trend zmien krajinnej štruktúry pokračoval, predpokladáme 32 ha novozastavaných plôch každých 10 rokov. Oba stanovené koeficienty poukázali na výraznú negatívnu zmenu po roku 2003 a očakávame, že ak sa neprijmú adekvátne opatrenia, hodnota CES by mohla klesnúť pod hranicu stability do roku 2028.

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