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LAND COVER CHANGES AND EROSION SUSCEPTIBILITY IN THE LARGEST SKI RESORTS IN THE POLISH CARPATHIANS

Abstract: The intensive development of ski resorts leads to significant changes in the environment. The most important issue is the increase in the susceptibility of hillslopes to erosion due to deforestation and degradation of vegetation cover. RGB-band orthophotos provided by GUGiK (Head Office of Geodesy and Cartography in Poland) were used to determine land cover changes in the ski areas of the three largest ski resorts in the Polish Carpathians for the years 2009–2019. The ski resorts were selected on the basis of their area, intensity of use and transport capacity. The ski resorts selected for the analysis were: COS Szczyrk and Szczyrk Mountain Resort in the Skrzyczne Massif, PKL Jaworzyna Krynicka in the Beskid Sądecki Mountains and Kotelnica Białczańska in the Gubałowskie Foothills. A semi-automatic image classification in ArcGIS Pro defined three land cover classes: tree cover, grass cover, and no vegetation. By comparing classes distribution, it was determined changes in the susceptibility of hillslopes to erosion. On the basis of the field surveys attention was paid to the maintain and the development of ski resorts. The results indicate that the stations located in the Skrzyczne massif developed most intensively in the 2009–2019 decade, leading to a significant decrease in tree-covered and grassy areas. Intense water erosion and mass movements on road undercuts and escarpments on ski runs were observed. The most positive changes in terms of erosion protection occurred on Jaworzyna Krynicka, where the area deprived of vegetation decreased in the studied period. This is a result of the environmental monitoring carried out and the use of various anti-erosion treatments e.g. hay spreading, sheep grazing. The research indicates that anti-erosion treatments and continuity of vegetation cover play a very important role on the possibility of erosion processes on ski run surfaces.

Keywords: land cover changes, image classification, erosion, human impact, ski resort, Polish Carpathians

INTRODUCTION

The intensive development of ski tourism causes that, there are more and more ski stations in mountain areas (Candela 1982; Elsasser, Messerli 2001; Krzesiwo 2014, 2021; Vanat 2022). In the Polish Carpathians, characterized by relatively small differences in elevation compared to the Alps, for example, and little snowfall, the largest ski stations, in order to maintain their competitiveness and attractiveness, invest in high-quality infrastructure. The basis of a well-functioning ski station is high-capacity cable cars, extensive drainage systems and advanced ways of preparing and maintaining ski runs (Krzesiwo 2014; Piątek et al. 2022). Stations are located in areas characterized by high denivelations and appropriate hillslopes (Baranowska-Janota 1978; Sibley 1982; Piątek et al. 2022). The most important treatments are hillslope shaping, artificial snowmaking and regular snow grooming. These activities, especially the preparation of ski runs surfaces and artificial snowmaking, cause significant changes in the natural environment, (Mosimann 1985; Tsuyuzaki 1994; Bayfield 1996; Ries 1996; Keller et al. 2004; Wipf et al. 2005; Barni et al. 2007; Duda, Ziaja 2010), particularly in the landforms of an area (Krzemień 1997; David et al. 2009; Pintar et al. 2009; Ristić et al. 2012; Fidelus-Orzechowska et al. 2018; Wrońska-Wałach et al. 2019). The construction and preparation of ski slopes often involves cutting down trees, using heavy construction machinery, leveling the surface of the hillslopes, making the gradient appropriate, and destroying the microrelief of the hillslopes (Krzemień 1997; Ruth-Balaganskaya, Myllynen-Malinen 2000; Ristić et al. 2012; Fidelus-Orzechowska et al. 2018). The use of snow groomers and skiing with insufficient snow cover thickness causes destruction of vegetation cover on the hillslope, plowing of debris, compaction of covers and, as a result, activation of soil erosion (Tsuyuzaki 1994; Bayfield 1996; Łajczak 1996; Krzemień 1997; Ruth-Balaganskaya, Myllynen-Malinen 2000; Wipf et al. 2005; Barni et al. 2007; Pintar et al. 2009; Duda, Ziaja 2010; Roux-Fouillet et al. 2011; Ristić et al. 2012). Moreover, the use of snow groomers causes snow compaction and delays snowmelt, in the ski run area, by up to 4 weeks (Keller et al. 2004). The use of artificial snowmaking can avoid the negative impact of snow groomers on hillslopes and improve snow conditions on ski runs; however, it leads to an increase in the volume of water circulating down the hillslope, which results in an increase in energy in circulation in the catchment area (Łajczak 1996). It can also lead to intense erosion in and outside the ski run area (Krzemień 1997; David et al. 2012; Ristić et al. 2012; Fidelus-Orzechowska et al. 2018; Wrońska-Wałach et al. 2019). The development and maintenance of ski stations often leads to the creation of zones without vegetation. Such zones are exposed to the direct impact of numerous morphogenetic processes. In Poland, with the exception of the Kasprowy Wierch area, all ski stations are located in the forest belt, that is, in an area where the basis of energy and matter circulation is the transport of loose weathered and organic material by water flowing towards lower elevations. For this reason, linear erosion, torrential runoff, and fluvial processes play the most important role

(Gorczyca et al. 2014; Płaczkowska, Krzemień 2018; Rączkowska 2021). In the area, soil piping (Bernatek-Jakiel et al. 2016, 2017) and landslide processes (Gorczyca 2004; Święchowicz et al. 2021) Hillslopes deprived of vegetation cover, especially silty ones, are exposed to intense water erosion (Święchowicz 2002, Święchowicz et al. 2021).

The aim of this study is to determine the change in land cover between 2009 and 2019 in the ski run area and the resulting change in erosion susceptibility. The study also gives examples of geomorphological processes, landforms and ski run management methods in the study area.

STUDY AREA

The following ski resorts located in the Polish Carpathians were selected for analysis (Fig. 1): Kotelnica Białczańska, PKL Jaworzyna Krynicka, ski resorts in the Skrzyczne massif: COS Szczyrk and Szczyrk Mountain Resort. These stations have the highest capacity per hour and the highest susceptibility to erosion in the Polish Carpathians (Piątek et al. 2022). They are also all characterized by a high level of ski run maintenance through prior proper profiling of the hillslopes and regular artificial snowmaking and grooming.

Fig. 1. Location of study areas in Poland the Polish Carpathians, based on J. Solon et al. (2018)

KOTELNICA BIAŁCZAŃSKA

The Kotelnica Białczańska ski resort is located in the Fore-Tatra Foothills (Fig. 1), in the Gubałowskie Foothills and includes the slopes of Kotelnica (917 m a.s.l.) Jankulakowski Wierch (938 m a.s.l.) and Wysoki Wierch (948 m a.s.l.) The range is formed of Podhale-type flysch consisting of sandstoneshale layers and conglomerate horizons (Watycha 1972), specifically known as Upper and Lower Chochołowskie layers. The Kotelnica Białczańska ski resort began operations in 2001 and has been expanded several times since then. In the analyzed period 2009–2019, 3 new chairlifts were opened in the central and southern parts of the resort. Before the ski resort extension, the ski run areas were used as meadows and pastures. At that time, the forest area was almost unchanged (Ciołkosz et al. 2011; Hełdak, Szczepański 2011). The ski runs of the Kotelnica resort are characterized by denivelations of up to 239 m, the average gradient of the slopes is 11.7° and the maximum is 24.6°. The area of ski runs is 79 ha and the capacity is 18,770 people per hour, which is the highest capacity in the Polish Carpathians (Table 1).

Table 1.

Characteristic of analyzed ski resorts. Source: D. Piątek et al. (2022), modified

Ski resort	Year of establish	Eleveation of the upper station	Eleveation of the lower station	Eleveation gain	Average slope	Max slope	Ski run area	Capacity
		(m a.s.l)			(°)		(ha)	(persons/h)
Kotelnica Białczańska	2001	943	704	239	11.7	24.6	79.0	18,770
Jaworzyna Krynicka	1997	1,113	641	472	15.14	32.0	43.8	10,700
Skrzyczne	1958	1,244	537	707	14.2	37.3	111.0	16,620

JAWORZYNA KRYNICKA

The PKL Jaworzyna Krynicka ski resort is located on the hillslopes of Jaworzyna Krynicka (1,114 m a.s.l.) the highest peak of the Jaworzyna range in Beskid Sądecki Mountains (Fig. 1). It is formed from sandstones that build the Piwniczna layers, which are part of the Magura unit of the Outer Carpathians (Chrząstkowski et al. 1993). PKL Jaworzyna Krynicka ski resort was established in 1997. The only extension took place in 2009, when a new chairlift was built in the eastern part and a new ski run was prepared.

The construction of ski runs at the beginning of operation in 1997 was associated with the clearing of 40 ha of forest (Kostuch et al. 2000). In 2000, the surface of the ski runs was adequately covered with grass and there was no significant erosion on their surface. The surfaces were sufficiently levelled and drained (Kostuch et. al 2000). Ski runs on Jaworzyna are characterized by denivelations of up to 472 m, the average gradient of the slopes is 15.1° and the maximum is 32.0°. The area of the trails is 43.8 ha and the capacity is 10,700 people per hour. The data is presented in Table 1.

SKI RESORTS IN THE SKRZYCZNE MASSIF: COS SZCZYRK AND SZCZYRK MOUNTAIN RESORT

The described ski stations are located in the Skrzyczne massif (1,257 m a.s.l.) in the Silesian Beskid (Fig. 1) and cover the slopes of Skrzyczne, Małe Skrzyczne (1,211 m a.s.l.) and Malinów (1,115 m a.s.l.). It is the largest ski resort in Poland. The area is built from rocks of the Silesian unit (Godulian strata). characterized by thin sandstone layers and a high share of shales (Nescieruk, Wójcik 1997). The resort has been in operation on Skrzyczne since 1958, and on Małe Skrzyczne since the late 1960s, having been expanded several times, with the most recent and largest expansion taking place in 2017. In the part managed by COS Szczyrk, the chairlifts were replaced in 2013 and 2017. In Szczyrk Mountain Resort, 4 new chairlifts were launched in the analyzed period 2009–2019. In the area of the Skrzyczne massif first deforestation for ski runs took place in the 1950s and 1960. In the 1970s, there was a significant decrease in the area of forests cut down for the construction of ski runs, which were expanded during the period analyzed in this study. The forest area also declined significantly as a result of windthrow in 2004 and an earlier pest gradation (Durło 2010; Ciołkosz et al. 2011). The areas previously occupied by the forest in 2006 were meadows, pastures, fallow land and ski areas (Ciołkosz et al. 2011). Denivelations in the complex are the highest and reach 707 m, the average gradient of the ski runs is 14.2° and the maximum is 37.3°. The area of the ski runs is the highest in the Polish Carpathians – 110.99 ha (Table 1).

MATERIALS AND METHODS

Ski resorts located in the Polish Carpathians, distinguished in terms of area, intensity of use, transport capacity and erosion potential, were selected for analysis (Piątek et al. 2022). These are the ski stations with the highest capacity, area and intensive use of artificial snowmaking. Once the ski resorts were selected, their spatial extent was determined in ESRI: Arc GIS Pro 3.0 software, based on ski run schemes provided by individual ski resorts on resort websites and orthophotos. Two time periods were assumed for the analysis: 2009 and 2019. The land cover of the ski runs was determined on the basis of orthophotos obtained from the GUGiK (Head Office of Geodesy and Cartography in Poland) resource made available at geoportal.gov.pl. Orthophotos with a spatial resolution of 0.25 m taken in the RGB band were analyzed. Three land cover classes were defined: tree cover, grass cover and no vegetation. The share of each land cover class was analyzed for both 2009 and 2019. Land cover classification was performed in Arc GIS Pro 3.0 software using semi-automatic pixel image classification. The field work was based on verification of the data of orthophotos concerning surface of ski runs in terms of erosion landforms and, especially, methods of managing the surface of ski runs.

RESULTS

LAND COVER CHANGES

KOTELNICA BIAŁCZAŃSKA

Changes in land cover at the Kotelnica Białczańska resort are primarily related to the significant expansion of the complex since 2009. Since then, 3 large ski runs have been built in the central and southern parts (Figs. 2, 3). The area covered by grass in 2009–2019 did not change significantly: there was an increase of 0.4% from 63.4% (50.1 ha) to 63.8% (50.4 ha) (Table 2). However, a big change occurred in the area without vegetation and covered with trees (Figs. 2, 3). The areas without vegetation increased from 22.5% (17.8 ha) to 36.2% (28.6 ha) (Table 2). All the trees in the area of the current ski runs, which in 2009 covered 14.1% of the total area of the current complex (11.1 ha), have been felled (Figs. 2, 3).

JAWORZYNA KRYNICKA

Analyzing the changes in land cover in the period 2009–2019 for the ski resort in Jaworzyna Krynicka, attention is drawn to the smallest changes from all the surveyed stations (Figs. 4, 5). The area of Jaworzyna Krynicka is the only one of the studied areas where the proportion of area covered by grass increased, from 52.3% (22.9 ha) in 2009 to 72.2% (31.6 ha) in 2019 (Table 2). In favor of an increase in the area covered with grass, the area without vegetation decreased (Figs. 4, 5). In 2009, it accounted for 35.9% (15.7 ha) and in 2019 it has decreased to 27.8% (12.2 ha). This is mainly related to

Table 2.

Land cover in 2009 and 2019 in the analyzed ski resorts

Research area	Year of imagery	Total area	Grass cover area	No vegetation area	Tree cover area	Share of grass cover area	Share of no vegetation area	Share of tree cover area
		(ha)				(%)		
Kotelnica Białczańska	2009	79.0	50.1	17.8	11.1	63.4	22.5	14.1
Kotelnica Białczańska	2019	79.0	50.4	28.6	0.0	63.8	36.2	0.0
Jaworzyna Krynicka	2009	43.8	22.9	15.7	5.2	52.3	35.9	11.8
Jaworzyna Krynicka	2019	43.8	31.6	12.2	0.0	72.2	27.8	0.0
Skrzyczne	2009	111.0	74.9	11.6	24.5	67.5	10.4	22.1
Skrzyczne	2019	111.0	49.7	61.3	0.0	44.8	55.2	0.0

Source: own elaboration.

the overgrowth of grass on the ski run in the southern part of the ski resort (Figs. 4, 5). However, the preparation of the new ski run, located in the eastern part of the complex (Figs. 4, 5), led to the felling of all the trees that grew in the area of the current ski runs. 5.2 ha of tree cover area was cut down, which represents a change from 11.8% of tree cover area in 2009 to 0% in 2019 (Table 2). The change in tree cover area is also related to the slight widening of the ski runs, mainly in the northern part of the resort (Figs. 4, 5).

COS SZCZYRK AND SZCZYRK MOUNTAIN RESORT (SKRZYCZNE MASSIF)

The analysis of the development history of the ski resorts shows that the stations located in the Skrzyczne massif developed most intensively in the decade 2009–2019, which led to a significant decrease in wooded and grassed areas (Figs. 6, 7). There was a significant increase in non-vegetated areas in 10 years, from 10.4% (11.6 ha) to 55.2% (61.3 ha) of all ski runs (Table 2). In particular, this occurred in the central part of the resort (Figs. 6, 7). During the study period, the area of land covered by grass decreased from 67.5% (74.9 ha) to 44.8% (49.7 ha) (Table 2). As a result of the resort expansion, all patches of forest were cleared for the construction of the current ski runs (Figs. 6, 7). In 2009, tree-covered areas accounted for up to 22.1% of the area (24.5 ha). No section of the area can be recorded as being overgrown with grass since 2009 (Figs. 6, 7).

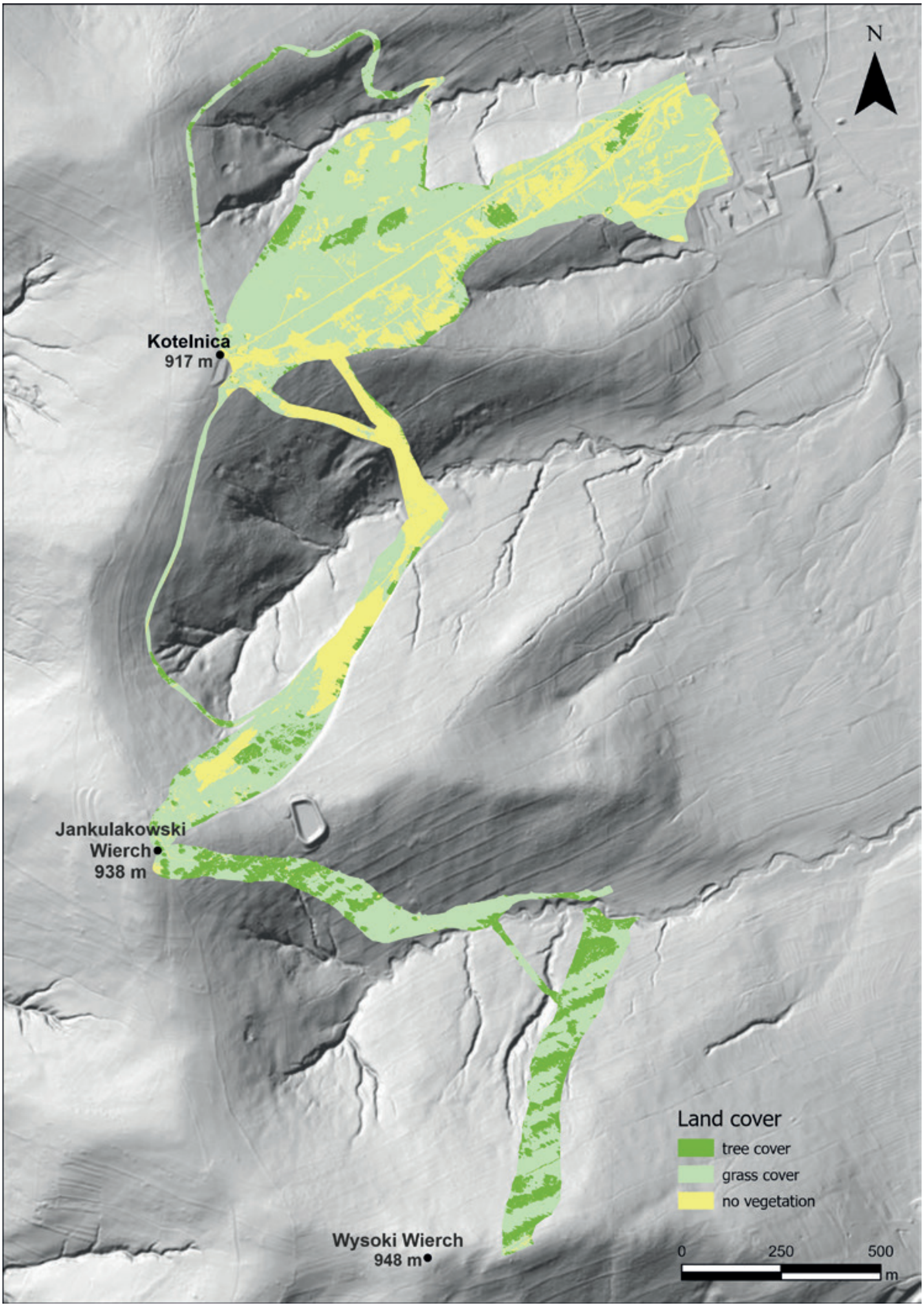

Fig. 2. Land cover at Kotelnica Białczańska ski resort in 2009

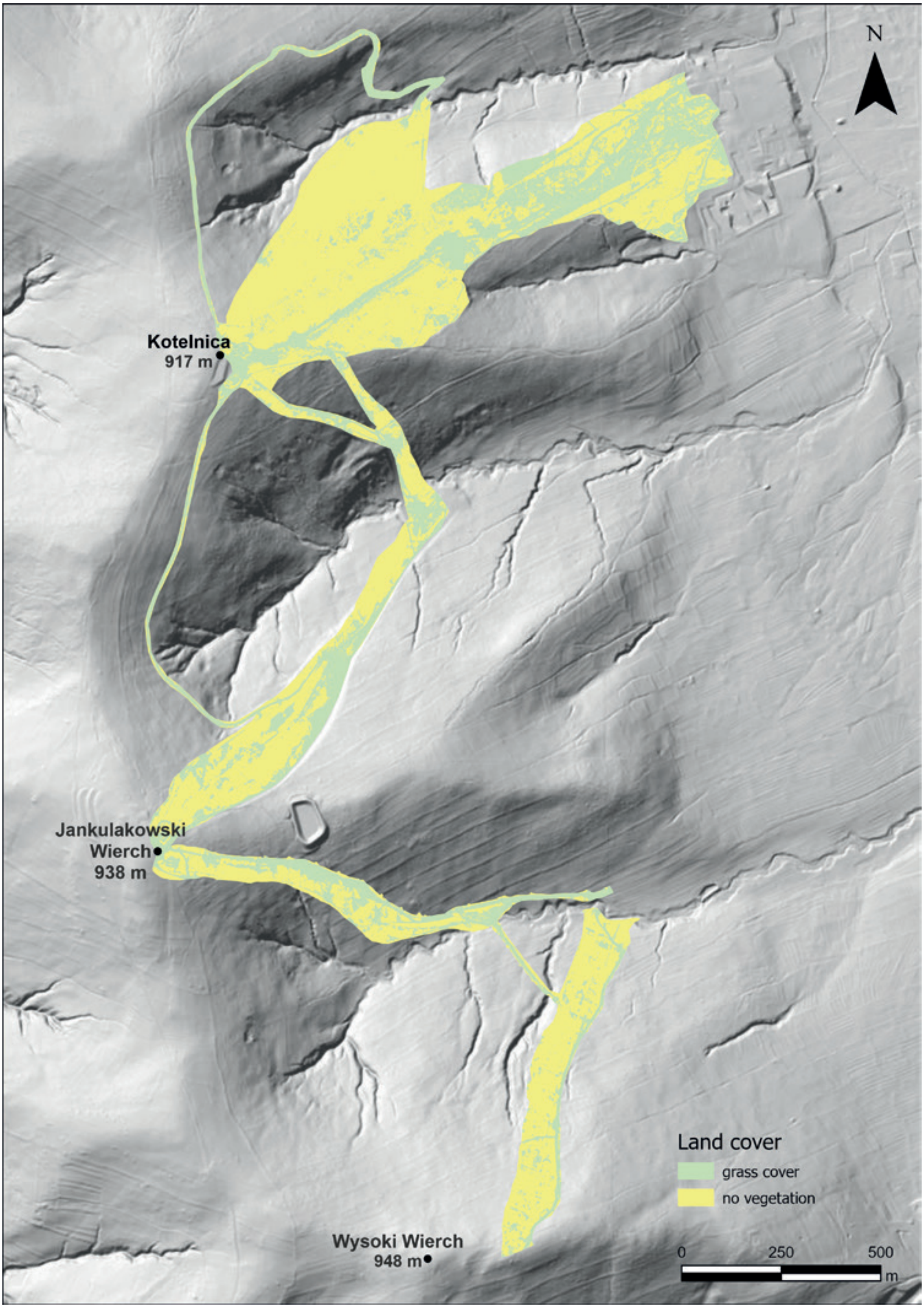

Fig. 3. Land cover at Kotelnica Białczańska ski resort in 2019

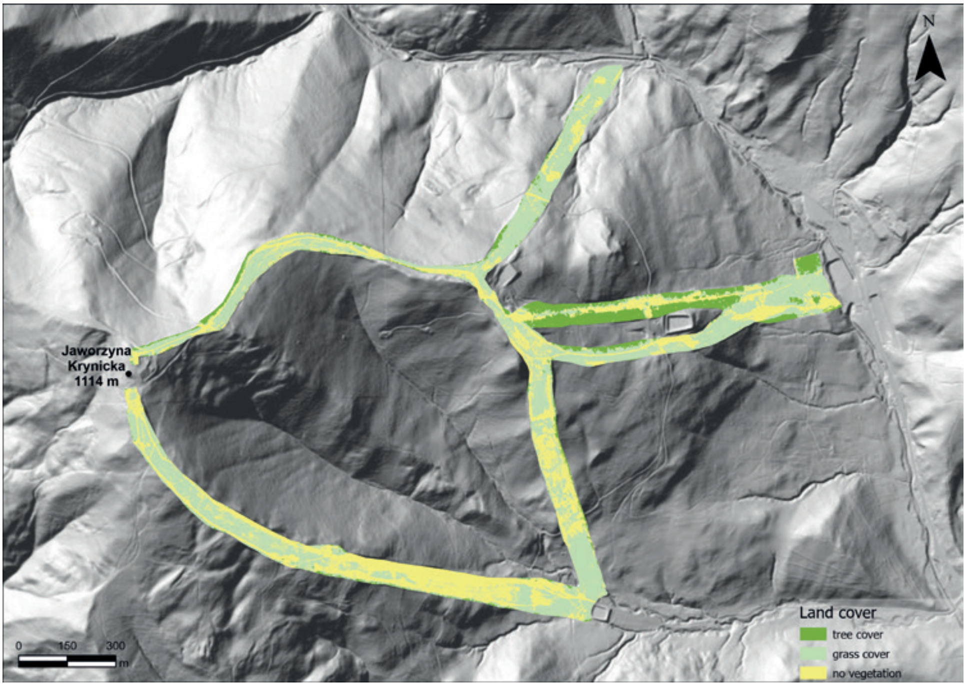

Fig. 4. Land cover at Jaworzyna Krynicka ski resort in 2009

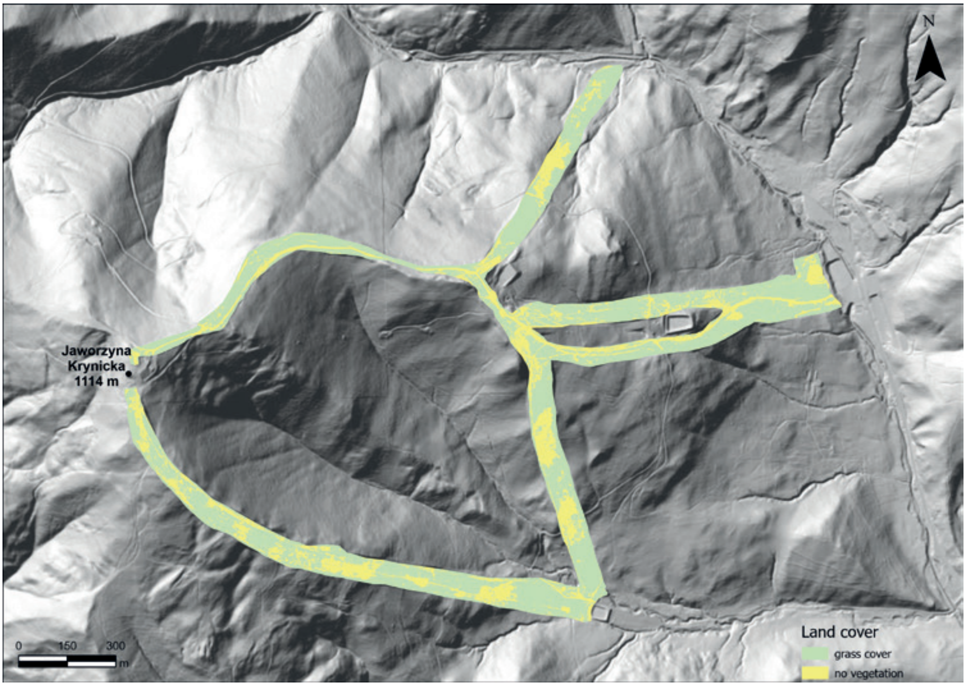

Fig. 5. Land cover at Jaworzyna Krynicka ski resort in 2019

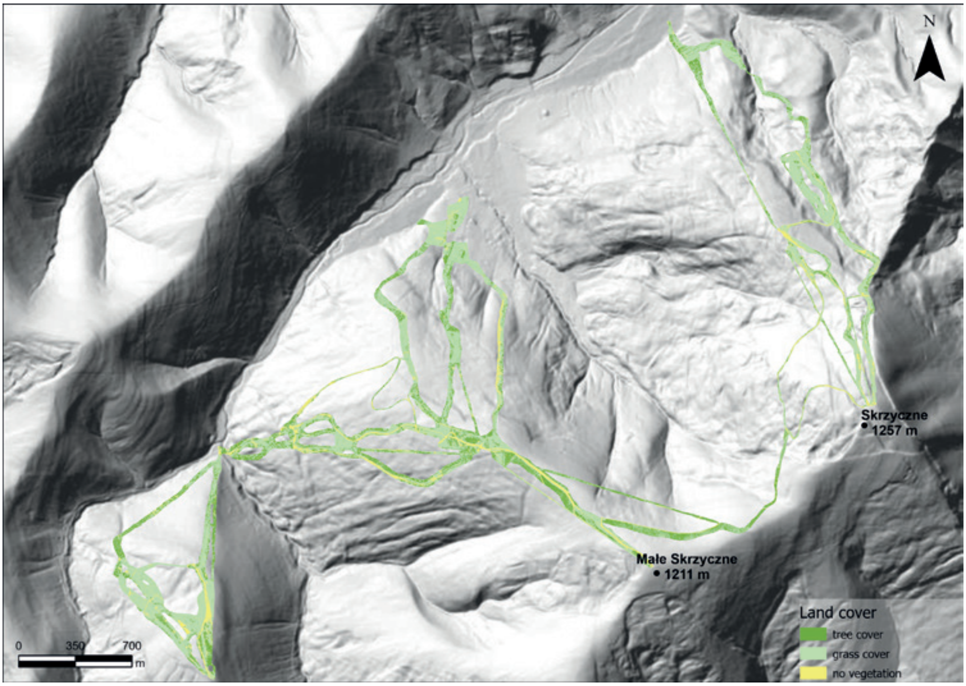

Fig. 6. Land cover at Skrzyczne massif resort in 2009

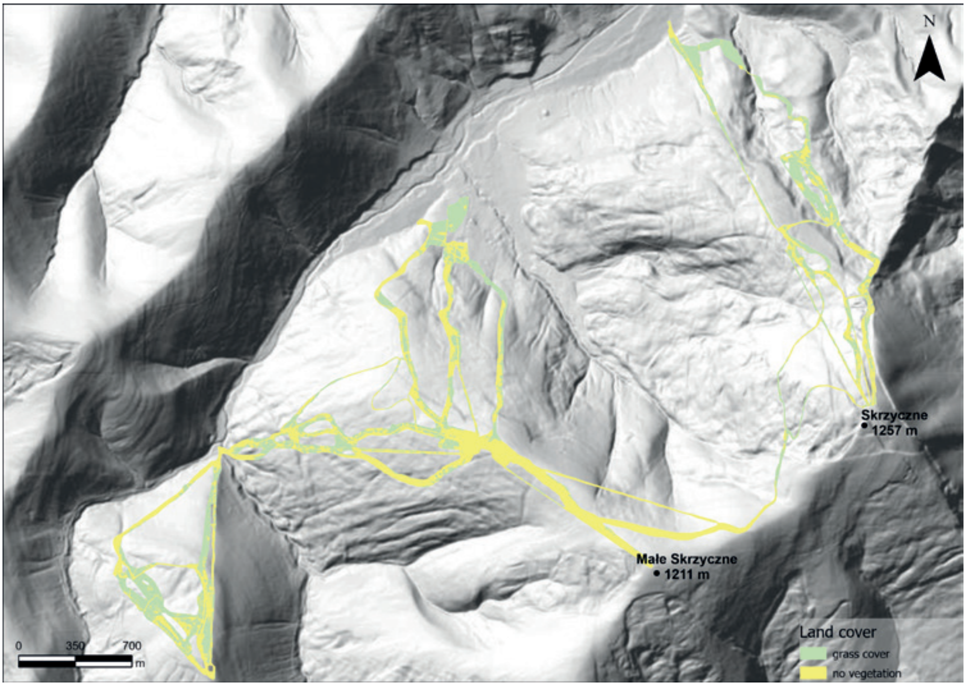

Fig. 7. Land cover at Skrzyczne massif ski resort in 2019

EROSION PROCESSES AND SKI RUN MANAGEMENT AT THE STUDIED SKI RESORTS

In the area of Kotelnica Białczańska, characteristic is the different routing of the drainage ditches. The ditches here are routed diagonally to the ski run, not perpendicularly as is usually the case (Fig. 8). Their dense network results in low intensity of linear erosion on the ski runs surface. The slope of the ditches directs water off from the ski run (Fig. 8). Erosional incision are created in the surrounding of ski runs, below the outlet of drainage ditches (Fig. 9). The depth of incisions is about 50 cm and in extreme cases exceed 1.5 m. Also in this area, sheep grazing is carried out, however, here traces of grass destruction by sheep were observed.

For the area of Jaworzyna Krynicka, the occurrence of few erosion and accumulation forms on the ski runs is typical. Field observations showed only the occurrence of 10–15 cm deep, several meters long erosional incisions in two areas of the station: on the ski run created in 2009 in the eastern part of the resort and on the north-south ski run in the southern part of the resort. Drainage ditches are perpendicular to the ski run. The slope of the ditches directs water to the center part of the ditch. This leads to filling up drainage ditches, which are regularly deepened (Fig. 10). It results in no erosion outside the ski run, at the outlet of ditches. Extensive sheep grazing was observed

Fig. 8. Diagonally routed drainage ditch, Kotelnica Białczańska

Fig. 9. Erosional incisions at the outlet of a drainage ditch from the ski run, Kotelnica Białczańska

Fig. 10. Perpendicularly routed, newly deepened drainage ditch, Jaworzyna Krynicka

on ski runs, with no damage to the vegetation.. Also to accelerate the growth of grass, the spreading of hay on surfaces without vegetation is used (Fig. 11).

The distribution of erosion traces in the Skrzyczne skiing area varies greatly. The eastern part, the oldest and rarely expanded is characterized by less intensive snowmaking and only few areas damaged by snow groomers have been observed. The situation is different in the rest of the resort. Here, intensive work has been carried out everywhere on extending or building new ski runs. However, the grassed ski runs are well maintained and hay is left on the surface after mowing (Fig. 12). In this case, the only areas susceptible to erosion are roads (Fig. 12). In addition to the exposed surfaces, an important aspect that can lead to the activation of geomorphological processes is the dense network of ski runs transverse the hillslope. This involves the creation of numerous road undercuts and escarpments, which are places where landslides can potentially occur (Fig. 13). Significant effects of water erosion occur primarily on the roads running in the ski run area (Fig. 13). These are used not only as access roads, but also intensively in summer as cycle routes which contributes to additional cutting. Most of drainage ditches are perpendicular to the ski run. Some of the drainage ditches, especially those on the newly developed ski runs, are masonry with large stones (Fig. 13). This is very beneficial because protects the ditch from erosion and, due to the stone roughness, causes a decrease in the energy of the water flowing through the ditch which reduces erosion off the ski run.

Fig. 11. Spreading hay on surfaces without vegetation, Jaworzyna Krynicka

Fig. 12. Well maintained ski run surface with hay left after mowing, visible access road without vegetation, Skrzyczne massif

Fig. 13. Ski run in the Skrzyczne massif. Visible road undercut and escarpment, surface without vegetation and the road running in the ski run area. Drainage ditch is masonry with large stones

DISCUSSION

The authors do not know of other works that present changes in land cover on ski runs on such a precise scale. However, these results can be compared with the general conditions of changes in land cover in the Carpathians. Such as the modern development of settlements, the development of ski infrastructure lead to an increase in the number of buildings, roads and different infrastructure reaching higher and steeper hillslopes (Kozak 2010; Bucała 2014; Krzesiwo 2014; Bucała-Hrabia 2017; Kaim et al. 2018). To summarize the changes in land cover at studied ski resorts in total in years 2009 and 2019, the area deprived of vegetation amounted to 102.0 ha and increased by 44.1% compared to 2009. It is 11.2% of the total area of ski runs of ski resorts with at least one cable car in the Polish Carpathians in 2019 (Piątek et al. 2022). The increase in the area deprived of vegetation and the intensity of erosion on hillslopes is mainly associated with the expansion of ski resorts and the earthworks carried out there (e.g. leveling hillslope surface). Such conclusions have already been presented in the literature (Ristić et al. 2012; Fidelus-Orzechowska et al. 2018). Due to the average slope gradient of ski runs prevailing in the Polish Carpathians in the range of 11–14° (Piątek et al. 2022) and the lack of similar studies in the area of ski runs, the potential erosion which may occur there may be compared to studies carried out in experimental plots in Szymbark (Gil et al. 2021) or in Jaworki (Kopeć, Misztal 1990). Surface runoff and the volume of eroded material were determined on: vegetation-free surfaces, potato crops, and grassland surfaces (entirely covered with grass). Potato crops are characterized by a low degree of vegetation cover and can be compare with plots without vegetation. Plot studies conducted in Szymbark, on the hillslope with 11° gradient proved that potato crops have 340 times higher soil erosion than grasslands (30-year measurement period) (Gil et al. 2021). In Jaworki this relation differs from 4 to 15 times (potato crops and grasslands, 3-year measurement period) and 9 to 24 times (no vegetation plots and grasslands) (Kopeć, Misztal 1990).

It should be emphasized, that the high degree of soil compaction occurring on the ski runs (Ruth-Balaganskaya, Myllynen-Malinen 2000) may modify the mass of eroded material. Moreover, artificial snowmaking and changes in snow melting patterns leading to an increase in the volume of water on the hillslope (Wrońska-Wałach et al. 2019), intensify water erosion in the ski run area (Krzemień 1997; Ristić et al. 2012; Fidelus-Orzechowska et al. 2018) and will undoubtedly increase the mass of eroded material on ski runs. Research carried out on ski runs and hiking trails indicates that areas devoid of vegetation, apart from the snowmelt period, are eroded most intensively during heavy rainfall in summer (Krzemień 1997; Ristić et al. 2012;

Fidelus-Orzechowska et al. 2017). Therefore, the recovery of the vegetation cover should take place as soon as possible after the ski season. Perhaps, in order to encourage grass growth before the summer rains, it is worth shortening the ski season in spring. In the studied areas, erosion on ski runs is reduced by reseeding of grass, grazing of sheeps, regular mowing, spreading of hay and appropriate drainage ditch routing and management. Seeding appropriate grass mixtures on ski runs is often discussed in the literature (Barni et al. 2007; Burt, Rice 2009; Pintaldi et al. 2017). The results indicate that the selection of grass mixtures should depend on the altitude above sea level (Barni et al. 2007; Burt, Rice 2009; Pintaldi et al. 2017). Similar study was conducted on the Jaworzyna Krynicka and presented that grass species was adequately selected and surface of ski runs was well covered (Kostuch et al. 2000; Kacorzyk, Kasperczyk 2014). Furthermore, the reinforcement of the hillslope surface with sisal nets also has a significant effect on reducing erosion and accelerating the growth of seeded grass, which has been described in the literature in Mont Dore (Krzemień 1997) and in the Italian Alps (Pintaldi et al. 2017). On ski runs in Jaworzyna Krynicka and Kotelnica Białczańska resorts, also sheep grazing was observed. As stated P. Kacorzyk and M. Kasperczyk (2014) it causes an increase in the areas covered with grass in Jaworzyna Krynicka resort. Good results of grass density and erosion protection causes by sheep grazing have also been shown in the Alps (Barni et al. 2007; Burt, Rice 2009). However, only extensive grazing will result in an increase in grass area. Grazing that is too intensive will lead to a decrease in the area covered by grass as well as to soil compaction. In this study, it was described in Kotelnica Białczańska. In the area of Jaworzyna Krynicka, hay is also spread on eroded surfaces. This practice brings positive results and is also used at Mont Dore (Krzemień 1997). The presence of roads plays an important role in intensifying erosion on ski runs. Roads as drainage lines and places of intense erosion, as well as the reasons for modifying the valley network, have been the subject of many studies (Froehlich, Słupik 1980; Wałdykowski 2006; Kroczak 2010), one of which was carried out in the Skrzyczne massif (Wrońska-Wałach et al. 2018). Diagonal routing drainage ditches with a significant gradient cause initiation of erosion outside the ski runs and even lead to reconstruction of the valley network. It was examined in Kotlenica Białczańska resort (Fidelus-Orzechowska et al. 2018; Wrońska-Wałach et al. 2019). It seems that the construction of a dense network of drainage ditches with a slight slope and their regular deepening may help reduce erosion both on and off the ski runs. However, further research is necessary to confirm this.

All these considerations undoubtedly indicate the high necessity of maintaining continuous vegetation cover on ski runs.

CONCLUSIONS

1. The development of ski resorts is the main reason for an increase in the non-vegetation areas on the ski runs. Changes in the grassed areas are also related to the maintenance methods (grass reseeding, grass mowing, grazing of animals).
2. Erosion processes affect the ski run area unevenly. The highest intensity is limited to surfaces devoid of vegetation. Even on these surfaces, there are morphodynamic zones, varying in modelling intensity.
3. Management and anti-erosion methods require diverse activities, often based on experiences from other mountains around the world.
4. Effective reduction of ski run degradation can be carried out by shortening the use of ski runs during periods of intense snowmelt and by recultivation work during periods after the snow has melted.
5. It should be emphasized that the analyzed ski resorts use many effective methods to reduce erosion on the ski runs. However, anti-erosion activities should focus on the road surfaces on the ski runs, which are eroded and transformed throughout the year and do not become overgrown with grass.

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