Acta geographica Slovenica, 66-1, 2026, 61–80

LAND-USE DYNAMICS AND GRASSLAND CONSERVATION CHALLENGES IN THE NATURA 2000 SITE KRAS: THE SOCIOECONOMIC PERSPECTIVE

Danijel Davidović, Jure Čuš, Danijel Ivajnšič

NATAŠA PIPENBAHER

Example of secondary karst grassland undergoing shrub encroachment due to reduced management intensity. The mosaic of grasses, shrubs and trees illustrates an intermediate successional stage.

DOI: https://doi.org/10.3986/AGS.14021
UDC: 711.14:633.2.03(497.472)"2002/2024"

Danijel Davidović[1], Jure Čuš[2], Danijel Ivajnšič[1]

Land-use dynamics and grassland succession challenges in the Natura 2000 site Kras: The socioeconomic perspective

ABSTRACT: Grasslands in the Natura 2000 site Kras are biodiversity hotspots with ecological, cultural and socioeconomic importance. However, the region faces challenges due to grassland loss and encroachment of forests and shrubs. This study examines land-use changes from 2002 to 2024 and the socioeconomic factors influencing these dynamics. Spatial analysis revealed substantial declines in grasslands, predominantly replaced by overgrown areas and forests. Socioeconomic factors such as farm holder age, livestock density and proximity to forests and roads showed complex interactions affecting grassland persistence, loss and gain. These findings underscore the urgent need for targeted conservation measures integrating adaptive grazing, sustainable forestry and enhanced policy support to balance grassland conservation with economic viability.

KEYWORDS: geography, biodiversity, ecosystem services, ecological succession, semi-natural grasslands, Agri-Environment Climate Scheme (AECS), Slovenia

Dinamika rabe tal in izzivi sukcesije travišč na Natura 2000 območju Kras: družbeno-ekonomski vidik

POVZETEK: Travniki na območju Natura 2000 Kras so žarišča biodiverzitete z ekološkim, kulturnim in družbeno-gospodarskim pomenom. Kljub temu se regija sooča z izzivi zaradi krčenja travnikov in širjenja gozda in grmičevja. Raziskava proučuje spremembe rabe tal od leta 2002 do 2024 in socio-ekonomske dejavnike, ki vplivajo na njihovo dinamiko. Prostorska analiza je pokazala obsežno krčenje travnikov, na katerih se razširijo predvsem zaraščene površine in gozd. Socio-ekonomski dejavniki, kot so starost nosilca kmetije, število glav velike živine ter bližina gozdnega roba in cest so pokazali kompleksne interakcije, ki vplivajo na ohranjanje, krčenje in širjenje travnikov. Ugotovitve kažejo nujno potrebo po ciljno usmerjenih ohranitvenih ukrepih, ki vključujejo prilagodljivo pašo, trajnostno gozdarstvo ter okrepljeno politično podporo za usklajevanje ohranjanja travnikov in profitabilnosti kmetovanja.

KLJUČNE BESEDE: geografija, biodiverziteta, ekosistemske storitve, ekološka sukcesija, polnaravna travišča, Kmetijsko-okoljska podnebna plačila (KOPOP), Slovenija

The article was submitted for publication on January 27th, 2025.
Uredništvo je prejelo prispevek 27. januarja 2025.

[1] University of Maribor, Maribor, Slovenia
[2] Independent researcher, Voličina, Slovenia

danijel.davidovic@um.si (https://orcid.org/0000-0003-3515-6139), jure.cus@gmail.com, dani.ivajnsic@um.si (https://orcid.org/0000-0003-4419-5295)

1 Introduction

Semi-natural grasslands are among the world's most biodiverse ecosystems (Wilson et al. 2012; Chytrý et al. 2015). Formed through low-intensity human activities, these herbaceous ecosystems differ from natural grasslands, having developed from early agricultural practices in areas unsuitable for natural grassland growth (Hejcman et al. 2013; Gigante et al. 2024). In the European Union (EU), they cover over one-third of agricultural land, making them one of its most extensive habitats (Schils et al. 2022). Additionally, environmental factors such as precipitation and insolation, combined with practices like swidden agriculture and grazing, created globally remarkable plant diversity, with record species richness per 50 m² plots (Horvatić 1973; Tüxen et al. 1974; Poldini 1989; Kaligarič and Poldini 1996; Kaligarič and Škornik 2002; Škornik et al. 2010; Pipenbaher et al. 2011). Despite their recognized importance (Tindale et al. 2023), abandonment and reduction persist, as cessation of grazing or mowing triggers secondary succession toward climax vegetation (Hejcman et al. 2013; Gigante et al. 2024).

Grasslands are biodiversity hotspots supporting diversity of plants, insects, birds, and mammals (Söderström et al. 2001; Perko et al. 2017; Šumrada and Erjavec 2023). They contribute to nutrient cycling, water regulation, microclimate balance, wildfire control, and carbon sequestration, thus aiding climate change mitigation (Ribeiro and Šmid Hribar 2019; Zhao et al. 2020; Bai and Cotrufo 2022). Additionally, they enhance soil structure and organic matter while preventing erosion in open habitats and forest understories (Hrvatin et al. 2006; Liu et al. 2020; Zhao et al. 2020).

Beyond ecology, grasslands are integral to rural traditions and livelihoods. Low-intensity grazing and haymaking provide food, including meat, dairy, honey, and wild edible or medicinal plants (Dasselaar et al. 2013; Žuna Pfeiffer et al. 2018; Zhao et al. 2020; Kose et al. 2022). They sustain pollinators and natural pest control (Bartual et al. 2019) and contribute to recreation, tourism, education, landscape aesthetics, cultural heritage, and psychological well-being (Reed et al. 2005; Hopkins and Holz 2006; Milcu et al. 2013; Rogerson et al. 2016; Zhao et al. 2020).

In Slovenia's Kras region (eng. *Karst*, ita. *Carso*), semi-natural grasslands are of exceptional ecological value. Originating around 2500 years ago (Kaligarič et al. 2006), they reached maximum extent in the 18th century, covering 82% of the area (Kaligarič and Ivajnšič 2014). These grasslands are now part of the Natura 2000 network. Despite protection, they are rapidly declining: since Slovenia's EU accession, over 5% of protected grasslands have disappeared (Kaligarič and Ivajnšič 2014).

Overgrowth in Kras has been studied for more than four decades (Feoli and Chiapella 1979; Lausi et al. 1979; Feoli et al. 1980; Feoli and Scimone 1982; Favretto and Poldini 1986). Between 1763 and 2002, 75% of grasslands were replaced by other land uses, and machine learning models predict further losses – from 20% of the landscape in 2012 to 7% by 2050, 5% by 2075, and 3% by 2100 (Kaligarič and Ivajnšič 2014). This trajectory signals major ecological and socio-economic change.

Like elsewhere in Europe (Gigante et al. 2024), Kras grassland decline is driven by succession following depopulation, land abandonment, and aging farm holders (Kaligarič and Ivajnšič 2014; Iberl et al. 2023). Their naturally low fertility and productivity (Envall et al. 2021) lead farmers either to abandon or intensify them, both hastening degradation (Hülber et al. 2017). Planned afforestation has accelerated these trends. The region's potential vegetation – forests of downy oak (*Quercus pubescens*) and sessile oak (*Quercus petraea*) – was long modified by human activities such as logging, swidden agriculture, and grazing (Zwitter and Rasran 2023). By the 18th–19th centuries, these practices left much of Kras barren and eroded, prompting extensive reforestation from the 19th through the 20th centuries (Kladnik 2011; Zorn et al. 2015).

Grassland conservation depends on maintaining traditional farming, which is often less profitable than intensive methods (Dahlström et al. 2013). The Agri-Environment Climate Scheme (AECS) offers subsidies for practices that exceed basic standards, supporting biodiversity, landscape integrity, and climate mitigation (Ivajnšič et al. 2018). However, uptake in Slovenia remains low. During 2007–2013 and 2014–2020, nearly half the subsidized grasslands lacked high conservation value, and 41% of funds went to intensively managed areas (Kaligarič et al. 2019). Despite €0.5 billion invested, declines in grassland flora, birds, and butterflies persisted (Jugovic et al. 2013; Jančar 2014; Kmecl et al. 2014).

Subsidies can still yield positive outcomes. In 2002–2012, EU payments encouraged sheep farming, slowing secondary succession (Veldkamp and Lambin 2001; Kaligarič and Ivajnšič 2014). Similarly, dairy production expansion curbed forest spread, contradicting earlier forecasts that Trieste Kras would be fully forested by 2013 (Favretto and Poldini 1986; Ivajnšič et al. 2013).

This study examines land-use change over the past two decades within the Natura 2000 site Kras, focusing on semi-natural grasslands, to answer: (1) Which land-use transitions dominate and to what extent? (2) Are grasslands still declining, and what processes drive their dynamics? (3) What are the main environmental and socio-economic factors of these changes?

2 Methods

2.1 Region of interest

The Kras Plateau in southwestern Slovenia represents a typical mid-latitude karst landscape extending over 429 km². Geologically, it forms a northwest–southeast-oriented anticline of limestone and dolomite, bordered by the flysch synclines of the Vipava Valley and the Gulf of Trieste. Due to its highly permeable bedrock, surface water is almost absent (Stepišnik 2011), although annual precipitation exceeds 1500 mm, supporting predominantly deciduous forests.

According to the Ministry of Agriculture, Forestry and Food, 72% of the plateau has low arable production potential; nevertheless, it remains a strategically important agricultural area. The gently undulating relief supports livestock farming, viticulture, and olive and fruit cultivation. However, industrialization after World War II led to widespread agricultural abandonment, peaking during the 1980s, as documented by Habič (1979) and Kladnik (2011).

Approximately 93% of the plateau (401 km²) lies within the Natura 2000 network, spanning eight municipalities. The region has 20,130 inhabitants, a low population density of 50 inh./km², and an aging demographic (mean age 45.8 years; 24% aged 65+). Statistical Office of the Republic of Slovenia reports that 53% of residents have secondary education and 24% have higher education. Data from the Ministry of Agriculture, Forestry and Food indicate that the area includes 1,562 registered farms covering 5,857 ha (15% of the total area), dominated by grasslands (85%) (Figure 1). The average farm size is 3.8 ha, farm holders average 62 years of age, and livestock density is low, at 1.6 livestock units (LU) per holding.

2.2 Data collection and preprocessing

To assess land-use dynamics, we analyzed land-use data for 2002, 2012, and 2024 obtained in vector format from the Ministry of Agriculture, Forestry and Food. To ensure comparability, existing land-use categories were reclassified into ten standardized classes (Table 1) and rasterized at a 5 × 5 m resolution, balancing spatial detail and computational efficiency.

Socioeconomic data were derived from the Ministry of Agriculture, Forestry and Food subsidy application database in vector format, containing information on land-use ID, farm-holder age, and livestock units (LU). Personal data were anonymized by replacing real identifiers with generated codes. Within the study area, 16,374 GERK (Graphical units of agricultural land use) were identified, of which 12,754 (78%) are under agricultural subsidies.

Spatial data delineating the Natura 2000 site Kras were obtained in vector format from the Institute of the Republic of Slovenia for Nature Conservation. All datasets were transformed to the Slovenia 1996 / Slovene National Grid (EPSG: 3794). Calculations, reclassification, rasterization, and visualization were performed using QGIS, TerrSet, and Excel.

2.3 Spatio-temporal analysis of land-use dynamics

The area of each land-use category was calculated in hectares and as a percentage of the total Natura 2000 site Kras for 2002, 2012, and 2024. Net land-use change and annual change rates were determined for three periods: 2002–2012, 2012–2024, and 2002–2024 overall.

Dominant change processes were identified using the Landscape Change Processes Analysis module in TerrSet Habitat and Biodiversity Modeler. A decision-tree algorithm compared raster pairs for all time

Figure 1: Location of the research area. ➤ p. 65

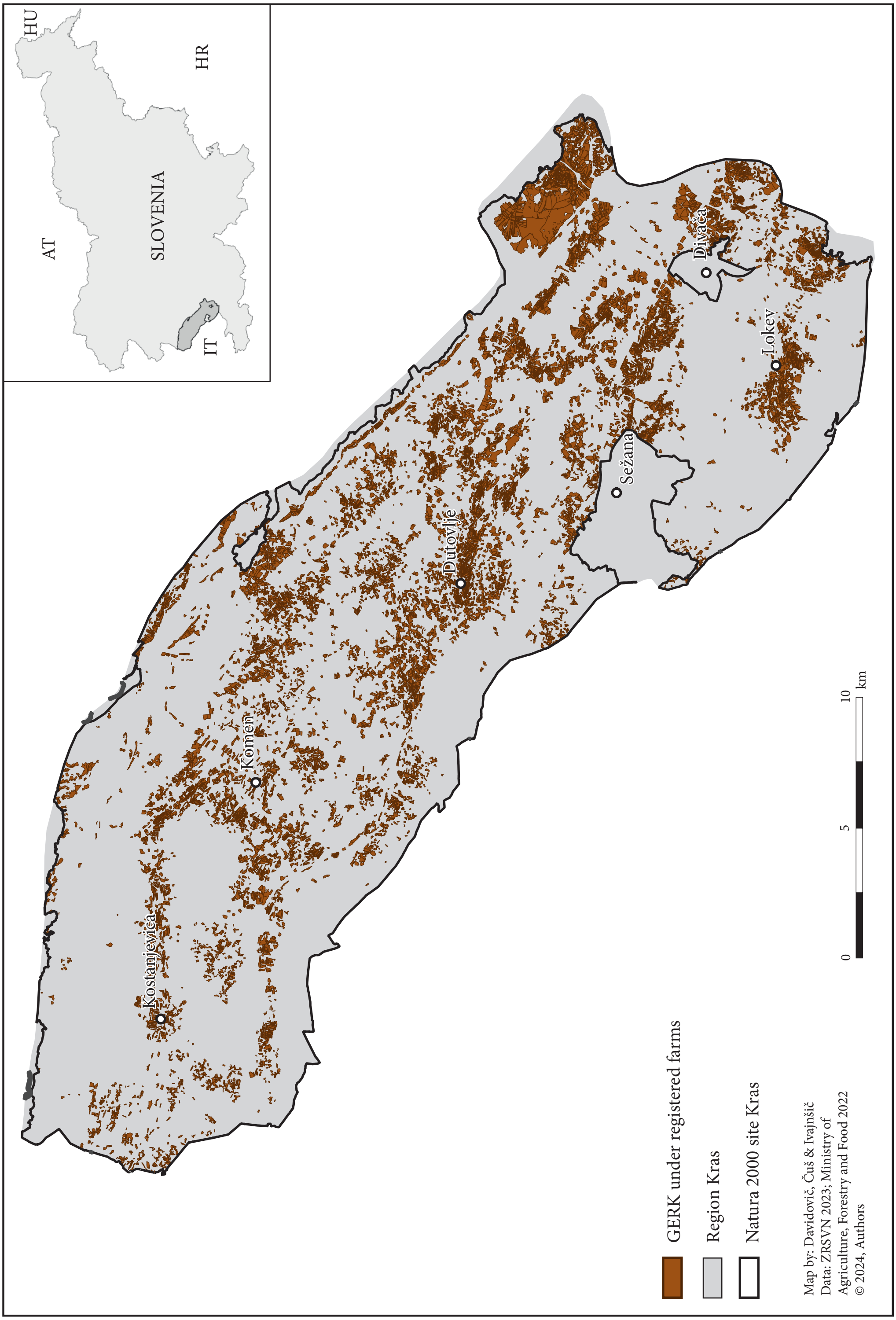

HU
HR
AT
SLOVENIA
IT
Divača
Lokev
Sežana
Dutovlje
Komen
Kostanjevica
0
5
10
km
GERK under registered farms
Region Kras
Natura 2000 site Kras
Map by: Davidovič, Čuš & Ivajnšič
Data: ZRSVN 2023; Ministry of
Agriculture, Forestry and Food 2022
© 2024, Authors

Table 1: Land-use categories reclassification.

ID	Original categories*	Reclassified categories
1100	Arable	Arable
1180	Perennial plants on arable land	
1190	Greenhouse	
1211	Vineyard	Vineyard
1221	Intensive orchard	Orchard
1222	Extensive orchard	
1230	Olive grove	Olive grove
1240	Other crop	Other crop
1300	Perennial grassland	Grassland
1321	Bog grassland	
1410	Overgrown agricultural land	Overgrown
1420	Forest tree plantation	
1500	Trees and shrubs	
1600	Uncultivated agricultural land	
1800	Agricultural land overgrown with forest trees	
2000	Forest	Forest
3000	Built-up	Built-up
4220	Other wetlands	Other
5000	Dry open land with specific plant cover	
6000	Open land with no or insignificant plant cover	
7000	Water	

* Categories not present in the listed years: 2002 – Perennial plants on arable land, Greenhouse, Forest tree plantation, Uncultivated agricultural land, Agricultural land overgrown with forest trees, Other wetlands; 2012 – Other crop, Bog grassland; 2024 – Bog grassland, Other wetlands

intervals, evaluating changes in patch number, area, and perimeter. Each land-use category was assigned one of three process categories: (1) creation – increase in patch number and area, denoting new land uses; (2) attrition – decrease in both metrics, indicating land-use loss; and (3) dissection – increased patch number with decreased total area, signifying fragmentation (Eastman 2024).

Given their biodiversity importance and notable transformations, subsequent analyses focused on grasslands. The Change Analysis module within TerrSet Land Change Modeler was used to map grassland persistence, gains, and losses, as well as transitions to other land-use types. Broader spatial patterns were explored with the Spatial Trend of Change module using a ninth-order polynomial function, producing maps of grassland loss, overgrowth, and forest expansion.

2.4 Modelling socioeconomic factors

To examine the influence of socioeconomic factors on land-use change, we used data on average farm-holder age and LU density from the Ministry of Agriculture, Forestry and Food. Additional spatial factors included distances from each farm holding to grassland persistence, gain, and loss zones, as well as to forest edges and roads, derived using the Proximity (raster distance) tool in QGIS. These factors reflect management intensity, spatial pressure, and accessibility affecting grassland dynamics.

Generalized Linear Models (GLMs) were fitted (family = gaussian; link = identity) in R (2024c), with the Rcmdr package (Fox et al. 2024), to test whether the predictors – (1) farm-holder age, (2) LU density, (3) forest proximity, and (4) road proximity – differentially explain grassland gain, loss, or persistence across the research area. This approach was selected since our response variables were not normally distributed.

The response variables were developed by calculating distance matrices from categories grassland gain, loss and persistence with the Proximity (raster distance) tool in QGIS. Moreover, explanatory variables were log- (farm-holder age, forest proximity and road proximity) or sqr- (LU density) transformed to secure normal distribution requirements. All models were evaluated at 0.05 α level. Model outputs were coefficients (β), standard errors (SE), t-values, and p-values for each predictor/explanatory variable.

3 Results

3.1 Land-use dynamics over two decades

Land-use analysis within the Natura 2000 site Kras for 2002 showed the dominance of forest cover, followed by grasslands and overgrown areas (Table 2). Forests were evenly distributed but fragmented in central zones, while grasslands prevailed in the central and southern parts. Overgrown patches were small and scattered. Built-up areas, vineyards, and arable land occurred mainly around larger settlements, occupying minimal total area (Figure 2, left).

By 2012, pronounced shifts were evident: forest area increased, grasslands declined sharply, and overgrown land moderately expanded. Arable land decreased, whereas built-up areas grew, with other categories showing minor variation (Figure 2, center).

In 2024, these trends largely continued. Forest cover slightly decreased, grasslands contracted further, and overgrown areas expanded substantially. Arable land recovered somewhat, vineyards declined, and built-up areas continued to grow at a slower pace. Other categories remained relatively stable (Figure 2, right).

Across the entire 2002–2024 period, several dominant patterns emerged (Figure 3). Forests expanded by 1,247 ha (5%) to 24,618 ha (61% of the area), at an average rate of 56 ha/yr, mainly in central and northern sectors. Grasslands declined by 2,815 ha (27%) to 7,667 ha (19%), contracting by 128 ha/yr, especially near settlements and in the north. Overgrown areas rose by 1,646 ha (47%), reaching 5,125 ha (13%), with an average gain of 75 ha/yr, dispersed across the region. In absolute terms, the most pronounced changes were grassland loss and overgrowth expansion.

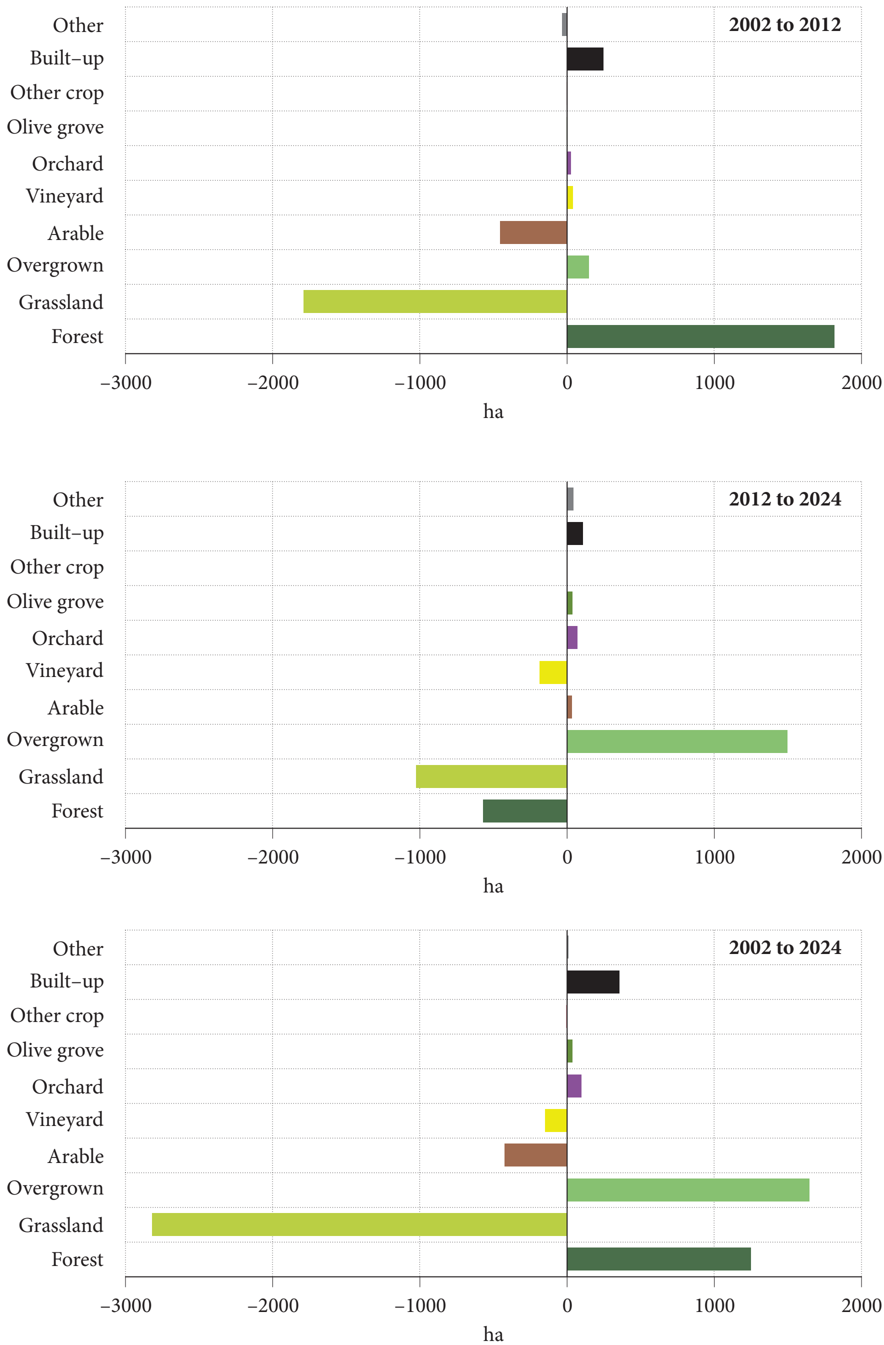
Other land-use classes also shifted: built-up areas increased by 33%, vineyards decreased 19%, and arable land shrank 57%. Orchards expanded 117%, while olive groves increased 23,430%. However, both together occupy only 215 ha (0.5%), and these extreme values may partly reflect methodological differences in data classification.

Table 2: Land-use changes in Natura 2000 site Kras (2002–2024).

Land use	Area 2002 (ha)	Area 2002 (%)	Area 2012 (ha)	Area 2012 (%)	Area 2024 (ha)	Area 2024 (%)	Δ 2002–2024 (ha)	Δ 2002–2024 (%)	Δ 2002–2024 (ha/year)
Forest	23375.57	58	25190.7	62.8	24618.2	61.4	1242.6	5.3	56
Grasslands	10481.85	26	8692.2	21.7	7666.9	19.1	–2814.9	–26.9	–128
Overgrown areas	3478.91	9	3629.4	9	5124.8	12.8	1645.9	47.3	75
Built-up areas	1075.89	3	1321.6	3.3	1430.9	3.6	355	33	16
Vineyards	770.64	2	809.8	2	621.8	1.6	–148.8	–19.3	–7
Arable land	742.01	2	286.7	0.7	319.6	0.8	–422.4	–56.9	–19
Other	113.27	0	80.5	0.2	121.3	0.3	8.1	7.1	0
Orchards	81.91	0	107.5	0.3	177.6	0.4	95.7	116.8	4
Other perennial crops	0.72	0	0	0	0.2	0	–0.6	–77.2	0
Olive groves	0.159	0	2.3	0	37.4	0.1	37.3	23429.6	2

Figure 2: Land use categories and structure. ➤ p. 68
Figure 3: Net land-use change by category. ➤ p. 69


2002
2012
2024
Kostanjevica
Komen
Dutovlje
Sežana
Divača
Lokev
58 %
26 %
9 %
63%
22%
9%
61%
19%
13%
Forest
Grassland
Built-up
Overgrown
Arable
Other
Vineyard
Orchard
Olive grove
Other crop
0
5
10
km
Map by: Davidović, Čuš & Ivajnšič
Data: Ministry of Agriculture,
Forestry and Food 2024b
© 2024, Authors


2002 to 2012
Other
Built–up
Other crop
Olive grove
Orchard
Vineyard
Arable
Overgrown
Grassland
Forest
–3000
–2000
–1000
0
1000
2000
ha
2012 to 2024
Other
Built–up
Other crop
Olive grove
Orchard
Vineyard
Arable
Overgrown
Grassland
Forest
–3000
–2000
–1000
0
1000
2000
ha
2002 to 2024
Other
Built–up
Other crop
Olive grove
Orchard
Vineyard
Arable
Overgrown
Grassland
Forest
–3000
–2000
–1000
0
1000
2000
ha

3.2 Spatial and temporal patterns of grassland change

During 2002–2012, creation was the dominant landscape process, affecting 77% of the region (Table 3). This reflected extensive expansion of forest and overgrown areas, particularly in the north, as well as the development of new vineyards, orchards, and olive groves. Dissection influenced 22% of the area, mainly within grasslands and agricultural zones, while attrition was limited and localized in the north, primarily reducing grasslands and cropland.

In the second period (2012–2024), dynamics shifted markedly: attrition became predominant, affecting 63% of the region, while dissection and creation impacted 19% and 18%, respectively. Although new land-use categories continued to emerge, the overall creation rate slowed, persisting mostly in forested areas near Komen and Dutovlje.

Across the full 2002–2024 period, two major processes prevailed – creation (79%) and dissection (21%). Creation reflected long-term forest and overgrowth expansion in northern and central sectors, whereas dissection indicated moderate fragmentation around urban areas. The dominance of creation over two decades highlights ongoing reforestation, natural succession, and agricultural decline, while the rise of attrition in the later period underscores accelerating grassland and farmland loss. Dissection decreased through time, showing reduced fragmentation.

Despite 60% persistence within the grassland class, major transformations occurred in 2002–2012. Grasslands declined by 27%, primarily around Lokvica and along main roads, contracting at 180 ha/yr. The south retained the most stable grasslands, while 13% of new grasslands emerged near settlements due to arable land abandonment (Figure 4, left).

Between 2012 and 2024, grassland dynamics stabilized: losses persisted but slowed to 21%, with a contraction rate of 85 ha/yr. Persistence rose to 69%, and new grassland formation declined to 10%. Although reduction continued, its pace lessened (Figure 4, centre).

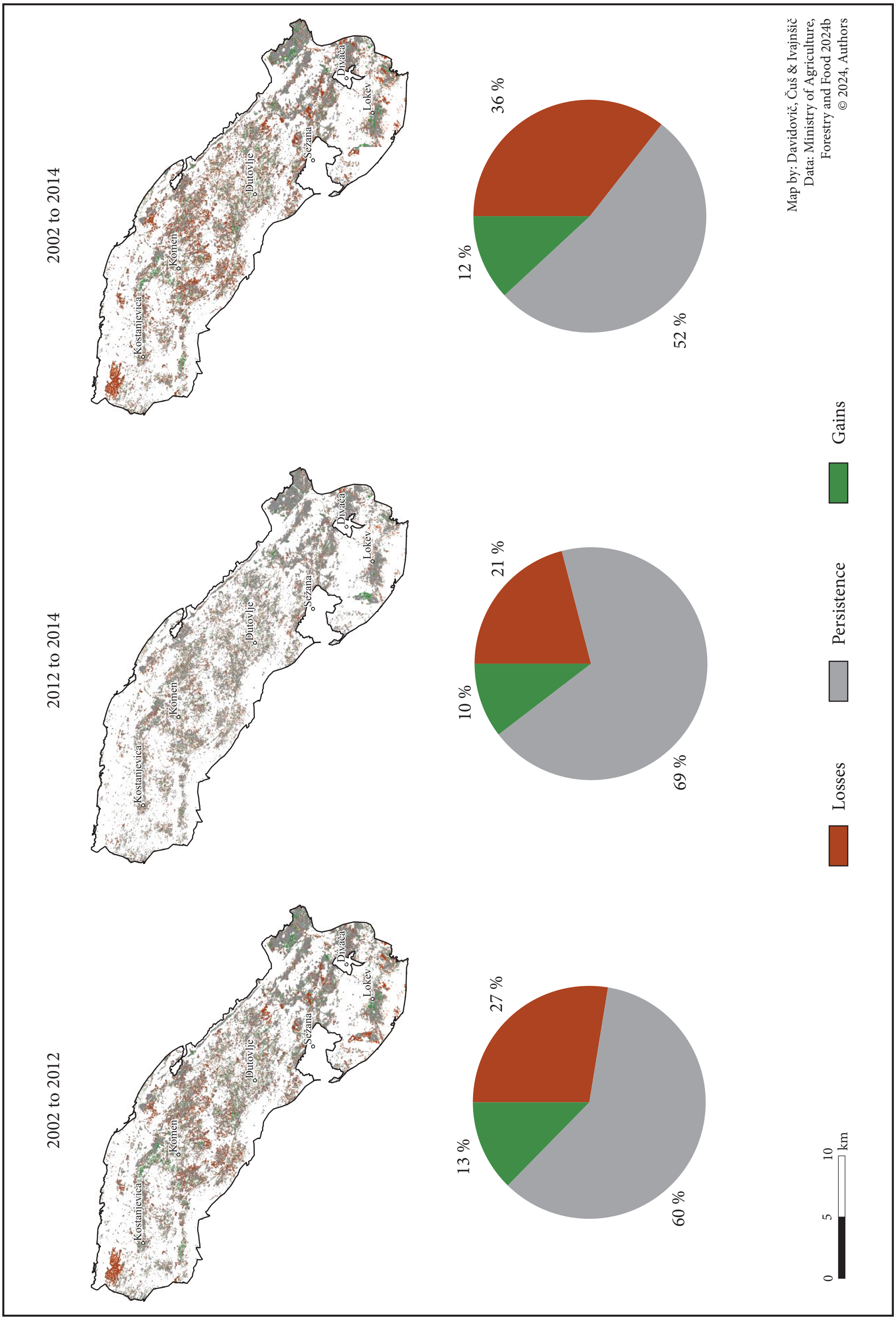
Over the full two decades, cumulative losses exceeded one-third (36%) of total grassland area, concentrated mainly in northern and central areas, where forests already border the plateau. The contraction rate averaged 128 ha/yr. Only 52% of grasslands remained stable, mainly in the south, while gains were minimal (12%), suggesting limited regeneration but indicating possible arable land abandonment (Figure 4, right).

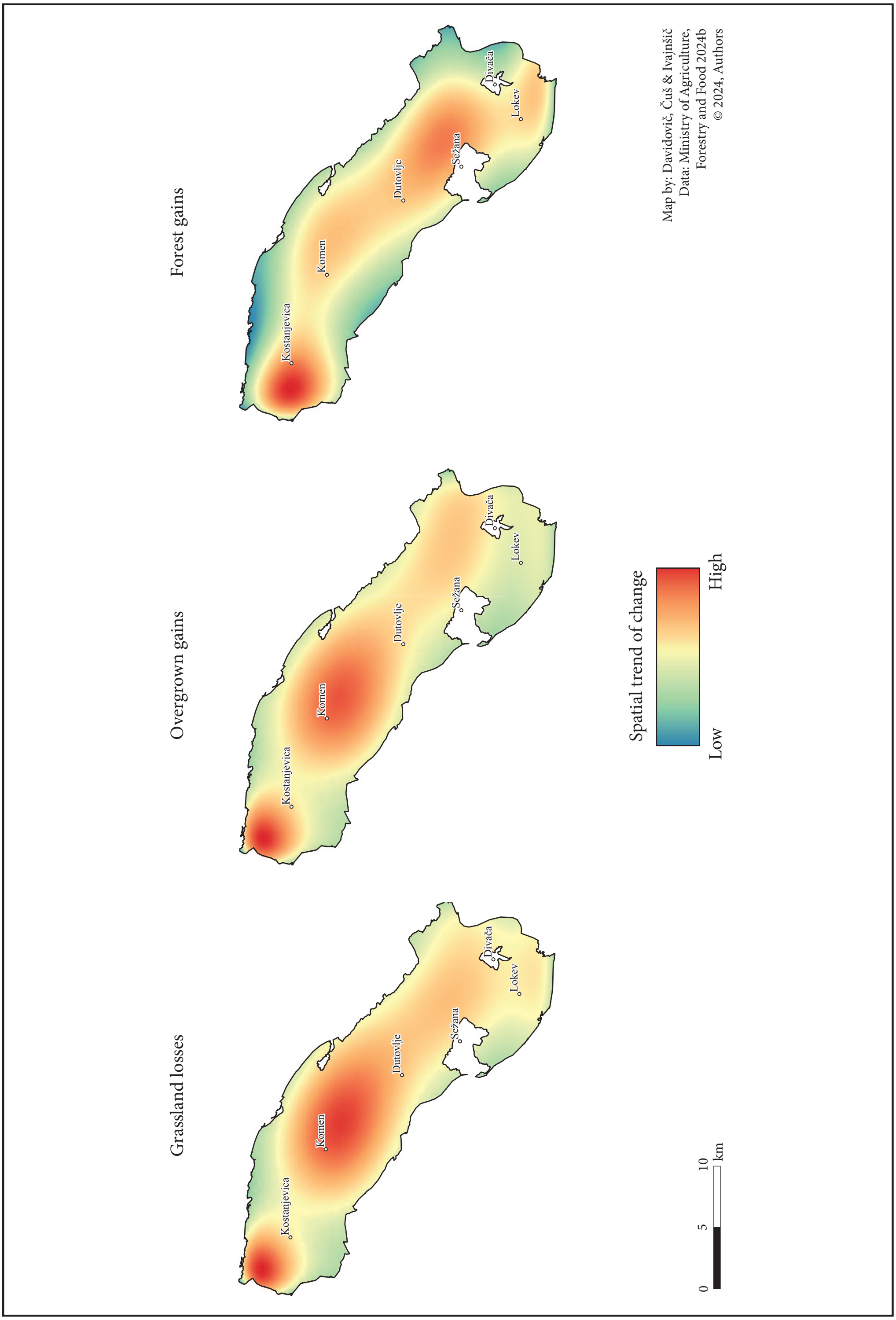
Spatial trend maps (Figure 5) reveal that landscape change was most dynamic in the central and northern parts of the region over the past two decades. The greatest grassland losses occurred around Kostanjevica na Krasu, Komen, Divača and Sežana. Overgrown areas expanded most intensively near Kostanjevica na Krasu and Komen, with additional hotspots around Sežana. Forest expansion was strongest near Kostanjevica na Krasu and Sežana and moderate in the Komen–Dutovlje area. The most stable zones are located along the regional margins, where higher elevations support climax forest communities. In contrast, southern areas show rapid grassland conversion directly into forest, with limited intermediate overgrowth.

Table 3: Dominant spatial process of grassland change in Natura 2000 site Kras (2002–2024).

Period	Process	Area (ha)	Area (%)
2002–2012	Attrition	80.54	0.20
	Creation	31060.44	77.42
	Dissection	8978.11	22.38
2012–2024	Attrition	25241.64	62.92
	Creation	7210.54	17.97
	Dissection	7666.92	19.11
2002–2024	Attrition	0.16	0.00
	Creation	31510.88	78.54
	Dissection	8608.06	21.46

Figure 4: Grassland transition dynamics. ➤ p. 71
Figure 5: Spatial trends of land-use changes. ➤ p. 72


2002 to 2012
2012 to 2014
2002 to 2014
Kostanjevica
Komen
Dutovlje
Sežana
Divača
Lokev
13 %
27 %
60 %
10 %
21 %
69 %
12 %
36 %
52 %
Losses
Persistence
Gains
0
5
10
km
Map by: Davidovič, Čuš & Ivajnšič
Data: Ministry of Agriculture, Forestry and Food 2024b
© 2024, Authors


Grassland losses
Overgrown gains
Forest gains
Kostanjevica
Komen
Dutovlje
Sežana
Lokev
Divača
Spatial trend of change
Low
High
0
5
10
km
Map by: Davidovič, Čuš & Ivajnšič
Data: Ministry of Agriculture,
Forestry and Food 2024b
© 2024, Authors

3.3 Socioeconomic factors of ecological succession

Results of the GLM analysis indicate that grassland dynamics are primarily shaped by spatial rather than demographic factors (Table 4). Grassland loss was primarily driven by landscape configuration. Forest proximity showed a moderate negative association ($\beta = -0.19$, $p = 0.02$), indicating that areas close to forests are more prone to conversion through shrub and tree encroachment. Road proximity had a moderate positive association ($\beta = 0.16$, $p = 0.04$), suggesting that accessibility facilitates gradual overgrowth. Neither farm-holder age ($\beta = -0.16$, $p = 0.77$) nor LU density ($\beta = 0.05$, $p = 0.38$) significantly affected this process.

Grassland persistence was most influenced by forest and road proximity. Forest proximity showed a strong negative association ($\beta = -0.56$, $p < 0.001$), confirming that encroaching forests substantially reduce grassland stability. Road proximity had a strong positive association ($\beta = 0.52$, $p < 0.001$), indicating that easier access enables continued management. LU density exhibited a moderate negative association ($\beta = -0.17$, $p = 0.02$), meaning that heavier grazing reduces long-term stability. Farm-holder age showed no significant effect ($\beta = 0.98$, $p = 0.23$).

Grassland gain was promoted by moderate grazing and limited by nearby forests. LU density had a moderate positive association ($\beta = 0.18$, $p = 0.02$), showing that balanced grazing supports regeneration. Forest proximity showed a moderate negative association ($\beta = -0.32$, $p = 0.01$), implying that forest adjacency constrains new grassland formation. Farm-holder age ($\beta = -0.39$, $p = 0.62$) and road proximity ($\beta = 0.09$, $p = 0.43$) were not significant.

Overall, the analysis shows that forest proximity, road proximity, and LU density are the principal factors of grassland change in the Natura 2000 site Kras. Forest edges accelerate succession and reduce persistence, road access enhances management but can also promote conversion, and moderate grazing intensity supports grassland renewal. Demographic factors such as farm-holder age exert only negligible influence.

Table 4: Descriptive statistics and regression analysis of grassland dynamics.

	Socioeconomic factors	$\bar{x}$	β	SE	t	p
Grassland losses	Age	61.6	–0.16	0.55	–0.3	0.77
	LU	1.8	0.05	0.05	0.88	0.38
	Forest proximity	**81.2**	**–0.19**	**0.08**	**–2.34**	**0.02**
	Road proximity	**169.5**	**0.16**	**0.08**	**2.03**	**0.04**
Grassland persistence	Age	63.2	0.98	0.82	1.19	0.23
	LU	**0.3**	**–0.17**	**0.08**	**–2.24**	**0.03**
	Forest proximity	**64.1**	**–0.56**	**0.12**	**–4.57**	**0.00**
	Road proximity	**117.8**	**0.52**	**0.11**	**4.63**	**0.00**
Grassland gains	Age	64.5	–0.39	0.79	–0.5	0.62
	LU	**0.7**	**0.18**	**0.08**	**2.36**	**0.02**
	Forest proximity	**93.8**	**–0.32**	**0.12**	**–2.72**	**0.01**
	Road proximity	161.4	0.09	0.11	0.78	0.43

$\bar{x}$ – mean; β – regression coefficient; SE – standard error; t – t-statistic; p – significance level.
Bold values indicate statistically significant results ($p < 0.05$; $\alpha = 0.05$).

4 Discussion

4.1 Processes driving grassland decline

Over the past two decades, the Natura 2000 site Kras experienced major land-use transitions, dominated by forest and overgrowth expansion and a pronounced grassland decline. These results confirm the long-term trend identified by Kaligarič and Ivajnšič (2014), who documented a drop in grassland cover from

82% in 1763 to 20% in 2012. Our findings (19% in 2024) align closely with these historical estimates, suggesting a continuing successional trajectory toward forest dominance, projected to reach 90% by 2100.

Forest and overgrown areas expanded by more than 50%, while grasslands contracted by over one-quarter, marking succession as the principal landscape process. These results mirror European trends of semi-natural grassland loss due to declining traditional land use and agricultural abandonment (Wilson et al. 2012; Dengler et al. 2014; Nita et al. 2019; Shipley et al. 2024). Land abandonment, depopulation, and farm-holder aging have reduced grazing and mowing, facilitating shrub and tree encroachment (Hülber et al. 2017; Loos et al. 2021). Minor increases in orchards and olive groves reflect localized intensification rather than broad agricultural recovery. Urban expansion, though spatially limited, has further replaced arable land and vineyards near settlements, emphasizing the need for integrated land-use planning to balance rural development and ecological integrity.

While natural succession remains the primary process behind grassland loss, anthropogenic and economic pressures accelerate it. Demographic effects were weak: farm-holder age showed no significant relationship to grassland dynamics ($p > 0.2$), likely due to uniformly older populations in the region. However, qualitative trends suggest that experienced farmers maintain traditional management beneficial for grassland stability (Ferreira-Rodríguez et al. 2021; Sucholas et al. 2022). Broader socioeconomic factors – particularly land-use profitability and market shifts – appear more decisive.

LU density is related to all processes, revealing a nonlinear relationship. High LU density correlated with grassland loss, supporting evidence that excessive grazing promotes degradation and succession (Eldridge et al. 2013; Pedley et al. 2023). Conversely, moderate LU values encouraged grassland gain, confirming that controlled grazing limits shrub encroachment and sustains open habitats (Rook and Tallowin 2003; Liang et al. 2021). These findings highlight the need for adaptive grazing management – reducing intensity on stable grasslands while promoting moderate grazing in overgrowing areas (Van Den Pol-van Dasselaar et al. 2020; Guo and Chen 2024).

Proximity to forests consistently emerged as the strongest spatial factor. Grasslands near forests were more prone to loss ($\beta = -0.19$, $p = 0.02$), confirming that adjacent forest edges accelerate succession via seed dispersal and altered microclimate (Lacasella et al. 2015; Rendeková et al. 2020). Yet, forest adjacency occasionally promoted persistence or gain by shielding grasslands from agricultural intensification (Wolański et al. 2021; Reeg et al. 2022). Hence, buffer-zone management and selective clearing along forest boundaries could balance protection and control of encroachment.

Road proximity exerted a dual effect. Grasslands closer to roads showed both higher persistence and higher loss rates – reflecting accessibility for management but also greater disturbance (Söderström et al. 2001; Deng et al. 2011). Remote sites were less disturbed yet more likely to undergo succession due to limited maintenance (Biró et al. 2013). Intermediate accessibility thus appears optimal, enabling periodic mowing and grazing without excessive pressure.

4.2 Ecological and socio-economic implications

Grassland transformation through abandonment and intensification has far-reaching ecological consequences. Fragmentation reduces landscape connectivity and biodiversity, disrupting pollination, dispersal, and trophic dynamics (Rösch et al. 2013; Staude et al. 2023). Shrub and forest encroachment lower habitat diversity and carbon storage potential (Rousset et al. 2024) and diminish erosion control (Liu et al. 2020). Biomass accumulation in overgrown areas increases wildfire risk, as demonstrated by large fires in 2022 and 2024.

Economically, grassland decline undermines local agriculture, tourism, and cultural identity (Premaratne and Somasiri 2015; Eriksson 2022). The disappearance of traditional landscapes weakens rural economies and erodes land-stewardship knowledge that once sustained ecological resilience.

Agri-environmental schemes have had limited success in halting grassland decline due to weak targeting, insufficient funding, and administrative barriers (Ivajnšič et al. 2018; Kaligarič et al. 2019). Many subsidized areas lacked high conservation value, and bureaucratic complexity discouraged participation. Effective policy should improve site selection, simplify procedures, ensure timely payments, and integrate local ecological knowledge (Žgavec et al. 2013; Dengler et al. 2014).

Climate change compounds these challenges. Rising temperatures, altered precipitation, and more frequent droughts intensify succession in sub-Mediterranean regions (Ivajnšič and Devetak 2020; Davidovič et al. 2022). In Kras, overgrowth may raise evapotranspiration by 75% (Ivajnšič and Kaligarič 2015), altering species composition and threatening up to 63% of conservation-priority species by 2100 (Araújo et al. 2011; Damgaard 2022).

Conservation of semi-natural grasslands requires multi-scale, adaptive management integrating ecological, spatial, and socioeconomic dimensions:

- Adaptive grazing management: Reduce intensity in stable grasslands; apply moderate grazing to control shrub encroachment (Milazzo et al. 2023).
- Forest-edge management: Implement controlled clearing and maintain buffer zones to balance biodiversity and succession control (Iberl et al. 2023).
- Silvopastoral and mixed land-use systems: Integrate trees, shrubs, and pastures to diversify land cover, enhance carbon storage, and maintain open habitats while sustaining agricultural productivity (Mosquera-Losada et al. 2018).
- Targeted access planning: Maintain limited road access to enable management while minimizing disturbance (Sangha 2024).
- Policy reform: Strengthen incentives for extensive agriculture, promote market access for sustainable products, streamline bureaucracy, and improve communication with farmers (Žgavec et al. 2013; Hülber et al. 2017).
- Integration of traditional knowledge: Combine low-intensity practices with science-based management to enhance productivity and ecosystem services (Mekonen 2017; Bartual et al. 2019; Schils et al. 2022).

4.3 Study limitations

Several methodological constraints should be acknowledged. First, while national land-use datasets offer valuable regional coverage, integrating localized field observations would improve detection of management effects such as rotational grazing or periodic mowing. Second, the regression models include only selected socioeconomic predictors, excluding potentially influential environmental factors such as microclimate, biodiversity indicators, and climate-change effects. Future research should combine both socioeconomic and ecological factors to capture a fuller picture of grassland dynamics.

Finally, the use of proximity metrics (forest and road distances) effectively highlights spatial influences but may oversimplify landscape complexity. For example, distance to a road does not account for traffic intensity, seasonality, or disturbance frequency, all of which can differently affect grassland persistence or recovery. Incorporating traffic datasets or advanced landscape-connectivity models could therefore enhance understanding of spatial processes shaping grassland change.

5 Conclusion

The Natura 2000 site Kras is a vital ecological and cultural landscape where semi-natural grasslands sustain biodiversity and key ecosystem services. Over the past two decades, these grasslands have declined due to ecological succession, socio-economic change, and insufficiently effective conservation measures.

This study identified proximity to forests and roads as the strongest spatial factors of grassland dynamics, while livestock density and farm-holder age showed weaker, context-dependent effects. Forest encroachment – accelerated by natural succession and reduced traditional management – remains the principal threat. Grasslands near forest edges are most vulnerable to woody invasion, whereas limited road access constrains management practices such as mowing and grazing. Excessive livestock densities and the gradual loss of traditional ecological knowledge further intensify degradation risks.

Agri-environmental schemes, though conceptually sound, have proven only partly effective due to weak targeting, misallocated funding, and insufficient incentives for extensive management. A re-evaluation of policy frameworks is needed to improve the precision and local adaptation of support measures.

Conservation of Kras grasslands requires an integrated approach linking adaptive grazing, forest-edge management, and selective access planning with policy reform and community participation. Enhanced financial and technical assistance, combined with education and stakeholder cooperation, is essential to maintain ecological and cultural resilience.

In the context of climate change and socio-economic transition, decisive action is necessary to secure the biodiversity, ecosystem services, and heritage values of the Kras region. This study provides an empirical foundation for adaptive, multi-scale strategies that place grassland conservation at the core of sustainable landscape management.

ACKNOWLEDGMENT: The authors acknowledge the research project the project »Development of Research Infrastructure for the International Competitiveness of the Slovenian RRI Space-RI-SI-LifeWatch«, co-financed by the Republic of Slovenia, Ministry of Education, Science and Sport and the European Union from the European Regional Development Fund, the NOO project »ZELEN.KOM (3330-22-3514 (PP5))«, financed by Ministry of Higher Education, Science and Innovation Republic of Slovenia, as well as the Research Program »Slovene Identity and Cultural Awareness in Linguistic and Ethnic Contact Areas in Past and Present (P6-0372)«, financed by Slovenian Research and Innovation Agency.

RESEARCH DATA: For information on the availability of research data related to the study, please visit the article webpage: https://doi.org/10.3986/AGS.14021.

6 References

Araújo, M. B., Alagador, D., Cabeza, M., Nogués-Bravo, D., Thuiller, W. 2011: Climate change threatens European conservation areas: Climate change threatens conservation areas. *Ecology Letters* 14-5. https://doi.org/10.1111/j.1461-0248.2011.01610.x

Bai, Y., Cotrufo, M. F. 2022: Grassland soil carbon sequestration: Current understanding, challenges, and solutions. *Science* 377-6606. https://doi.org/10.1126/science.abo2380

Bartual, A. M., Sutter, L., Bocci, G., Moonen, A.-C., Cresswell, J., Entling, M., Giffard, B. et al. 2019: The potential of different semi-natural habitats to sustain pollinators and natural enemies in European agricultural landscapes. *Agriculture, Ecosystems & Environment* 279. https://doi.org/10.1016/j.agee.2019.04.009

Biró, M., Czúcz, B., Horváth, F., Révész, A., Csatári, B., Molnár, Z. 2013: Drivers of grassland loss in Hungary during the post-socialist transformation (1987–1999). *Landscape Ecology* 28-5. https://doi.org/10.1007/s10980-012-9818-0

Chytrý, M., Dražil, T., Hájek, M., Kalníková, V., Preislerová, Z., Šibík, J., Ujházy, K. et al. 2015: The most species-rich plant communities in the Czech Republic and Slovakia (with new world records). *Preslia* 87-3.

Dahlström, A., Iuga, A.-M., Lennartsson, T. 2013: Managing biodiversity rich hay meadows in the EU: a comparison of Swedish and Romanian grasslands. *Environmental Conservation* 40-2. https://doi.org/10.1017/s0376892912000458

Damgaard, C. 2022: Spatio-temporal modelling of the effect of selected environmental and land-use factors on species-rich calcareous grasslands: overgrazing and nitrogen deposition. *Basic and Applied Ecology* 72. https://doi.org/10.1016/j.baae.2023.07.001

Dasselaar, A. van den P., Golinski, P., Hennessy, D., Huyghe, C., Parente, G., Peyraud, J. L., Stienezen, M. W. J. 2013: Appreciation of current and future functions of grassland by international stakeholders in Europe. In: The Role of Grasslands in a Green Future: Threats and Perspectives in Less Favoured Areas. Proceedings of the 17th Symposium of the European Grassland Federation, Akureyri, Iceland, 23–26 June 2013. CABI.

Davidovič, D., Ivajnšič, D., Čuš, J. 2022: Interakcija naravnih in družbenih razmer kot pospeševalec zaraščanja Krasa. In: Primeri prostorskih analiz vplivov podnebnih sprememb: Monografija v okviru projekta Preprečevanje toplotnega stresa v urbanih sistemih v luči podnebnih sprememb (ARRS J7-1822). Univerza v Mariboru, Univerzitetna založba. https://doi.org/10.18690/um.fnm.8.2022.5

Deng, X., Huang, J., Huang, Q., Rozelle, S., Gibson, J. 2011: Do roads lead to grassland degradation or restoration? A case study in Inner Mongolia, China. *Environment and Development Economics* 16-6. https://doi.org/10.1017/S1355770X11000180

Dengler, J., Janišová, M., Török, P., Wellstein, C. 2014: Biodiversity of Palaearctic grasslands: A synthesis. *Agriculture, Ecosystems & Environment* 182. https://doi.org/10.1016/j.agee.2013.12.015

Eastman, R. J. 2024: TerrSet liberaGIS: Geospatial monitoring and modelling system. Clark University.

Eldridge, D. J., Soliveres, S., Bowker, M. A., Val, J. 2013: Grazing dampens the positive effects of shrub encroachment on ecosystem functions in a semi-arid woodland. *Journal of Applied Ecology* 50-4. https://doi.org/10.1111/1365-2664.12105

Envall, I., Bengtsson, J., Jakobsson, S., Rundlöf, M., Åberg, C., Lindborg, R. 2021: What is the effect of giving the grazers access to additional nutrient sources on biodiversity in semi-natural pastures? A systematic review protocol. *Environmental Evidence* 10-1. https://doi.org/10.1186/s13750-021-00230-2

Eriksson, O. 2022: Coproduction of food, cultural heritage and biodiversity by livestock grazing in Swedish semi-natural grasslands. *Frontiers in Sustainable Food Systems* 6. https://doi.org/10.3389/fsufs.2022.801327

Favretto, D., Poldini, L. 1986: Extinction time of a sample of Karst pastures due to bush encroachment. *Ecological Modelling* 33-2,4. https://doi.org/10.1016/0304-3800(86)90033-5

Feoli, E., Chiapella, L. F. 1979: Changements of vegetation pattern towards reforestation. *Colloquia Phytosociology* 8.

Feoli, E., Feoli-Chiapella, L., Ganis, P., Sorge, A. 1980: Spatial pattern analysis of abandoned grasslands of the Karst region by Trieste and Gorizia. *Studia Geobot* 1-1.

Feoli, E., Scimone, M. 1982: Gradient analysis in the spontaneous reforestation process of the Karst region. *Gortania* 3.

Ferreira-Rodríguez, N., Pavel, A. B., Cogălniceanu, D. 2021: Integrating expert opinion and traditional ecological knowledge in invasive alien species management: *Corbicula* in Eastern Europe as a model. *Biological Invasions* 23-4. https://doi.org/10.1007/s10530-020-02420-4

Fox, J., Marquez, M. M., Bouchet-Valat, M. 2024: Rcmdr: R Commander. R package version 2.9-5. *Software*.

Gigante, D., Angelucci, S., Bonini, F., Caruso, F., Di Cecco, V., Donnini, D., Morbidini, L. et al. 2024: Seminatural grasslands: An emblematic challenge for nature conservation in protected areas. *Land* 13-3. https://doi.org/10.3390/land13030386

Guo, Y., Chen, Y. 2024: A review of the impact of grazing on grassland ecosystems: Research progress and prospects. *Advances in Resources Research* 4-3. https://doi.org/10.50908/arr.4.3_455

Habič, P. 1979: Problematika geografskega vrednotenja krasa. *Geografski vestnik* 51.

Hejcman, M., Hejcmanová, P., Pavlů, V., Beneš, J. 2013: Origin and history of grasslands in Central Europe – a review. *Grass and Forage Science* 68-3. https://doi.org/10.1111/gfs.12066

Hopkins, A., Holz, B. 2006: Grassland for agriculture and nature conservation: Production, quality and multi-functionality. *Agronomy research* 4-1.

Horvatić, S. 1973: Syntaxonomic analysis of the vegetation of dry grassland and stony meadows in Eastern Adriatic coastal karst district based on the latest phytocoenological research. *Fragmenta Herbologica Jugoslavica* 32.

Hrvatin, M., Perko, D., Petek, F. 2006: Land use in selected erosion-risk areas of Tertiary low hills in Slovenia. *Acta geographica Slovenica* 46-1. https://doi.org/10.3986/AGS46103

Hülber, K., Moser, D., Sauberer, N., Maas, B., Staudinger, M., Grass, V., Wrbka, T., Willner, W. 2017: Plant species richness decreased in semi-natural grasslands in the Biosphere Reserve Wienerwald, Austria, over the past two decades, despite agri-environmental measures. *Agriculture, Ecosystems & Environment* 243. https://doi.org/10.1016/j.agee.2017.04.002

Iberl, K., Poschlod, P., Reisch, C. 2023: Restoration of calcareous grasslands by natural recolonization after forest clearing and its impact on the genetic variation of three common herb species. *Biodiversity and Conservation* 32-2. https://doi.org/10.1007/s10531-022-02518-2

Ivajnšič, D., Devetak, D. 2020: GIS-based modelling reveals the fate of antlion habitats in the Deliblato Sands. *Scientific Reports* 10-1. https://doi.org/10.1038/s41598-020-62305-3

Ivajnšič, D., Kaligarič, M. 2015: Can evapotranspiration be considered an additional indicator for understanding the changed landscape identity of the classic Karst? *Annales. Series historia naturalis* 25-2.

Ivajnšič, D., Pintarič, D., Škornik, S., Kaligarič, M., Pipenbaher, N. 2018: SOSKOPOP Haloze: podporni sistem potencialnim uveljaviteljem ukrepov KOPOP na nivoju travišč. *Revija za geografijo* 14-1.

Ivajnšič, D., Škornik, S., Kaligarič, M. 2013: Spremembe rabe tal med leti 1830 in 2008 na območju Movraškega Krasa in na bližnjih flišnih predelih. *Revija za geografijo* 8-1.

Jančar, T. 2014: Uničujoč vpliv kmetijske politike na travniške ptice. *Svet ptic* 20-2.

Jugovic, J., Črne, M., Pečnikar, Ž. F. 2013: The impact of grazing, overgrowth and mowing on spring butterfly (Lepidoptera: Rhopalocera) assemblages on dry karst meadows and pastures. *Natura Croatica* 22-1.

Kaligarič, M., Culiberg, M., Kramberger, B. 2006: Recent vegetation history of the North Adriatic grasslands: Expansion and decay of an anthropogenic habitat. *Folia Geobotanica* 41-3. https://doi.org/10.1007/BF02904940
Kaligarič, M., Čuš, J., Škornik, S., Ivajnšič, D. 2019: The failure of agri-environment measures to promote and conserve grassland biodiversity in Slovenia. *Land Use Policy* 80. https://doi.org/10.1016/j.landusepol.2018.10.013
Kaligarič, M., Ivajnšič, D. 2014: Vanishing landscape of the »classic« Karst: changed landscape identity and projections for the future. *Landscape and Urban Planning* 132. https://doi.org/10.1016/j.landurbplan.2014.09.004
Kaligarič, M., Poldini, L. 1996: New contributions on the typology of the vegetation of dry grasslands (Scorzoneretalia villosae H-IĆ 1975) in the North Adriatic karst. *Gortania* 19.
Kaligarič, M., Škornik, S. 2002: Contribution to the knowledge of the dry grassland vegetation on the highland areas of the Pohorje mountain (Slovenia). *Annales. Series historia naturalis* 12-1.
Kladnik, D. 2011: Širjenje gozda na krasu kot dejavnik prostorskega razvoja. *Geografski vestnik* 83-2.
Kmecl, P., Figelj, J., Jančar, T. 2014: Monitoring splošno razširjenih vrst ptic za določitev slovenskega indeksa ptic kmetijske krajine – poročilo za leto 2014. *Technical report*. DOPPS.
Kose, M., Melts, I., Heinsoo, K. 2022: Medicinal plants in semi-natural grasslands: Impact of management. *Plants* 11-3. https://doi.org/10.3390/plants11030353
Lacasella, F., Gratton, C., De Felici, S., Isaia, M., Zapparoli, M., Marta, S., Sbordoni, V. 2015: Asymmetrical responses of forest and »beyond edge« arthropod communities across a forest–grassland ecotone. *Biodiversity and Conservation* 24-3. https://doi.org/10.1007/s10531-014-0825-0
Lausi, D., Pignatti, S., Poldini, L. 1979: Statistische Untersuchungen über die Wiederbewaldung auf dem Triester Karst. In: Gesellschaftsentwicklung (Syndynamik). *Berichte der Internationalen Symposien der Internationalen Vereinigung für Vegetationskunde* 11. Springer Netherlands. https://doi.org/10.1007/978-94-011-7593-7_31
Liang, M., Liang, C., Hautier, Y., Wilcox, K. R., Wang, S. 2021: Grazing-induced biodiversity loss impairs grassland ecosystem stability at multiple scales. *Ecology Letters* 24-10. https://doi.org/10.1111/ele.13826
Liu, Y.-F., Liu, Y., Shi, Z.-H., López-Vicente, M., Wu, G.-L. 2020: Effectiveness of re-vegetated forest and grassland on soil erosion control in the semi-arid Loess Plateau. *CATENA* 195. https://doi.org/10.1016/j.catena.2020.104787
Loos, J., Krauss, J., Lyons, A., Föst, S., Ohlendorf, C., Racky, S., Röder, M. et al. 2021: Local and landscape responses of biodiversity in calcareous grasslands. *Biodiversity and Conservation* 30-8. https://doi.org/10.1007/s10531-021-02201-y
Mekonen, S. 2017: Roles of traditional ecological knowledge for biodiversity conservation. *Journal of Natural Sciences Research* 7-15.
Milazzo, F., Francksen, R. M., Abdalla, M., Ravetto Enri, S., Zavattaro, L., Pittarello, M., Hejduk, S. et al. 2023: An overview of permanent grassland grazing management practices and the impacts on principal soil quality indicators. *Agronomy* 13-5. https://doi.org/10.3390/agronomy13051366
Milcu, A., Hanspach, J., Abson, D., Fischer, J. 2013: Cultural ecosystem services: A literature review and prospects for future research. *Ecology and Society* 18-3. https://doi.org/10.5751/ES-05790-180344
Mosquera-Losada, M. R., Santiago-Freijanes, J. J., Rois-Díaz, M., Moreno, G., den Herder, M., Aldrey-Vázquez, J. A., Ferreiro-Domínguez, N. et al. 2018: Agroforestry in Europe: A land management policy tool to combat climate change. *Land Use Policy* 78. https://doi.org/10.1016/j.landusepol.2018.06.052
Nita, A., Hartel, T., Manolache, S., Ciocanea, C. M., Miu, I. V., Rozylowicz, L. 2019: Who is researching biodiversity hotspots in Eastern Europe? A case study on the grasslands in Romania. *PLoS ONE* 14-5. https://doi.org/10.1371/journal.pone.0217638
Pedley, D., McWilliam, W., Doscher, C. 2023: Forests from the grass: Natural regeneration of woody vegetation in temperate marginal hill farmland under minimum interference management. *Restoration Ecology* 31-3. https://doi.org/10.1111/rec.13852
Perko, D., Hrvatin, M., Ciglič, R. 2017: Determination of landscape hotspots of Slovenia. *Acta geographica Slovenica* 57-1. https://doi.org/10.3986/AGS.4618
Pipenbaher, N., Kaligarič, M., Škornik, S. 2011: Floristic and functional comparision of karst pastures and karst meadows from the North Adriatic Karst. *Acta Carsologica* 40-3. https://doi.org/10.3986/ac.v40i3.61

Poldini, L. 1989: La vegetazione del Carso isontino e triestino: studio del paesaggio vegetale fra Trieste, Gorizia e i Territori Adiacenti. Lint.

Premaratne, S., Somasiri, S. 2015: Strengthening livelihood of rural farmer populations through improved grasslands. In: Proceedings of the 23rd International Grassland Congress. Range Management Society of India.

Reed, H. E., Seastedt, T. R., Blair, J. M. 2005: Ecological consequences of C_4 grass invasion of a C_4 grassland: A dilemma for management. *Ecological Applications* 15-5. https://doi.org/10.1890/04-0407

Reeg, J., Strigl, L., Jeltsch, F. 2022: Agricultural buffer zone thresholds to safeguard functional bee diversity: Insights from a community modeling approach. *Ecology and Evolution* 12-3. https://doi.org/10.1002/ece3.8748

Rendeková, A., Miškovic, J., Mičieta, K., Michalová, M., Eliašová, M., Ballová, D. 2020: Changes in the diversity of dry calcareous grasslands after abandonment of traditional management in Devínska Kobyla national nature reserve (Southwestern Slovakia, Central Europe). *Ekológia (Bratislava)* 39-2. https://doi.org/10.2478/eko-2020-0008

Ribeiro, D., Šmid Hribar, M. 2019: Assessment of land-use changes and their impacts on ecosystem services in two Slovenian rural landscapes. *Acta geographica Slovenica* 59-2. https://doi.org/10.3986/AGS.6636

Rogerson, M., Brown, D. K., Sandercock, G., Wooller, J.-J., Barton, J. 2016: A comparison of four typical green exercise environments and prediction of psychological health outcomes. *Perspectives in Public Health* 136-3. https://doi.org/10.1177/1757913915589845

Rook, A. J., Tallowin, J. R. B. 2003: Grazing and pasture management for biodiversity benefit. *Animal Research* 52-2. https://doi.org/10.1051/animres:2003014

Rösch, V., Tscharntke, T., Scherber, C., Batáry, P. 2013: Landscape composition, connectivity and fragment size drive effects of grassland fragmentation on insect communities. *Journal of Applied Ecology* 50-2. https://doi.org/10.1111/1365-2664.12056

Rousset, C., Segura, C., Gilgen, A., Alfaro, M., Mendes, L. A., Dodd, M., Dashpurev, B. et al. 2024: What evidence exists relating the impact of different grassland management practices to soil carbon in livestock systems? A systematic map protocol. *Environmental Evidence* 13. https://doi.org/10.1186/s13750-024-00345-2

Sangha, S. 2024: Ecosystem Services and Urban Planning. *Journal of Applied Geographical Studies* 3-1. https://doi.org/10.47941/jags.1621

Schils, R. L. M., Bufe, C., Rhymer, C. M., Francksen, R. M., Klaus, V. H., Abdalla, M., Milazzo, F. et al. 2022: Permanent grasslands in Europe: Land use change and intensification decrease their multifunctionality. *Agriculture, Ecosystems & Environment* 330. https://doi.org/10.1016/j.agee.2022.107891

Shipley, J. R., Frei, E. R., Bergamini, A., Boch, S., Schulz, T., Ginzler, C., Barandun, M. et al. 2024: Agricultural practices and biodiversity: Conservation policies for semi-natural grasslands in Europe. *Current Biology* 34-16. https://doi.org/10.1016/j.cub.2024.06.062

Škornik, S., Vidrih, M., Kaligarič, M. 2010: The effect of grazing pressure on species richness, composition and productivity in North Adriatic Karst pastures. *Plant Biosystems – An International Journal Dealing with all Aspects of Plant Biology* 144-2. https://doi.org/10.1080/11263501003750250

Söderström, B., Svensson, B., Vessby, K., Glimskär, A. 2001: Plants, insects and birds in semi-natural pastures in relation to local habitat and landscape factors. *Biodiversity & Conservation* 10-11. https://doi.org/10.1023/A:1013153427422

Staude, I. R., Segar, J., Temperton, V. M., Andrade, B. O., de Sá Dechoum, M., Weidlich, E. W. A., Overbeck, G. E. 2023: Prioritize grassland restoration to bend the curve of biodiversity loss. *Restoration Ecology* 31-5. https://doi.org/10.1111/rec.13931

Stepišnik, U. 2011: Sediments in collapse dolines on the Kras plateau, Slovenia. *Acta geographica Slovenica* 51-2. https://doi.org/10.3986/AGS51201

Sucholas, J., Molnár, Z., Łuczaj, Ł., Poschlod, P. 2022: Local traditional ecological knowledge about hay management practices in wetlands of the Biebrza Valley, Poland. *Journal of Ethnobiology and Ethnomedicine* 18. https://doi.org/10.1186/s13002-022-00509-9

Šumrada, T., Erjavec, E. 2023: Will farmers cooperate to conserve biodiversity? The use of collective bonus in the High Nature Value farmland in Slovenia. *Acta geographica Slovenica* 63-3. https://doi.org/10.3986/AGS.11015

Tindale, S., Vicario-Modroño, V., Gallardo-Cobos, R., Hunter, E., Miškolci, S., Price, P. N., Sánchez-Zamora, P. et al. 2023: Citizen perceptions and values associated with ecosystem services from European grassland landscapes. *Land Use Policy* 127. https://doi.org/10.1016/j.landusepol.2023.106574

Tüxen, R., Horvat, I., Tüxen, R. 1974: Vegetation Südosteuropas: Tab. = Vegetation of Southeast-Europe. *Geobotanica selecta / hrsg. von R. Tüxen*. G. Fischer.

Van Den Pol-van Dasselaar, A., Hennessy, D., Isselstein, J. 2020: Grazing of dairy cows in Europe – An in-depth analysis based on the perception of grassland experts. *Sustainability* 12-3. https://doi.org/10.3390/su12031098

Veldkamp, A., Lambin, E. F. 2001: Predicting land-use change. *Agriculture, Ecosystems & Environment* 85-1. https://doi.org/10.1016/S0167-8809(01)00199-2

Wilson, J. B., Peet, R. K., Dengler, J., Pärtel, M. 2012: Plant species richness: The world records. *Journal of Vegetation Science* 23-4. https://doi.org/10.1111/j.1654-1103.2012.01400.x

Wolański, P., Bobiec, A., Ortyl, B., Makuch-Pietraś, I., Czarnota, P., Ziobro, J., Korol, M. et al. 2021: The importance of livestock grazing at woodland-grassland interface in the conservation of rich oakwood plant communities in temperate Europe. *Biodiversity and Conservation* 30-3. https://doi.org/10.1007/s10531-021-02115-9

Zhao, Y., Liu, Z., Wu, J. 2020: Grassland ecosystem services: A systematic review of research advances and future directions. *Landscape Ecology* 35-4. https://doi.org/10.1007/s10980-020-00980-3

Zorn, M., Kumer, P., Ferk, M. 2015: From forest to forest or where is the bare rocky Karst? *Kronika* 63-3.

Žuna Pfeiffer, T., Špoljarić Maronić, D., Petrošanec, S., Štolfa Čamagajevac, I., Stević, F. 2018: Steppe-like grassland as a refuge of the wild edible and medicinal plant species in anthropogenic landscape in north-eastern Croatia. *Plant Biosystems – An International Journal Dealing with all Aspects of Plant Biology* 152-5. https://doi.org/10.1080/11263504.2017.1415992

Zwitter, Ž., Rasran, L. 2023: Okoljska zgodovina med interdisciplinarnimi izzivi in rešitvami. In: Izzivi slovenskega zgodovinopisja v 21. stoletju: jubilejno 40. zborovanje slovenskih zgodovinark in zgodovinarjev. Zveza zgodovinskih društev Slovenije. Žgavec, D., Eler, K., Udovč, A., Batič, F. 2013: Contribution of agricultural policy measures to maintain grassland areas (the case of Radensko Polje Landscape Park). *Acta agriculturae Slovenica* 101-1. https://doi.org/10.14720/aas.2013.101.1.14949