Received: 6 July 2023 | Revised: 19 September 2023 | Accepted: 22 September 2023
DOI: 10.1002/ldr.4941

RESEARCH ARTICLE

WILEY

Mapping grasslands' preservation potential: A case study from the northern Carpathians

Mateusz Szczęch[1] | Maciej Kania[1] | Jan Loch[2] | Katarzyna Ostapowicz[1,3] | Paweł Struś[4]

[1]Faculty of Geography & Geology, Jagiellonian University in Kraków, Kraków, Poland
[2]Gorce National Park, Poręba Wielka, Poland
[3]Norwegian Institute for Nature Research (NINA), FRAM—High North Research Centre for Climate and the Environment, Tromsø, Norway
[4]Institute of Law, Administration and Economics (Geoinformation Research Team), Pedagogical University of Krakow, Kraków, Poland

Correspondence
Mateusz Szczęch, Faculty of Geography & Geology, Jagiellonian University in Kraków, Gronostajowa 7, Kraków 30-387, Poland.
Email: mateusz.szczech@uj.edu.pl

Funding information
National Science Centre, Grant/Award Number: 2018/29/B/ST10/02979

Abstract

The grasslands which are an important part of an ecosystem are endangered due to abandonment of traditional forms of land use. Preservation of biodiversity of semi-natural grassland communities is of great importance, therefore it is important to identify threats and prepare a sustainable plan for their protection The goal of this study was to develop an approach to predict threatened grasslands hotspots, basing on multi-factor machine learning analyses. The Gorce Mountains in the Polish Carpathians were chosen as a study area, as it is region partially protected by National Park, surrounded by villages with different socio-economic conditions (agriculture or touristic oriented). The grasslands were identified and classified on Sentinel-2 multispectral imagery. As lack of regular mowing of grasslands was found as main factor promoting forest succession. Therefore, in order to find endangered grasslands areas, support vector machines' algorithm was used to classify them in mowed and unmowed categories. Then the preservation potential of grasslands was modeled with the random forest method, based on the grasslands' mowing classification, digital terrain model, land-use and population statistical data, and the historical forest extent. We found the grasslands above 750 m above sea level to be the most endangered. Also, the tourism activity and ongoing changes in employment structure from agriculture to services has had a negative influence on the grasslands preservation potential. On the other hand, the Gorce National Park's active grassland conservation by mowing and grazing was shown as a positive element in keeping with the high biodiversity of the area.

KEYWORDS
Google Earth Engine, Gorce National Park, grasslands preservation, random forest, Sentinel-2 imagery, support vector machines

1 | INTRODUCTION

Grassland ecosystems are an important part of the European agriculture and landscape (Bengtsson et al., 2019; Wesche et al., 2012). They cover more than one-third of all the agricultural land of agriculture areas in Europe (Schils et al., 2022). Moreover, grasslands secure important ecosystems' functionality and contribute to essential ecosystems' services (Bengtsson et al., 2019; Habel et al., 2013;

O'Mara, 2012), including nutritional functions (the source of food and forage; regulating functions, e.g., soil protection against erosion, the regulation of water flow, and the carbonate cycle), habitat functions (forming of complex biocenoses), and cultural functions (influence on the esthetical elements of the landscape) (Habel et al., 2013; Wesche et al., 2012).

Most of the grassland in the temperate-climate zone in Central and Western Europe was developed as a result of human activity and can be considered as semi-natural habitats (Dengler et al., 2020; Pärtel et al., 2005). As a consequence of the social and economic changes since the nineteenth century in the Alps and the beginning of the twentieth century in the Carpathians, the grasslands' area has changed drastically, which is a threat to this ecosystem's biodiversity. The main problem is the abandonment of traditional management forms (Babai & Molnár, 2014; Middleton, 2013), which leads in most cases to secondary forest succession and afforestation (Bucała-Hrabia, 2017; Dengler et al., 2020; Murtinová, 2020; Ostafin et al., 2017; Péter Török et al., 2020). Further, deep economic, social, and cultural changes in Central and Eastern Europe including Poland in the twentieth and twenty-first centuries resulted in land cover and use change (Cegielska et al., 2018; Dengler et al., 2020; Kozak et al., 2013), including significant changes in the grassland ecosystems. Another threat is the tree plantation frenzy which is also included into the EU Biodiversity strategy the planting of millions of trees (Holl & Brancalion, 2022; Tölgyesi et al., 2022).

The protection of grassland is overseen by the European Union within the subject of sustainable rural development, including through the policy within the Common Agricultural Policy (CAP) in terms of the reduction of the negative influences of agriculture on the environment. One of the aims of the CAP is the preservation of valuable communities created by traditional agricultural activities, while maintaining their biodiversity (European Commission, 2023a), which is particularly important from the perspective of sensitive semi-natural grasslands' biocenoses. To save valuable grasslands' biocenoses, research and active protective measures are carried out within the Carpathian national parks, reserves, and other protected areas (Ruciński et al., 2015).

In recent years, the use of Earth Observations for the mapping and monitoring of grassland types, phenology, and their changes has increased due to the availability of global satellite products. In particular, the use of vegetation indices, notably the Normalized Difference Vegetation Index (NDVI), has been widespread to determine changes in vegetation on different spatial scales, ranging from kilometers to centimeters (e.g., Nouri et al., 2017), and time scale, ranging from days to years (Griffiths et al., 2020; Kolecka et al., 2018; Maselli, 2004). Currently, satellite imagery like Landsat are commonly applied for global vegetation change studies (Madonsela et al., 2017), while the Sentinel-2 (S2) sensor, part of the European Union's Copernicus program, has provided the renewed possibility of addressing vegetation phenological changes with high spatial and temporal resolutions (10–20 m and 5 days), and an improved spectral resolution providing narrow bands in the red-edge region. Despite the short time series available (from July 2015 to the present), S2 has been used for the monitoring of vegetation, addressing aspects such as phenology, complementing other sensor datasets such as MODIS or Landsat, and monitoring biophysical variables through the proposal of new indices making use of the red-edge bands (Jönsson et al., 2018; Nguy-Robertson & Gitelson, 2015). However, its potential for improving the accuracy of estimating the phenological transition stages has not yet been fully explored, and in particular, the use of seasonal S2 data and approaches (Fauvel et al., 2020).

The main goal of this study was therefore to develop an approach that allowed the prediction of threatened grassland hotspots that indicated areas of high potential in terms of their habitat values, and also in contrast with the high probability of biodiversity loss and in the longer term the threat of secondary forest succession in mountainous regions. Our specific objectives were to:

- map the current grasslands and abandoned grassland ecosystems using S2 imagery, and
- evaluate the grasslands' biodiversity preservation potential using machine learning technics.

Accomplishing of these goals should provide methods for nature conservation prioritization. The framework proposed will also make possible to better understand processes responsible for losing biodiversity related to lack of sustainable development in the mountain areas.

2 | MATERIALS AND METHODS

2.1 | Study area

We selected the Gorce Mountains and the Gorce National Park located in Central Europe in the central part of the Polish Outer Carpathians (Figure 1). This was chosen as an example of a relatively large, well-preserved natural area. The Gorce Mountains, containing forests and characterized by a high degree of biodiversity, are surrounded by dense built-up areas (Chwistek, 2006; Kurzeja, 2006). Moreover, from a geomorphological point of view the Gorce Mountains are different from other Outer Carpathian mountain belts, due to the horn-like structure of the mountain range (Kroh & Pawlik, 2021). The area is characterized by high anthropogenic impact: it is a popular tourist destination (Popko-Tomasiewicz, 2006), but also subject to the increasing impact of motorized vehicles. The structure of the ownership of the land is characterized by a high percentage of private lands outside of the National Park, while some grasslands within the National Park are also private.

The study area covers approximately 548 km^2. The elevation range here is from about 300 m above sea level (a.s.l.) up to 1310 m a.s.l. at the Turbacz peak (Figure 2a). Denivelation in the area, measured in a grid 1 × 1 km are between 100 m in the external part of the massif and 400 m in its central part. Morphology is mainly related to the bedrock composed of flysh (sandstones, shales) deposits and geological structure (Szczęch et al., 2016; Szczęch & Cieszkowski, 2021;

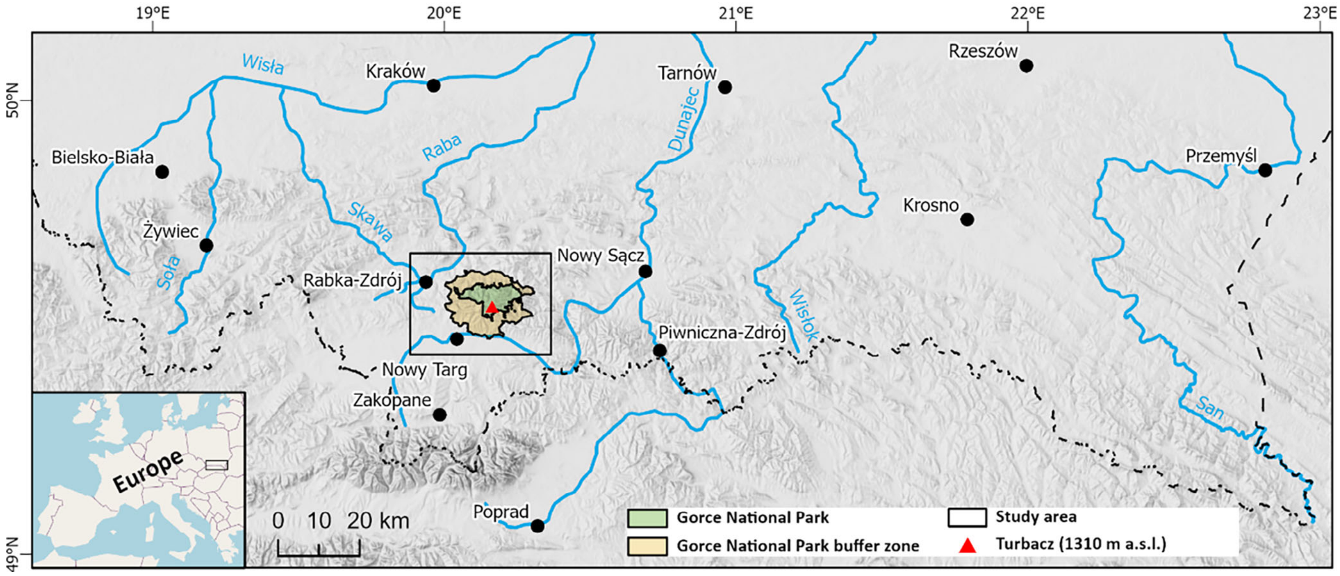

FIGURE 1 Location of the studied area and Gorce National Park. [Colour figure can be viewed at wileyonlinelibrary.com]

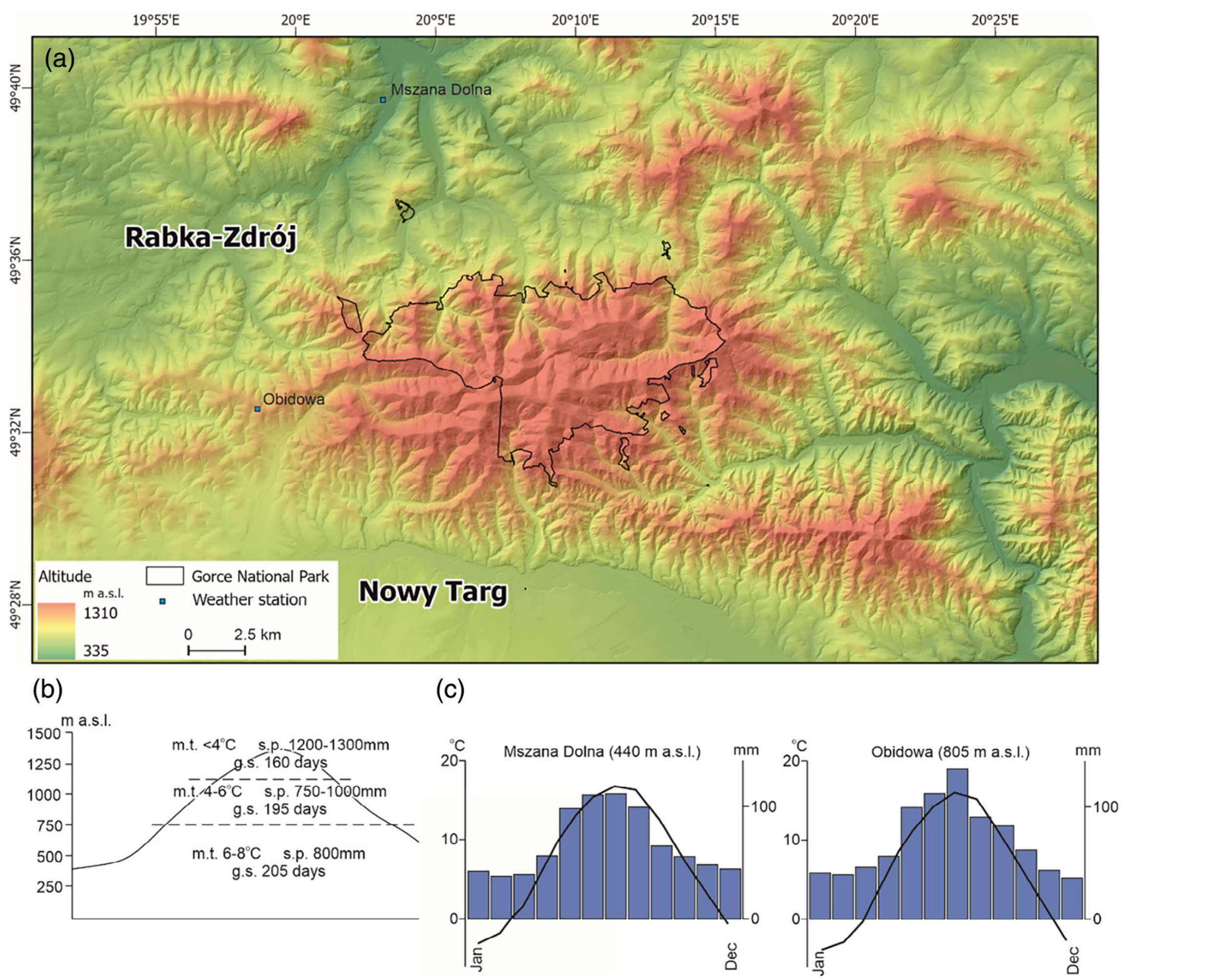

FIGURE 2 Geographical features of the research area: (a) Altitude map; (b) altitude climatic zones (m.t.—mean yearly temperature, s.p.—yearly sum precipitation, g.s.£growth season); (c) climate diagrams for Mszana Dolna and Obidowa stations. [Colour figure can be viewed at wileyonlinelibrary.com]

Szczęch & Waśkowska, 2023). Resources of groundwaters are of good quality and mainly related to the fissured flysh sediments of Magura Beds Basin and sand-gravel cover (Żaczek & Porowski, 2017). As for the climate conditions, absolute maximal temperatures are between 33.2°C (Obidowa station, 805 m a.s.l.) and 36.0°C (Mszana Dolna, 440 m a.s.l.). Minimal absolute temperatures are −28.0°C in Obidowa and −34°C in Mszana Dolna. The Obidowa station is however located on southern slopes (Kroh & Pawlik, 2021). Annual sum of precipitation is 800 mm in altitudes below 750 m a.s.l. to 1300 mm above 1100 m a.s.l. (Figure 2b, c; Miczyński, 2006). River network is radial with density up to 5.5 km km^{-2}. All the geographical conditions apart from the socio-economic aspects also affect the rate of abandonment of the grassland areas (Bucała, 2014).

Over years, the land use in the study region has been changing intensively. The forest cover in the Gorce Mountains, as in the entire Polish Carpathians, has gradually increased from approximately 27% in the nineteenth century to 47% now, with a simultaneous decline in agricultural areas. However, grassland ecosystems dominate the agricultural lands in the study area, while arable land occurs occasionally. The settlements are located within the valleys, apart from some hamlets, which together with agricultural areas occupy small fragments of ridges (Bucała-Hrabia, 2017; Kurzeja et al., 2015; Ruciński et al., 2015). The central part of our study area is part of the Gorce National Park (established in 1981) covering 70.3, and 166.47 km^2 of an additional area that is the national part buffer zone (Figure 1).

2.2 | Grasslands in the Gorce Mountains

The most of grassland ecosystems in the Gorce Mountains are not natural communities. They were established in the early stage of settlement and were related to the need to graze cattle and sheep, and to obtain feed for the winter period. The diversity of climatic and soil conditions, as well as the various applications of land use, have resulted in the formation of numerous plant communities here. Within the Gorce National Park, sixteen communities were distinguished, four of which were included in Annex I of the EU Habitats Directive (European Commission, 2023b, Table 1). Of these, the *Nardus* grasslands (6230) have been classified as a priority habitat. Some of the communities occurring in the meadows (e.g., blueberries and raspberries) are the result of the abandonment of pastoral management, which leads to the withdrawal and disappearance of many species of meadow plants, and ultimately to the degradation of the communities and their succession toward forest ecosystems. In previous centuries, when the meadows were systematically mowed and grazed, the most common community was the *Gladiolo-Agrostietum capillaris* meadows, occupying the more fertile and humid parts of the meadows (Figure 3). Dryer and poorer fragments of meadows were occupied by the *Nardus* grasslands. Recent decades have seen the rapid disappearance of these two, formerly dominant communities. In the most humid surroundings of the marsh, springs, and watercourses are the rich species of the *Cirsietum rivularis* and *Valeriano-Caricetum flavaerich* meadows (Figure 3). Due to the high soil humidity, the succession of forest species is slower in these habitats, and thus the risk of overgrowth is lower (Stańko & Horabik, 2015).

TABLE 1 Natura 2000 grasslands habitats occurring in the research area.

Natura 2000 habitat code	Habitat type	Characteristic species combination
6230	Species-rich Nardus grasslands	*Hieracio-Nardetum*
6430	Hydrophilous tall herb fringe communities	*Petasitetum kablikiani, Petasitetum albi*
6520	Mountain hay meadows	*Gladiolo-Agrostietum capillaris*
7230	Alkaline fens	*Valeriano-Caricetum flavae*

2.3 | Data

In our study, we used various data including (1) the satellite imagery S2: Multispectral Instrument (MSI) Level-2A collected on the Google Earth Engine (GEE) platform; (2) the LiDAR-obtained Digital Elevation Model (DEM); (3) topographic data (BDOT) created by the Head Office of Geodesy and Cartography (GUGiK); (4) vector historical forest maps (Ostafin et al., 2017); and (5) statistical data from the Polish Head Statistical Office; as well as (6) field data.

2.4 | Grasslands' mapping—Imagery, training, and validation data

In order to map the grasslands and their management—mowing—between 2017 and 2020, we used data from the Copernicus mission of the S2A/B MSI Level-2A optical sensor collected in the Google Earth Engine platform (https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S2_SR). We applied ten bands with a special resolution of 10 m (bands: 2, 3, 4, 8) and 20 m (bands: 5, 6, 7, 8a, 11, 12), and a ready-made mask in the Q60 channel to mask clouds and shadows. All bands were resampled to 10 m spatial resolution with the nearest neighbor algorithm. We assumed the relevant cloudiness conditions, namely, less than 20% of clouds for the scene. Finally, we used 138 imageries in total for the 2017–2020 period from April to October. Individual years were allocated the following number of images: 2017—23 images, 2018—42 images, 2019—33 images, and 2020—40 images. The selected interval from April to October, covering the growing season in the northern Carpathians (Miczyński, 2006; Wypych et al., 2018), is adequate to follow changes in land use and management, and to determine whether the grasslands have been mowed or not. This interval is also useful because most years the snow cover has already melted by April, even at higher altitudes (Miczyński, 2006). Moreover, in the Gorce Mountains, there are a lot of days with cloud cover, which makes the use of imagery from optical sensors challenging.

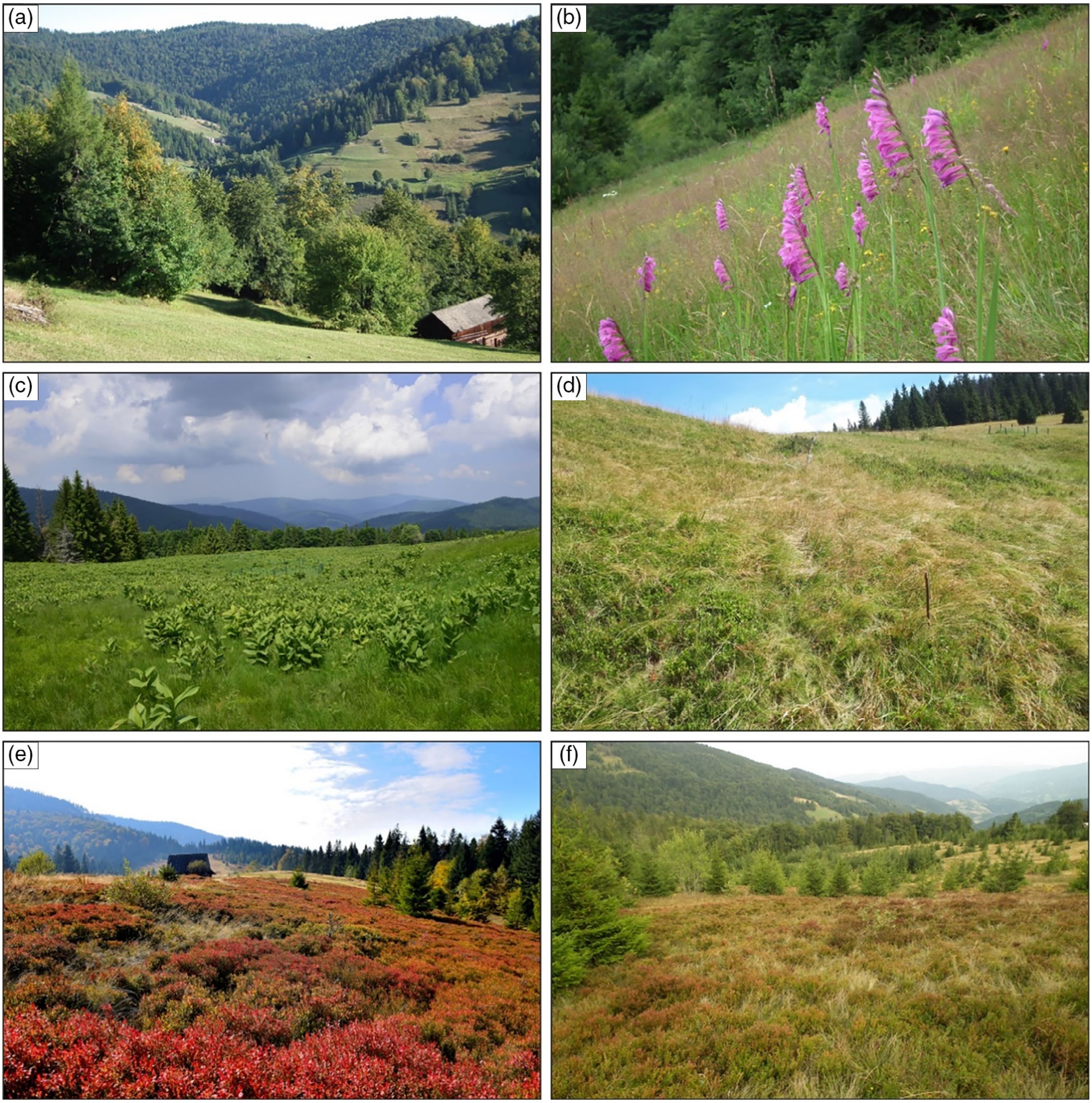

FIGURE 3 The grasslands' habitats: (a) meadows and grazelands in Ochotnica Górna village; (b) *Gladiolo-Agrostietum capillaris* grasslands in the Ochotnica valley; (c) grasslands with *Veratrum lobelianu*; (d) *Nardus* grasslands on the Hala Długa; (e) *Vaccinietum* on the non-mowed grasslands (Pod Skały meadow); (f) succession of the *Vaccinium myrtillus* and *Picea abies* on the non-mowed grasslands (Podgorcowe meadows). All photos by Loch J. [Colour figure can be viewed at wileyonlinelibrary.com]

We used aerial and satellite images from the Google Earth Pro application to create a training dataset for grassland and non-grassland area mapping. We vectorized 35 polygons of grasslands and 48 of non-grasslands including the following land cover classes: forests, croplands, water, and built-up areas. Only stable areas without land cover change for the 2017–2020 period were finally selected for further processing. In addition, we verified and identified stable areas for the training based on previously created S2 seasonal composites in the Google Earth Engine for the study period. Then, based again on aerial imagery, we identified additional grassland polygons, where mown grasslands (31 fields) and unmown grasslands (34) were located. The complete flowchart of the data processing is shown in Figure 4. The spectral differences between mowed and unmowed grasslands can be showed as differences between mean NDVI value: the mowed grasslands shows in general lesser NDVI values, due to episodes of mowing during vegetation season (Figure 5).

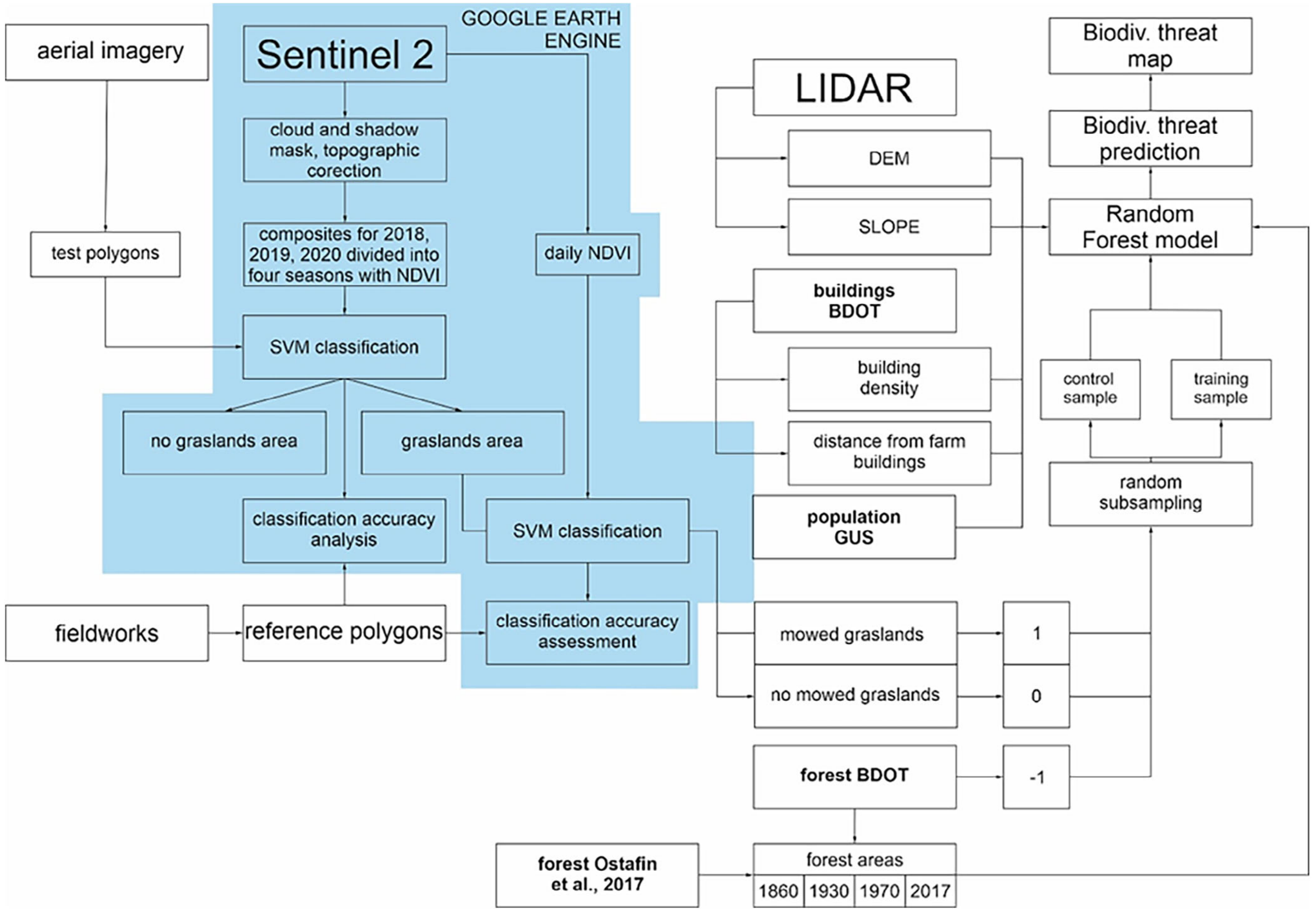

FIGURE 4 The workflow of data processing. [Colour figure can be viewed at wileyonlinelibrary.com]

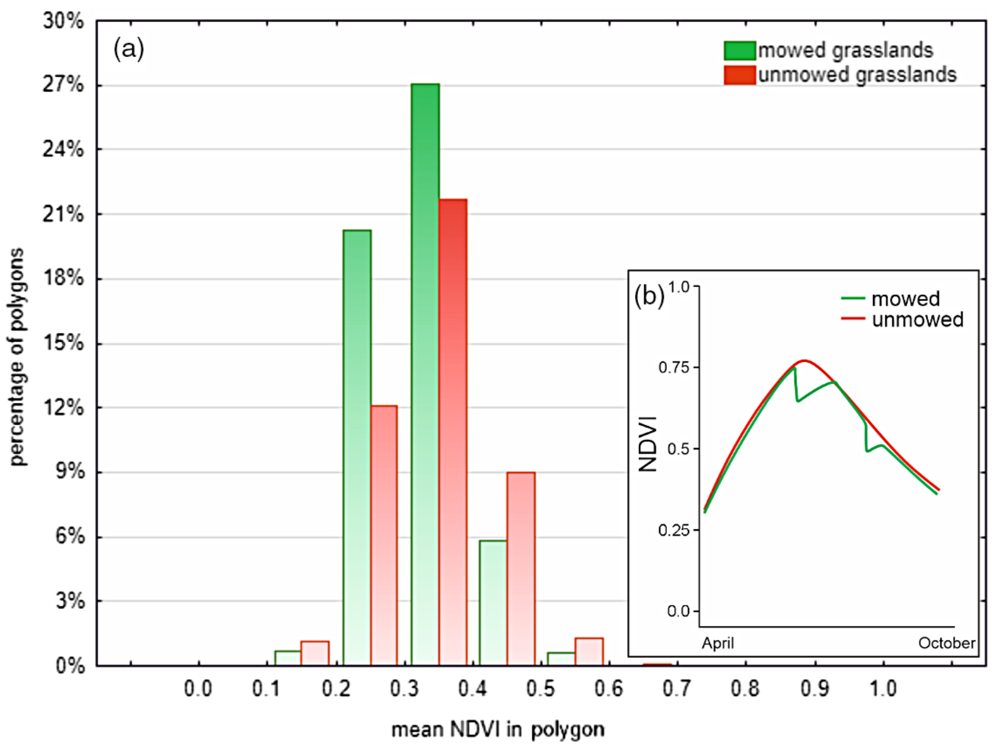

FIGURE 5 NDVI of the grasslands: (a) Mean NDVI values in polygons of mowed and unmowed grasslands for the 2018 vegetation season; (b) generalized change in NDVI during vegetation season. [Colour figure can be viewed at wileyonlinelibrary.com]

Finally, we carried out fieldwork in order to collect validation data about grasslands' mowing. The fieldwork was conducted at the end of October 2020, to identify mowed and non-mowed grassland areas. We collected information about the location of the grasslands and interviewed the National Park staff about the dates of mowing. We mapped 115 reference polygons using a handheld GPS Garmin S62, which were randomly distributed and described throughout the entire study area, whereof 61 of the reference polygons were represented by non-mowed grasslands and 54 by mowed grasslands (Figure 6).

2.5 | Grasslands' modeling—Preservation predictors

To locate threatened grassland areas we used various spatial datasets, from which we obtained environmental and demographic variables that determined the grasslands' preservation potential (GPP) (Table 2). From the airborne LiDAR (ALS)-derived DEM obtained from the GUGiK/ISOK project (Wężyk, 2014) with 1 m spatial resolution with a 15 cm error, we obtained information about the elevation and slopes. This allowed us to analyze the geodiversity in the context of altitude, which is related to the climate and vegetation diversity (Balon et al., 2021), and slope steepness that is one of the most important factors in agriculture and can be a proxy for accessibility. The historical forest cover for the 1860s, 1930s, and 1970s was obtained from vector layers, from a dataset prepared by Ostafin et al. (2017). These historical data allowed us to quantify land-use change in the region over the last 150 years—the increase of forested areas and the decrease in agriculture (Munteanu et al., 2014; Ostafin et al., 2017). The current land cover—information about forests and built-up areas—was taken from the state topographical database (BDOT, delivered from the GUGiK). The building density was calculated in the

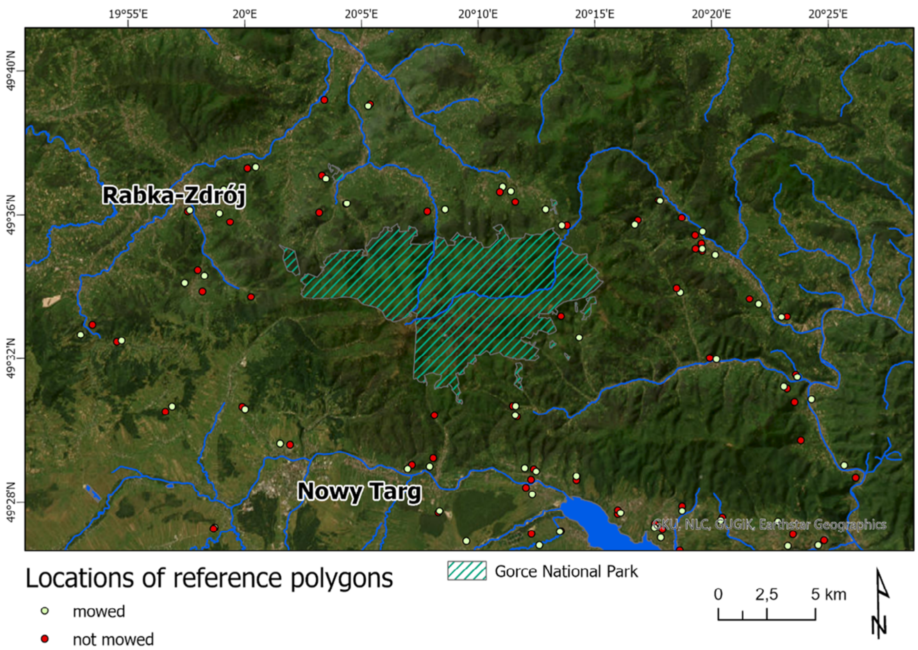

FIGURE 6 Locations of the reference polygons. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Predictors and data sources used to modeling grasslands preservation potential (GPP) with random forest method.

Predictor	Data source	Data resolution	Variable code	Variable importance in RF
Elevation	ISOK/LiDAR DEM	1 m	dem	37.49
Slope angle	ISOK/LiDAR DEM	1 m	slope	36.10
Distance from farm buildings	BDOT	10 m	building	46.82
Distance from 1860 forest boundary	Ostafin et al., 2017	10 m	forest_1860	40.75
Distance from 1930 forest boundary	Ostafin et al., 2017	10 m	forest_1930	38.30
Distance from 1970 forest boundary	Ostafin et al., 2017	10 m	forest_1970	48.23
Distance from 2020 forest boundary	BDOT	10 m	forest_2020	120.81
Population density	GUS	Community	gestosc_2020	38.87
Building density (weighted by storey number)	BDOT	2500 m squares	bd_dens	35.21

Note: ISOK/LiDAR DEM—1 × 1 m digital elevation model derived from ALS by Poland State Geodesy and Cartography Office. BDOT—Topographic features database by Poland State Geodesy and Cartography Office. GUS—Poland State Statistics Office.

regular tessellation grid of squares (2.5 × 2.5 km), which was tested to be the best indicator of the dispersed buildings of the Carpathian villages. Population data for the year 2019 were collected from the Statistical Office Poland (GUS, 2023) at NUTS-5 level administrative units (communities). For each community, the population density was calculated.

All layers were converted or resampled to 10 m spatial resolution raster layers, which were equal to the original S2 data. The final database of variables for modelling was created as a multilayer raster (each layer for a single factor), which was stored as a R raster class object.

3 | METHODS

3.1 | Mapping grasslands

We preprocessed the input imagery and mapped grasslands in the Google Earth Engine platform. In the first step, we masked out clouds and shadows for individual tiles. However, due to the low accuracy of the data provided by ESA from the Q60 channel, pixel artefacts with cloudiness and shadows remained in many places in significant grassland areas. Therefore, we applied an approach that was based on a ratio between the blue channel (B2) and short wave infrared channel (B10) (Bréon & Colzy, 1999; Hagolle et al., 2015). Pixels representing cloudiness were removed. Contemporaneously, it was also necessary to remove the cloud shadows. For this purpose, we used Housman et al.'s (2018) approach, which detects dark outliers in time series. Additionally, we buffered the identified shadows and clouds with 100 × 100 m area (10 pixels). Moreover, the remaining isolated pixels or pixel clusters, which did not exceed 100 m^2, were removed.

Then, using clear-sky observation, we computed the best available pixel (BAP) composites using the GEE algorithm by White et al. (2014) and spectral-temporal metrics (STM; Pflugmacher et al., 2019) for four seasons periods—spring (April), late spring (May), summer (June–August), and autumn (September–October)—for each year in the 2017–2020 period. In total, we obtained 16 datasets containing BAP composites for each S2 band (10 for each season) and band-wise statistics. We used all the composites for further processing, which allowed us to distinguish between grassland and non-grassland areas.

Using the same clear-sky observation we calculated the NDVI (Wang et al., 2004) using bands 4 (red) and 8 (NIR), as the NDVI is extremely useful in vegetation analysis (Esch et al., 2014; Jia et al., 2014). Analysis of a time series of the NDVI with an average resolution of 8 days in 2017, 5 days in 2018, 6 days in 2019, and 5 days in 2020 allowed us to detect disorders resulting from grassland mowing and to classify grassland areas into two classes: mowed and non-mowed grasslands. Different average resolution in subsequent years is due to different number of days without cloud cover in each year.

We mapped the grassland and non-grassland areas using support vector machines (SVMs), which is a contemporary, popular method of satellite imagery processing in heterogeneous landscapes (e.g., Grabska et al., 2020). The method is one of the supervised, classification machine-learning methods and is based on constructing hyperplanes separating classes defined in the training set (Shi & Yang, 2015). The classification was performed in the Google Earth Engine platform using all the seasonal data composited with BAP and STM (16 datasets: four years and four seasons for each year) and the Classifier.svm function. We used the following parameters: kernel type, Radial Basis Function (RBF); gamma, 0.5; and cost, 10. In the next step, only for the grassland areas we again applied SVM, which allowed us to distinguish between mowed and non-mowed grasslands. We performed the SVM classification in the R language with the e1071 package (Meyer et al., 2020) using NDVI seasonal spatial–temporal metrics (16 datasets: four years and four seasons for each year), with the following parameters: RBF Kernel; sigma, 0.099; and C, 1.

Next, to evaluate our classifications, we performed the validation of the grasslands and non-grasslands map, and the mowed and non-mowed grasslands map using the validation data described above in the "Grasslands' mapping—imagery, training, and validation data" section. We computed the area-adjusted confusion matrices, as well as the overall, producer's, and user's accuracies. For the overall accuracies, 95% confidence intervals were applied based on the overall accuracy variance (Olofsson et al., 2014). The resulting map shows the grasslands in the Gorce Mountains with the distinction of mowed and non-mowed areas in 2017–2020.

To evaluate the predictive capacity of the models, random partitions were used. We generated them randomly choosing 70% of the presence records as calibration data, and the remaining 30% as evaluation data for mowed and non-mowed grasslands. We measured the accuracy of the models using area under a receiver operating characteristic (ROC) curve (AUC). The curve is plotted in coordinates system of unitless true positive (also known as sensitivity, vertical) and false positive (specificity, horizontal) ratios. The AUC value is in the 0.5–1.0 range, where 1.0 is perfect classifier and 0.5 is random classification (Melo, 2013).

3.2 | Modeling the grasslands' preservation potential

We assumed that the threatened grassland areas with loss potential are the ones where mowing has stopped resulting in promoting forest succession, while potentially preserved grassland with low potential of loss are those which will be mowed in the future. The regular mowing of grasslands is an important part of biodiversity preservation, since all of the grasslands in the study region are non-natural. We distinguished between three classes of GPP and grassland threat/loss (GPL): strong, moderate, and low (Table 3). The spatial distribution of the three types of grassland areas with different GPP was predicted using machine learning. We predicted the land usage with the following arbitrary assigned discrete coding values for the present landuse: −1, forests; 0, non-mowed grasslands; and 1, mowed grasslands. The result GPP prediction value was therefore in a range from −1 to 1. These values should be understood as qualitative rather than

TABLE 3 Values assigned to different forms of landuse used to modelling grasslands preservation potential with random forest method.

Value	Present landuse	Points in training sample	Points in testing sample
−1	Forests	802	193
0	Not-mowed grasslands, shrubs	2526	639
1	Mowed grasslands	2268	567

quantitative ones. However, because of codes assignment, values near to −1 are the most endangered by forest succession. On the other hand, values near 1 are most probably to be mowed, thus have the highest preservation potential. The result GPP values were then categorized into three classes: low GPP, < −0.1; moderate GPP, −0.1–0.2; and high GPP, > 0.2.

To predict the GPP/GPL, we applied another machine learning method—random forest—which is an algorithm based on developing a set of decision trees and calculating a result as an average regression of each of the trees (Ho, 1995). This is again a common method used in environmental sciences and ecology for various studies focusing on the assessment of biodiversity changes and evaluation studies (e.g., Evans et al., 2011).

The GPP was constructed using the R package "caret" (Classification and Regression Training; Kuhn, 2020) with the "rf" kernel for prediction (Liaw & Wiener, 2002), which is the basic kernel for such applications. For random forest, we grew a forest of 500 classification trees with a minimum size of terminal nodes equal to 5.

The calibration dataset for modeling contained centroids of grasslands mapped using S2 imagery, with the mowing attribute coded as described above. The sample was a random subset of all the detected and classified grasslands. To increase the size of the training data for modeling and to better separate forest areas, a set of randomly distributed non-grassland points (forests) were added with the −1 code for forests (Table 3). In total, 5855 points were used for training and 1145 for validation.

To optimize the data processing, the trained model was applied to predict the preservation potential in a regular 100 × 100 m point grid covering the whole study area. Then, the values were interpolated with the empirical Bayesian kriging method to assign information with 10 m spatial resolution to each pixel in the study area.

Finally, the spatial distribution of grasslands was analyzed in the elevation intervals of below 500 m a.s.l., 500–750 m a.s.l., 750–1000 m, and above 1000 m a.s.l. The intervals chosen are according to the mean altitudinal zonation of vegetation in the Gorce Mountains (Obrębska-Starklowa et al., 1995). The altitude classes were analyzed separately in the Gorce National Park, as well as outside its area.

4 | RESULTS

4.1 | Spatial distribution of mowed and non-mowed grasslands in the Gorce Mountains

Our study shows that grasslands cover 330.5 km^2 (27% of the study area), of which approximately 25% (83.8 km^2) were not mowed between 2017 and 2020. In total, 0.2% of the grasslands in the study area are located within the Gorce National Park (Figure 6).

Larger regions with non-mowed grasslands occur in the area of the Czarny Dunajec in the south-western part of the studied area, as well as in the areas to the north from Lake Czorsztyńskie in the vicinity of the villages of Kluszkowce and Czorsztyn. A large area of non-mowed meadows also occurs in the region of Rabka (the north-western part of the area) (Figure 8). The highest percentage of the area of mowed grasslands occurs in the altitude interval range below 500 m a.s.l., which are located mainly within flat river valleys. The biggest areas of the grassland occupy the altitude interval range of 500–750 m a.s.l. In this interval, the acreage of non-mowed land is close to the average for the entire analyzed area, which is about 25%. In the interval of 750–1000 m a.s.l. and in areas above 1000 m a.s.l., the most valuable grassland plant communities in the study area occur. The grassland areas in this altitude range constitute only 5.5% (19.38 km^2) of all the grassland areas in the study area. In these altitudes, the highest percentage of non-mowed grassland areas occur, which in the interval of 750–1000 m a.s.l. is approximately 45%, while in the highest height range above 1000 m a.s.l. they constitute 69% (Figure 8). In the Gorce National Park, grasslands cover 2.4% in the area above 1000 m a.s.l. (30.7 km^2). Fifty-five percent of this area is mowed grasslands.

The overall classification accuracy for grasslands and non-grasslands was 92%. The same mowed and non-mowed grasslands' mapping was performed, with a high overall accuracy of 91%. Area under the ROC curve (AUC) statistic for this classification was 0.93 (Figure 7).

4.2 | Grassland's preservation potential in the Gorce Mountains

The results of the GPP modeling show that about 32% of all the grassland areas in the Gorce Mountains has low or moderate GPP, of which almost 23% (75.72 km^2) involves areas with the lowest preservation potential, and 9% (31 km^2) has moderate GPP (Figure 9). Significant grassland areas at medium and high risk occur in the Orawa-Nowy Targ Basin, and in particular in the Czarny Dunajec area, as well as between the strip from Nowy Targ to Nowa Biała (Figure 9). The areas directly adjacent to the forests also have low GPP (Figure 9). The most endangered areas of grasslands are those located above 1000 m a.s.l., where more than 85% have low GPP, and only 5% are areas with high GPP. Equally, a lot of at-risk habitats of grassland areas are located in the altitude range of 750–1000 m a.s.l., where more than half of the area of grassland habitats has low GPP (∼51%), and 30% of the meadow area has moderate GPP. In this interval, only

20% of the grasslands area will retain its high biodiversity values in the future. The greatest number of low-endangered meadow habitats are located in the two lowest height ranges of below 500 m a.s.l. and 500–750 m a.s.l., where they constitute 70% and 74%, respectively. However, in the altitude range of 500–750 m a.s.l. there are clearly more grasslands that are highly endangered by forest succession, which amount to 21%, while in the lower height range they constitute only 7% (Figure 9). The RMSE of the GPP prediction was 0.47.

5 | DISCUSSION AND CONCLUSIONS

Our results show that intensive changes in grassland ecosystems and in agriculture are still taking place in the Carpathians, which are related in particular to the abandonment of agricultural land, including grassland areas. They were initiated in the nineteenth century and a systematic increase of forest cover is observed since this time, which increased particularly in the twentieth century and intensified even more after the Second World War (Munteanu et al., 2014). Forest areas in 1860 accounted for around 27% of the study area, while in 1930 this was 35%, and in 1970 increased to 39% (Ostafin et al., 2017). The fastest abandonment of agricultural areas and their succession by forests was in the highest situated areas (Bucała-Hrabia, 2017). It is also associated with a decrease in the height of agricultural activity that, as indicated by Bucała-Hrabia (2017), lowered by about 100 m. Our results show that in the near future approximately 50% of the area of meadows located above 750 m a.s.l. will be permanently degraded by forest succession (low values of GPP). Of particular importance is that these are valuable species-rich areas (Ruciński et al., 2015). It is particularly important to preserve the currently existing meadow communities at these heights because they are habitats for rare species, some of which are included in Annex I of the EU Habitats Directive (European Commission, 2023b). Also, areas located in more favorable climatic and altitudinal conditions with relatively gentle slopes are abandoned; however, these places are located much lower and our GPP indicates that these changes are much less likely to occur (average GPP). The abandonment of such agricultural areas is observed throughout the entire Carpathian Mountains (Griffiths et al., 2020; Munteanu et al., 2014).

As a significant part of the meadows in the Gorce Mountains and in general in the Carpathians are seminatural biocenoses, agriculture, sustainable planning, and farming are important elements for the preservation of these valuable plant communities. The abandonment of these land-use types leads to the disappearance of some species and consequently the loss of habitats of meadow vegetation and their replacement by other communities (Michalik, 1990; Ruciński et al., 2015). The *Gladiolo-Agrostietum capillaries* meadows were

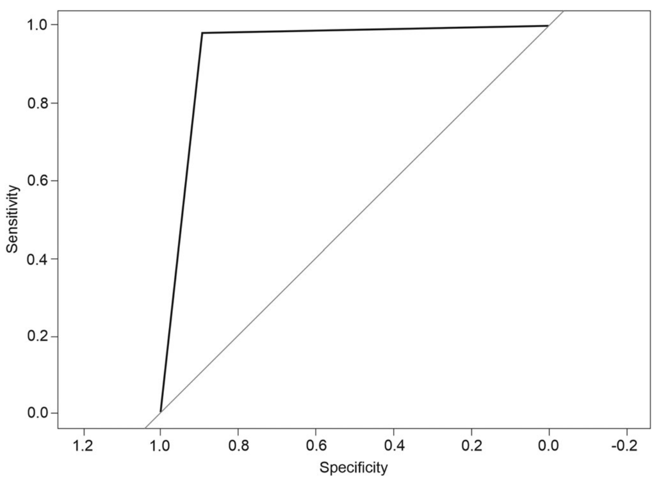

FIGURE 7 ROC (receiver operating characteristic) curve for mowed – unmowed grasslands classification. Sensitivity and specificity are unitless values.

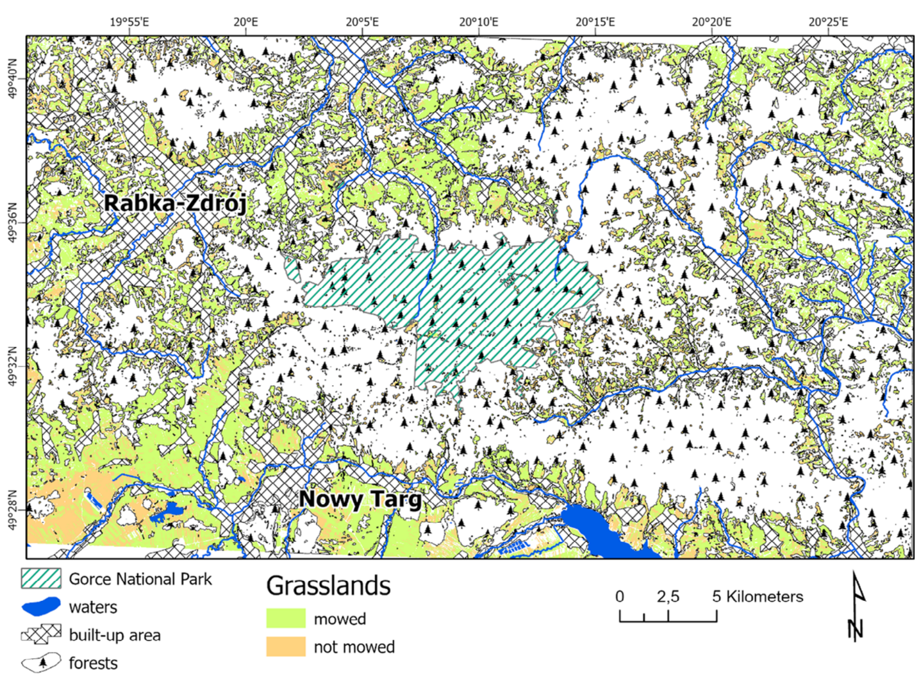

FIGURE 8 The map of the mowed and not mowed grasslands. [Colour figure can be viewed at wileyonlinelibrary.com]

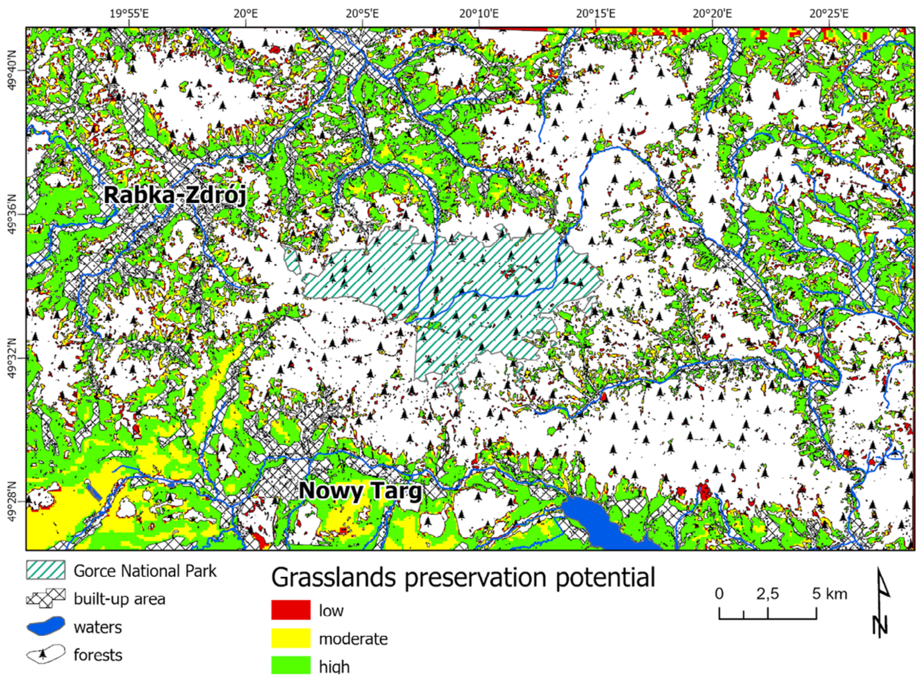

FIGURE 9 The map of the grassland preservation potential (GPP). [Colour figure can be viewed at wileyonlinelibrary.com]

common in the landscape 20–30 years ago, especially in the Lower Regions, where they were fertilized with manure and grazed. However, they have been replaced in many places by other species. Meadows, as communities of habitats, are included in Annex 1 of the Habitats Directive (European Commission, 2023b). The areas of clearings and meadows in the Gorce Mountains are subject to protection in the Natura 2000 area of Ostoja Gorczańska (Ruciński et al., 2015).

Additionally, semi-natural clearing communities are the most endangered habitat of the Gorce National Park (Ruciński et al., 2015). This is why one of the important protective tasks of the Gorce National Park is the protection of semi-natural communities of mountain meadows. For this purpose, selected clearings with the highest natural, landscape, and scenic values are subjected to planned, systematic protective measures, the most important of which are mowing with biomass harvesting, sheep grazing, and remand moving bushes (removing undesirable trees and shrubs). Currently, in the area of the Gorce National Park, due to the ownership structure of the meadows, only approximately 50% of the meadows are the subject of conservation. The vast majority of those belonging to the Gorce National Park are under active protection, while most of those belonging to private owners are abandoned. Our results show that these areas, with high ecological value but low GPP, should be strongly protected either by including them in the Gorce National Park or by changing the regulations that would encourage mowing or grazing them to a greater extent.

In the study area, there are places with a greater share of abandoned grassland areas or areas with a significantly slower rate of their abandonment compared to the average. The Niedźwiedź and northern part of the Mszana Dolna communities are characterized by a large area of mowed grasslands despite their location on the Gorce Mountains' slopes. However, this is an area with relatively poor road accessibility, where travel to the nearest cities of Rabka or Nowy Targ takes more longer than in other communities. Moreover, in this area, in addition to gainful employment, agricultural activity is also carried out as an additional source of income. On the other hand, the Czarny Dunajec community, located along the Rabka Zdrój-Chochołów road, has a large area of non-mowed grasslands. While Czarny Dunajec has no dense road network, it is clear that rather than the density it is the accessibility to main routes that decides the structure of land utilization, and consequently, the conservation of grasslands. In addition, this area in many places has unfavorable hydrological conditions and the occurrence of many wetlands. Negative effects have also included the large fragmentation of farms and the change in the employment structure in this area, as well as tourism influencing the abandonment of the grasslands. The most popular touristic places in the research area are the communities of Rabka Zdrój and Czorsztyn: the former is a well-established, popular place for the treatment of children's illnesses, while the latter is located in the vicinity of the Pieniny National Park and the famous Dunajec Gorge. The influence of tourism on the grasslands' condition is especially visible in the Czorsztyn community, where there is a large area of non-mowed grasslands mainly in the vicinity of Lake Czorsztyn. This effect is not so visible in the Rabka Zdrój area; however, this is in a general, more urbanized area, concentrated around a town.

6 | CHALLENGES DURING THE STUDY

The most challenging part of our study was the large fragmentation of agricultural land, in particular within the Orava-Nowy Targ Basin, where the width of the fields often does not exceed 10 m, which is near to the satellite imagery resolution (ESA, 2023). This generates issues with the use of data for the detection of single abandoned plots of meadow vegetation.

An additional issue is the central part of the studied area in the Gorce Mountains where there is often cloud cover, which has a negative impact on the test results, as signaled in the literature (e.g., Griffiths et al., 2020; Kolecka et al., 2018). Therefore, some meadow areas located in this part of the area had a few satellite images without clouds, with this area thus having worse classification parameters. Additionally, the negative classification results were often influenced by small areas of mountain meadows. Despite these shortcomings, the results are reliable for all the research areas. However, in order to obtain more accurate results in such local areas, the use of radar images that are more difficult to elaborate on should be considered (Steinhausen et al., 2018).

7 | CONCLUSIONS

We found the most endangered by degradation by forest succession of these located above 750 m a.s.l. The Gorce National Park plays a key role in protecting the grasslands on its territory; active protection by mowing and grazing is importantly increasing the grass preservation potential. The protection of grasslands on lower altitudes is related to the infrastructure of the area and the type of employment structure. Villages with a higher share of agriculture are the areas where the grasslands are more likely to be preserved. On the other hand, tourism has a negative influence on the grasslands.

The proposed multifactor modeling of the preservation potential incorporating different data sources was shown to be a useful tool in analyzing and planning activities in order to preserve grasslands, which are a valuable part of the area's biodiversity. The method has the potential to be applied in a bigger area, even the whole Carpathian belt.

AUTHOR CONTRIBUTIONS

Mateusz Szczęch: Conceptualization, data curation; formal analysis; investigation; methodology; validation; visualization; writing – original draft; Maciej Kania: conceptualization, data curation; formal analysis; investigation; methodology; validation; visualization; writing – original draft; Jan Loch: visualization; writing – original draft; Katarzyna Ostapowicz: funding acquisition; validation; project administration; writing – original draft; Paweł Struś: writing – original draft;

ACKNOWLEDGMENTS

We gratefully acknowledge support by the National Science Centre, project TRACE no. 2018/29/B/ST10/02979 (PI: Katarzyna Ostapowicz). The Global Land Programme also contributed to the project. The publication and proofreading of this publication have been supported by a grant from the Priority Research Area (Anthropocene) under the Strategic Programme Excellence Initiative at Jagiellonian University. We thank the anonymous reviewers for their careful reading of our manuscript and their insightful comments and suggestions.

CONFLICT OF INTEREST STATEMENT

There is no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Mateusz Szczęch https://orcid.org/0000-0001-9089-7947
Maciej Kania https://orcid.org/0000-0001-5307-4714
Katarzyna Ostapowicz https://orcid.org/0000-0002-4830-8202
Paweł Struś https://orcid.org/0000-0001-8970-7632

REFERENCES

Babai, D., & Molnár, Z. (2014). Small-scale traditional management of highly species-rich grasslands in the Carpathians. *Agriculture, Ecosystems & Environment*, *182*, 123–130.

Balon, J., Jodłowski, M., & Krąż, P. (2021). Beskidy Zachodnie. In A. Richling, J. Solon, A. Macias, J. Balon, J. Borzyszkowski, & M. Kistowski (Eds.), *Regionalna geografia fizyczna Polski* (pp. 481–496). Bogucki Wydawnictwo Naukowe, Poznań.

Bengtsson, J., Bullock, J. M., Egoh, B., Everson, C., Everson, T., O'Connor, T., O'Farrell, P. J., Smith, H. G., & Lindborg, R. (2019). Grasslands—More important for ecosystem services than you might think. *Ecosphere*, *10*(2), e02582. https://doi.org/10.1002/ecs2.2582

Bréon, F. M., & Colzy, S. (1999). Cloud detection from the spaceborne POLDER instrument and validation against surface synoptic observations. *Journal of Applied Meteorology and Climatology*, *38*(6), 777–785.

Bucała, A. (2014). The impact of human activities on land use and land cover changes and environmental processes in the Gorce Mountains (Western polish Carpathians) in the past 50 years. *Journal of Environmental Management*, *138*, 4–14. https://doi.org/10.1016/j.jenvman.2014.01.036

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. https://doi.org/10.1016/j.landusepol.2017.03.013

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

Chwistek, K. (2006). Gospodarka leśna. In W. Różański (Ed.), *Gorczański Park Narodowy 25 lat ochrony dziedzictwa przyrodniczego i kulturowego Gorców* (pp. 230–236). Gorczański Park Narodowy.

Dengler, J., Biurrun, I., Boch, S., Dembicz, I., & Török, P. (2020). Grasslands of the Palaearctic biogeographic realm: Introduction and synthesis. In M. I. Goldstein & D. A. DellaSala (Eds.), *Encyclopedia of the World's Biomes* (pp. 617–637). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.12432-7

ESA. (2023). Sentinel-2 MSI User Guide. https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-2-msi

Esch, T., Metz, A., Marconcini, M., & Keil, M. (2014). Combined use of multi-seasonal high and medium resolution satellite imagery for parcel-related mapping of cropland and grassland. *International Journal of Applied Earth Observation and Geoinformation*, *28*, 230–237.

European Commission. (2023a). The common agricultural policy at a glance. https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cap-glance_en

European Commission. (2023b). Council directive 92/43/EEC of 21 may 1992 on the conservation of natural habitats and of wild fauna and flora. Annex 1. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:31992L0043&from=EN

Evans, J. S., Murphy, M. A., Holden, Z. A., & Cushman, S. A. (2011). Modeling species distribution and change using random Forest. In C. Drew, Y. Wiersma, & F. Huettmann (Eds.), *Predictive species and habitat modeling in landscape ecology* (pp. 139–159). Springer. https://doi.org/10.1007/978-1-4419-7390-0_8

Fauvel, M., Lopes, M., Dubo, T., Rivers-Moore, J., Frison, P. L., Gross, N., & Ouin, A. (2020). Prediction of plant diversity in grasslands using Sentinel-1 and-2 satellite image time series. *Remote Sensing of Environment*, *237*, 111536. https://doi.org/10.1016/j.rse.2019.111536

Grabska, E., Frantz, D., & Ostapowicz, K. (2020). Evaluation of machine learning algorithms for forest stand species mapping using Sentinel-2 imagery and environmental data in the polish Carpathians. *Remote Sensing of Environment*, *251*, 112103. https://doi.org/10.1016/j.rse.2020.112103

Griffiths, P., Nendel, C., Pickert, J., & Hostert, P. (2020). Towards national-scale characterization of grassland use intensity from integrated Sentinel-2 and Landsat time series. *Remote Sensing of Environment*, *238*, 111124. https://doi.org/10.1016/j.rse.2019.03.017

GUS. (2023). Statistics Poland. https://stat.gov.pl/en/

Habel, J. C., Dengler, J., Janišová, M., Török, P., Wellstein, C., & Wiezik, M. (2013). European grassland ecosystems: Threatened hotspots of biodiversity. *Biodiversity and Conservation*, *22*, 2131–2138. https://doi.org/10.1007/s10531-013-0537-x

Hagolle, O., Huc, M., Pascual, D. V., & Dedieu, G. (2015). A multi-temporal and multi-spectral method to estimate aerosol optical thickness over land, for the atmospheric correction of FormoSat-2, LandSat, VENμS and Sentinel-2 images. *Remote Sensing*, *7*(3), 2668–2691. https://www.mdpi.com/2072-4292/7/3/2668#

Ho, T. K. (1995). Random decision forests. In *Proceedings of 3rd international conference on document analysis and recognition* (Vol. 1, pp. 278–282). IEEE.

Holl, K. D., & Brancalion, P. H. S. (2022). Which of the plethora of tree-growing projects to support? *One Earth*, *5*(5), 452–455. https://doi.org/10.1016/j.oneear.2022.04.001

Housman, I. W., Chastain, R. A., & Finco, M. V. (2018). An evaluation of Forest health insect and disease survey data and satellite-based remote sensing Forest change detection methods: Case studies in the United States. *Remote Sensing*, *10*(8), 1184. https://doi.org/10.3390/rs10081184

Jia, K., Liang, S., Wei, X., Yao, Y., Su, Y., Jiang, B., & Wang, X. (2014). Land cover classification of Landsat data with phenological features extracted from time series MODIS NDVI data. *Remote Sensing*, *6*(11), 11518–11532. https://doi.org/10.3390/rs61111518

Jönsson, P., Cai, Z., Melaas, E., Friedl, M. A., & Eklundh, L. A. (2018). Method for robust estimation of vegetation seasonality from Landsat and Sentinel-2 time series data. *Remote Sensing*, *10*(4), 635. https://doi.org/10.3390/rs10040635

Kolecka, N., Ginzler, C., Pazur, R., Price, B., & Verburg, P. (2018). Regional scale mapping of grassland mowing frequency with Sentinel-2 time series. *Remote Sensing*, *10*(8), 1221. https://doi.org/10.3390/rs10081221

Kozak, J., Ostapowicz, K., Bytnerowicz, A., & Wyżga, B. (2013). The Carpathian Mountains: Challenges for the central and eastern European landmark. In J. Kozak, K. Ostapowicz, A. Bytnerowicz, & B. Wyżga (Eds.), *The Carpathians: Integrating nature and society towards sustainability* (pp. 1–13). Springer.

Kroh, P., & Pawlik, Ł. (2021). Recent advances on geomorphology of the Gorce Mountains, the outer Western Carpathians – State-of-the-art and future perspectives. *Geographia Polonica*, *94*, 47–67. https://doi.org/10.7163/GPol.0193

Kuhn, M. (2020). caret: Classification and Regression Training. R package version 6.0–86. https://CRAN.R-project.org/package=caret

Kurzeja, M. (2006). Historia osadnictwa. In W. Różański (Ed.), *Gorczański Park Narodowy 25 lat ochrony dziedzictwa przyrodniczego i kulturowego Gorców* (pp. 207–212). Gorczański Park Narodowy.

Kurzeja, M., Barmuta, M., Chwistek, K., Czarnota, P., Strauchmann, E., & Popko-Tomasiewicz, K. (2015). Człowiek i przyroda w Gorcach. In P. Czrnota & M. Stefanik (Eds.), *Gorczński Park Narodowy przyroda i krajobraz pod ochroną* (pp. 261–292). Gorczański Park Narodowy.

Liaw, A., & Wiener, M. (2002). Classification and regression by randomForest. *R News*, *2*(3), 18–22.

Madonsela, S., Cho, M. A., Ramoelo, A., & Mutanga, O. (2017). Remote sensing of species diversity using Landsat 8 spectral variables. *ISPRS Journal of Photogrammetry and Remote Sensing*, *133*, 116–127. https://doi.org/10.1016/j.isprsjprs.2017.10.008

Maselli, F. (2004). Monitoring forest conditions in a protected Mediterranean coastal area by the analysis of multiyear NDVI data. *Remote Sensing of Environment*, *89*(4), 423–433. https://doi.org/10.1016/j.rse.2003.10.020

Melo, F. (2013). Area under the ROC curve. In W. Dubitzky, O. Wolkenhauer, K. H. Cho, & H. Yokota (Eds.), *Encyclopedia of systems biology*. Springer. https://doi.org/10.1007/978-1-4419-9863-7_209

Meyer, D., Dimitriadou, E., Hornik, K., Weingessel, A., & Leisch, F. (2020). E1071: Misc functions of the Department of Statistics, probability theory group (formerly: E1071), TU Wien. R Package Version 1.7–4. https://CRAN.R-project.org/package=e1071

Michalik, S. (1990). Sukcesja roślinności na polanie reglowej w Gorczańskim Parku Narodowym w okresie 20 lat w wyniku zaprzestania wypasu. *Prądnik*, *2*, 137–148.

Miczyński, J. (2006). Klimat. In W. Różański (Ed.), *Gorczański Park Narodowy 25 lat ochrony dziedzictwa przyrodniczego i kulturowego Gorców* (pp. 35–37). Gorczański Park Narodowy.

Middleton, B. A. (2013). Rediscovering traditional vegetation management in preserves: Trading experiences between cultures and continents. *Biological Conservation*, *158*, 271–279. https://doi.org/10.1016/j.biocon.2012.10.003

Munteanu, C., Kuemmerle, T., Boltiziar, M., Butsic, V., Gimmi, U., Halada, L., Kaim, D., Király, G., Konkoly-Gyuró, E., Kozak, J., Lieskovský, J., Mojses, M., Müller, D., Ostafin, K., Ostapowicz, K., Shandra, O., Štych, P., Walker, S., & Radeloff, V. C. (2014). Forest and agricultural land change in the Carpathian region—A meta-analysis of long-term patterns and drivers of change. *Land Use Policy*, *38*, 685–697. https://doi.org/10.1016/j.landusepol.2014.01.012

Murtinová, V. (2020). Zhodnotenie miery zárastov trvalých trávnych porastov v kú chrámec (Chko Cerová Vrchovina) po roku 1950. *Acta Facultatis Ecologiae*, *43*, 7–17.

Nguy-Robertson, A. L., & Gitelson, A. A. (2015). Algorithms for estimating green leaf area index in C3 and C4 crops for MODIS, Landsat TM/-ETM+, MERIS, sentinel MSI/OLCI, and Venμs sensors. *Remote Sensing Letters*, *6*(5), 360–369. https://doi.org/10.1080/2150704X.2015.1034888

Nouri, H., Anderson, S., Sutton, P., Beecham, S., Nagler, P., Jarchow, C. J., & Roberts, D. A. (2017). NDVI, scale invariance and the modifiable areal unit problem: An assessment of vegetation in the Adelaide parklands. *Science of the Total Environment*, *584-585*, 11–18. https://doi.org/10.1016/j.scitotenv.2017.01.130

Obrębska-Starklowa, B., Hess, M., Olecki, Z., Trepińska, J., & Kowanetz, L. (1995). Klimat. In J. Warszyńska (Ed.), *Karpaty Polskie* (pp. 31–47). Uniwersytet Jagielloński.

Olofsson, P., Foody, G. M., Herold, M., Stehman, S. V., Woodcock, C. E., & Wulder, M. A. (2014). Good practices for estimating area and assessing accuracy of land change. *Remote Sensing of Environment*, *148*, 42–57. https://doi.org/10.1016/j.rse.2014.02.015

O'Mara, F. P. (2012). The role of grasslands in food security and climate change. *Annals of Botany*, *110*, 1263–1270. https://doi.org/10.1093/aob/mcs209

Ostafin, K., Iwanowski, M., Kozak, J., Cacko, A., Gimmi, U., Kaim, D., Psomas, A., Ginzler, C., & Ostapowicz, K. (2017). Forest cover mask from historical topographic maps based on image processing. *Geoscience Data Journal*, *4*(1), 29–39. https://doi.org/10.1002/gdj3.46

Pärtel, M., Bruun, H. H., & Sammul, M. (2005). Biodiversity in temperate European grasslands: Origin and conservation. *Grassland Science in Europe*, *10*(1), 14.

Péter Török, P., Dembicz, I., Dajić-Stevanović, Z., & Kuzemko, A. (2020). Grasslands of Eastern Europe. In D. A. DellaSala (Ed.), *Goldstein, M. I* (pp. 703–713). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.12042-1

Pflugmacher, D., Rabe, A., Peters, M., & Hostert, P. (2019). Mapping pan-European land cover using Landsat spectral-temporal metrics and the European LUCAS survey. *Remote Sensing of Environment*, *221*, 583–595. https://doi.org/10.1016/j.rse.2018.12.001

Popko-Tomasiewicz, K. (2006). Turystyka. In W. Różański (Ed.), *Gorczański Park Narodowy 25 lat ochrony dziedzictwa przyrodniczego i kulturowego Gorców* (pp. 237–242). Gorczański Park Narodowy.

Ruciński, M., Pierścińska, A., Loch, J., & Matysek, M. (2015). Na polanach reglowych. In P. Czrnota & M. Stefanik (Eds.), *Gorczński Park Narodowy przyroda i krajobraz pod ochroną* (pp. 261–292). Gorczański Park Narodowy.

Schils, R. L. M., Bufe, C. M., Rhymer, R. M., Francksen, R. M., Klaus, V. H., Abdalla, M., Milazzo, F., Lellei-Kovács, E., ten Berge, H., Bertora, C., Chodkiewicz, A., Dămătîrcă, C., Feigenwinter, I., Fernández-Rebollo, P., Ghiasi, S., Hejduk, S., Hiron, M., Janicka, M., Pellaton, R., … Newell Price, J. P. (2022). Permanent grasslands in Europe: Land use change and intensification decrease their multifunctionality. *Agriculture, Ecosystems & Environment*, *330*, 107891. https://doi.org/10.1016/j.agee.2022.107891

Shi, D., & Yang, X. (2015). Support vector machines for land cover mapping from remote sensor imagery. In J. Li & X. Yang (Eds.), *Monitoring and modeling of global changes: A geomatics perspective*. Springer Remote Sensing/Photogrammetry (pp. 265–279). Springer. https://doi.org/10.1007/978-94-017-9813-6_13

Stańko, R., & Horabik, D. (2015). Siedliska podmokłe. In P. Czarnota & M. Stefanik (Eds.), *Gorczański Park Narodowy, Przyroda i krajobraz pod ochroną* (pp. 139–149). Gorczański Park Narodowy.

Steinhausen, M. J., Wagner, P. D., Narasimhan, B., & Waske, B. (2018). Combining Sentinel-1 and Sentinel-2 data for improved land use and land cover mapping of monsoon regions. *International Journal of Applied Earth Observation and Geoinformation*, *73*, 595–604. https://doi.org/10.1016/j.jag.2018.08.011

Szczęch, M., & Cieszkowski, M. (2021). Geology of the Magura nappe, south-western Gorce Mountains (outer Carpathians, Poland). *Journal of Maps*, *17*, 453–464. https://doi.org/10.1080/17445647.2021.1950579

Szczęch, M., Cieszkowski, M., Chodyń, R., & Loch, J. (2016). Geotouristic values of the Gorce National Park and its surroundings (the outer Carpathians, Poland). *Geotourism*, *44–45*, 27–44.

Szczęch, M., & Waśkowska, A. (2023). Stratigraphy and geological structure of the Magura nappe in the south-western part of the Gorce Mountains, outer Carpathians, Poland. *Annales Societatis Geologorum Poloniae*, *93*, 103–136. https://doi.org/10.14241/asgp.2023.04

Tölgyesi, C., Buisson, E., Helm, A., Temperton, V. M., & Török, P. (2022). Urgent need for updating the slogan of global climate actions from “tree planting” to “restore native vegetation”. *Restoration Ecology*, *30*, e13594. https://doi.org/10.1111/rec.13594

Wang, J., Rich, P. M., Price, K. P., & Kettle, W. D. (2004). Relations between NDVI and tree productivity in the central Great Plains. *International Journal of Remote Sensing*, *25*(16), 3127–3138. https://doi.org/10.1080/0143116032000160499

Wesche, K., Krause, B., Culmsee, H., & Leuschner, C. (2012). Fifty years of change in central European grassland vegetation: Large losses in species richness and animal-pollinated plants. *Biological Conservation*, *150*, 76–85. https://doi.org/10.1016/j.biocon.2012.02.015

Wężyk, P. (2014). Podręcznik dla uczestników szkoleń z wykorzystania produktów LiDAR.

White, J. C., Wulder, M. A., Hobart, G. W., Luther, J. E., Hermosilla, T., Griffiths, P., Coops, N. C., Hall, R. J., Hostert, P., Dyk, A., & Guindon, L. (2014). Pixel-based image compositing for large-area dense time series applications and science. *Canadian Journal of Remote Sensing*, *40*(3), 192–212. https://doi.org/10.1080/07038992.2014.945827

Wypych, A., Ustrnul, Z., & Schmatz, D. (2018). Long-term variability of air temperature and precipitation conditions in the polish Carpathians. *Journal of Mountain Science*, *15*, 237–253. https://doi.org/10.1007/s11629-017-4374-3

Żaczek, J., & Porowski, A. (2017). Hydrogeological settings and origin of groundwater composition in the southern part of the Gorce Mts, Kowaniec Mały catchment. *Annales. Societatis Geologorum Poloniae*, *87*, 183–197. https://doi.org/10.14241/asgp.2017.008

How to cite this article: Szczęch, M., Kania, M., Loch, J., Ostapowicz, K., & Struś, P. (2023). Mapping grasslands' preservation potential: A case study from the northern Carpathians. *Land Degradation & Development*, 1–14. https://doi.org/10.1002/ldr.4941