ACTA GEOGRAPHICA SLOVENICA

GEOGRAFSKI ZBORNIK

2023
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SLOVENSKE AKADEMIJE ZNANOSTI IN UMETNOSTI
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ACTA GEOGRAPHICA SLOVENICA

GEOGRAFSKI ZBORNIK

63-1

2023

Založba ZRC

LJUBLJANA
2023

ACTA GEOGRAPHICA SLOVENICA

63-1
2023

ISSN: 1581-6613
UDC: 91
2023, ZRC SAZU, Geografski inštitut Antona Melika

Issued by/izdajatelj: Geografski inštitut Antona Melika ZRC SAZU
Published by/založnik: Založba ZRC
Co-published by/sozaložnik: Slovenska akademija znanosti in umetnosti

Address/naslov: Geografski inštitut Antona Melika ZRC SAZU, Gosposka ulica 13, p. p. 306, SI – 1000 Ljubljana, Slovenija; ags@zrc-sazu.si

The articles are available on-line/prispevki so dostopni na medmrežju: http://ags.zrc-sazu.si (ISSN: 1581–8314)

Ordering/naročanje: Založba ZRC, Novi trg 2, p. p. 306, SI – 1001 Ljubljana, Slovenija; zalozba@zrc-sazu.si

Annual subscription/letna naročnina: 20 € for individuals/za posameznika, 28 € for institutions/za ustanove
Single issue/cena posamezne številke: 12,50 € for individuals/za posameznika, 16 € for institutions/za ustanove

Cartography/kartografija: Geografski inštitut Antona Melika ZRC SAZU
Translations/prevodi: DEKS, d. o. o.
DTP/prelom: SYNCOMP, d. o. o.
Printed by/tiskarna: Present, d. o. o.
Print run/naklada: 300 copies/izvodov

The journal is subsidized by the Slovenian Research Agency and is issued in the framework of the Geography of Slovenia core research programme (P6-0101)/Revija izhaja s podporo Javne agencije za raziskovalno dejavnost Republike Slovenije in nastaja v okviru raziskovalnega programa Geografija Slovenije (P6-0101).

The journal is indexed also in/revija je vključena tudi v: Clarivate Web of Science (SCIE – Science Citation Index Expanded; JCR – Journal Citation Report/Science Edition), Scopus, ERIH PLUS, GEOBASE Journals, Current geographical publications, EBSCOhost, Georef, FRANCIS, SJR (SCImago Journal & Country Rank), OCLC WorldCat, Google Scholar, CrossRef, and DOAJ.

Design by/Oblikovanje: Matjaž Vipotnik

Front cover photography: After a major storm, the carbonate Nullarbor Plain was flooded due to its impermeable layer of clay (photograph: Matej Lipar).
Fotografija na naslovnici: Po močnejši nevihti je bila sicer karbonatna ravnina Nullarbor poplavljena zaradi nepropustne plasti gline (fotografija: Matej Lipar).

ACTA GEOGRAPHICA SLOVENICA

ISSN: 1581-6613
UDC: 91
Number: 63-1
Year: 2023

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Gordana Jovanović

Durmitor National Park, Montenegro, mountain peak Međed above the Crno jezero.

DOI: https://doi.org/10.3986/AGS.10834
UDC: 551.583:551.324(497.16)

Gordana Jovanović[1]

The North Atlantic Oscillation influence on the Debeli Namet Glacier

ABSTRACT: This article presents the relationship between climate variables in the Durmitor Massif (Montenegro) and the North Atlantic Oscillation (NAO). A new climate standard for temperatures and precipitation over the last 30 years has been presented. The Debeli Namet Glacier is an indicator of climate change. We have shown that the size of this glacier is affected by the NAO which mainly affects the precipitation in the accumulation period from December to March. During the ablation period from June to September, the influence of the NAO on precipitation and temperatures is less pronounced. El Niño and La Niña events are significant, especially in years with a low NAO index. The relationship between El Niño/La Niña and the NAO is still a subject of scientific debate.

KEY WORDS: The North Atlantic Oscillation, precipitation, temperatures, Debeli Namet Glacier, glacier size

Vpliv severnoatlantske oscilacije na ledenik Debeli Namet

POVZETEK: Članek predstavlja povezavo med podnebnimi spremenljivkami v masivu Durmitor (Črna gora) in severnoatlantsko oscilacijo (NAO). Predstavljen je nov podnebni standard za temperature in padavine v zadnjih 30 letih. Ledenik Debeli Namet je pokazatelj podnebnih sprememb. Pokazali smo, da na velikost tega ledenika vpliva NAO, ki vpliva predvsem na količino padavin v akumulacijskem obdobju od decembra do marca. V obdobju ablacije od junija do septembra je vpliv NAO na padavine in temperature manj izrazit. Dogodki El Niño in La Niña so pomembni zlasti v letih z nizkim indeksom NAO. Razmerje med El Niño/La Niña in NAO je še vedno predmet znanstvenih razprav.

KLJUČNE BESEDE: Severnoatlantska oscilacija, padavine, temperature, ledenik Debeli Namet, velikost ledenika

The article was submitted for publication on 20th May, 2022.
Uredništvo je prejelo prispevek 20. maja 2022.

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1 Introduction

The last Ice Age, which ended 11,000–12,000 years ago, left its mark on the Balkan Peninsula. Thanks to the pioneering research of Jovan Cvijić traces of glaciation and interglaciation periods were discovered in the Balkans (Cvijić 1920). His discovery of an ancient glacial relief on Rila in Bulgaria, in 1896, then on Durmitor (Montenegro), Lovćen (Montenegro), Prokletije (Montenegro, Albania) and other high mountains, made him one of the greatest geographers in Europe at that time. Albrecht Penck, better known for his classic glacier work in the Alps, was another glacier pioneer who worked in the Balkans (Penck 1900). A significant contribution to glacier research was made by Louis (1926) who also worked extensively in the area. Glacier research was particularly active in the period between 1920 and 1940 (Milojević 1937; see reviews in Messerli 1967; Hughes and Woodward 2009) and after World War II, with notable research in Montenegro (Liedtke 1962; Nicod 1968; Marović and Marković 1972) and Greece (Hagedorn 1969). Looking back at the history of glacial research in the Balkan Peninsula, three distinct phases can be identified in the development of this research area (Hughes and Woodward 2016): the pioneering phase characterized by the first descriptive observations of glacial landforms, the mapping phase when the distribution of glacial landforms and sediments was first depicted on sophisticated geomorphological maps and the contemporary advanced phase characterized by the use of modern technologies (Hughes et al. 2010; Onaca et al. 2020; 2022; Gachev 2022).

Mountains with approximately the same elevation had more glaciers when they were closer to the Adriatic Sea due to higher atmospheric precipitation. The lowest Pleistocene glaciers in the Balkans, and in all of southern Europe, formed in the coastal Dinaric Alps bordering the Adriatic Sea (Penck 1900; Cvijić 1917). In these areas, moraines are present at elevations below 1000 m, and in northern Dalmatia (Croatia), glacial deposits have even been reported at sea level (see Hughes et al. 2010 and references therein). The largest glaciers on the peninsula were found in the highest Dinaric mountains – Prokletije, Komovi and Durmitor, whose peaks are above 2500 m. Traces of glaciation in Greece are described by Hughes (Hughes et al. 2010; Hughes 2018).

Today, there are 16 glaciers on the Balkan Peninsula: 13 on Prokletije, 2 on the Pirin Mountains in Bulgaria and 1 on Durmitor (Gachev 2017). Many of them are below the current snow line thanks to favorable topology and local climate. They cover an area of 0.5–5 hectares, and their thickness is estimated at 10–20 m (Onaca et al. 2022; Gachev 2017). The alternation of very warm summers and winters with low snowfall over several years can cause glaciers to retreat or melt throughout the Balkans (Nadbath 1999; Hughes 2008; Grunewald and Scheithauer 2010). The Debeli Namet Glacier (Figure 1) is the only contemporary glacier in the Durmitor massif. Scientists who have studied the Debeli Namet Glacier have been interested in its reconstruction since the Pleistocene (Djurović 2009), its dynamics from the second half of the 20th century to the present (Djurović 2012; Gachev 2017; 2020), and its response and adaptation to climate change (Hughes 2008; Grunewald and Scheithauer 2010). In this article we are interested in the causes of the climate variability and consequential glacier response. One of them is the North Atlantic Oscillation (NAO). As the dominant low-frequency atmospheric oscillation in the Northern Hemisphere it has extensive and pronounced climate impacts around the globe (Hurrell 1995; Woodward 2009; Cattiaux et al. 2010; Hurrell and Deser 2009; Cohen et al. 2012; Li et al. 2013; Li and Ruan 2018). It explains much of the observed temperature and precipitation variability over Eurasia and North America (Hurrell 1996; Wang, Liu and Lee 2010). The influence of the NAO on climate has been assessed by the NAO index defined as the difference in atmospheric pressure at sea level between the Azores and Iceland. A positive NAO index (or positive NAO phase) is associated with warmer conditions and an increase in precipitation in northern Europe and cooler conditions and a decrease in precipitation over the Mediterranean (Eshel and Farrell 2000; Criado-Aldeanueva and Soto-Navarro 2020). During the negative NAO index (or negative NAO phase) warm moist air enters the Mediterranean region and cold air enters northern Europe.

Another important climate pattern is the El Niño–Southern Oscillation (ENSO), which is measured by the Oceanic Niño Index (ONI). The ONI is the rolling three-month average temperature anomaly in the surface waters of the eastern and central tropical Pacific Ocean. Index values of +0.5 or higher indicate El Niño while index values of –0.5 or lower indicate La Niña.

While climate responses to ENSO in the North Pacific and North America are well understood, the physical linkages between ENSO and climate variability over the North Atlantic-European region are still unclear and subject to scientific debate (Seager et al. 2010; Zhang, Mei and Geng 2018; Mezzina et al. 2019).

The combined effects of ENSO and NAO are confirmed to be more profound than the effects they produce individually (Marengo 2004). The results of recent studies show that the ENSO-NAO relationship is dominated in 1980–1982 and 1991–1993. From 2015 to 2017, the NAO showed a high correlation with the fluctuation of the ENSO (Mu et al. 2022).

In this article, the influence of the NAO and ENSO phenomena on climate variables in the Durmitor region, and thus on evolution of the Debeli Namet Glacier, has been examined. Two characteristic periods are focused on: the accumulation period from December to March, when the glacier volume increases, and the ablation period from June to September, when the glacier volume decreases (Gachev 2020).

New climate parameters for temperatures and precipitation for the last 30 years in the Durmitor region were introduced. These form the basis for the analysis in this article.

2 Glaciation in the Durmitor mountains

The massif of Durmitor, Montenegro, located at 43°26' N and 19°10' E was intensely glaciated. Carbonate rocks of different structure and age are involved in its structure (Mirković 1983). The Durmitor forms a classic glacial landscape (Cvijić 1889; 1903; 1914; Milojević 1937; 1951; Messerli 1967; Nicod 1968; Marović and Marković 1972; Djurović 2009). Deep valley troughs, separated by sharp aretes, radiate outwards in all directions from the highest central Durmitor Mountains, which culminate at Bobotov Kuk (2,523 m). Eighteen lakes are located in these valleys bounded by sedimentary or rocky ridges. The highest valley areas are characterized by armchair-shaped hollows and perennial ice is present at the head of Karlica below the peak of Šljeme (Kern et al. 2007) and also in caves such as Ledina Pećina (Veselinović et al. 2001). Two phases of Pleistocene glaciation were observed on the Durmitor mountains, the older being stronger than the younger phase. During the old phase 54% of the total surface of Durmitor was covered by ice, while during the young phase 36% of this surface was under ice (Djurović 2009). After these two phases of

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Figure 1: The Debeli Namet Glacier, Durmitor mountains, Montenegro, is one of the southernmost glaciers in Europe (August, 2010).

glaciation the present cirque glaciation phase came. It is represented by the Debeli Namet Glacier. The existence of the Debeli Namet Glacier indicates that the glaciation process on the Durmitor has not been interrupted after the Little Ice Age. This glacier is located at an elevation of 2,030–2,200 m (Djurović 2012; Gachev 2017), which is much lower than the climatic snow line estimated at 2700 m in the western (Milivojević, Menković and Ćalić 2008) and 3,200 m in the eastern part of the Balkan Peninsula (Gachev 2011). The north/northeast exposure of the terrain, as well as the highest mountain peaks surrounding this area, enabled the accumulation of significantly more snow through avalanches and blizzards than can be supplied by the atmospheric precipitation falling directly over glacier surface. Therefore, conditions still prevail in this part of the Durmitor Mountain that allow the feeding of the existing glacier. The specific position of the Debeli Namet Glacier is a factor for the smaller decrease of this glacier in comparison with other glaciers in Southern Europe during the last 50 years (Djurović 2012), regardless of the increase in temperature evident at the end of the 20th and the first decades of the 21th century (Gachev 2017).

3 Methods

For the assessment of temperatures and precipitation in the region of Debeli Namet Glacier the data from Žabljak meteorological station of the Institute for Hydrometeorology and Seismology of Montenegro (Zavod za hidrometeorologiju i seizmologiju Crne Gore) in the period from 1991 to 2021 were used. Correlations between the NAO and climate variables is evaluated by the NAO index data from the Hurrel Station-Based NAO Index (https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based).

The volume of the Debeli Namet Glacier is calculated on the basis of rope measurements and photographs available on the website of the Institute of Hydrometeorology and Seismology of Montenegro (www.meteo.co.me; Gachev 2020; Table 1), using the Chen and Ohmura empirical equation (1990):

$$V = 28.5S^{1.357},$$

where V is glacier volume in 10^6 m^3 and S is glacier surface area in 10^6 m^2.

Temperatures in the region of glacier (2,035 m) were calculated on the basis of extrapolated temperature data from the meteorological stationat Žabljak (1,450 m) using a lapse rate of 0.6 °C/100 m. The lowest point of the glacier was chosen for the reference point because it has the highest temperature.

Based on instrumental measurements (Weather almanacs, Institute for Hydrometeorology and Seismology of Montenegro) and statistical calculations, average annual temperature and precipitation in Žabljak were

Table 1: Average temperatures for Žabljak meteorological station in glacier accumulation period December–March (upper row) and glacier ablation period June–September (lower row) in two consecutive 30-year periods (provided by the Institute for Hydrometeorology and Seismology of Montenegro 2022).

Average temperature for December–March,1961–1990	Average temperature for December–March,1991–2020
T = –6.5 °C	T = –5.5 °C
Average temperature for June–September,1961–1990	Average temperature for June–September,1991–2020
T = 8.9 °C	T = 10.5 °C

Table 2: Average precipitation for Žabljak meteorological station in glacier accumulation period December–March (upper row) and glacier ablation period June–September (lower row) in two consecutive 30-year periods (provided by the Institute for Hydrometeorology and Seismology of Montenegro 2022).

Average precipitation for December–March, 1961–1990	Average precipitation for December–March, 1991–2020
122.1 mm	135.6 mm
Average precipitation for June–September, 1961–1990	Average precipitation for June–September, 1991–2020
97.4 mm	85.9 mm

4.7 °C and 1493.6 mm respectively during the standard climate period 1961–1990. The new climate parameters in the next 30-year period from 1991 to 2020 are different: average annual temperature and precipitation are 5.9 °C and 1505.2 mm, respectively. There is an increase in both variables, the average annual temperature increasing by $\Delta T = 1.2$ °C while the average annual precipitation increased for 11.6 mm (about 0.8%). It is obvious that the annual temperature change is significant while the annual change in amount of precipitation is negligible. The temperature of the glacier accumulation period increased for +1 °C while temperature of the glacier ablation period increased by +1.6 °C in these two consecutive 30-year periods (Table 1).

Temperatures are lower than those suggested when a lapse rate of 0.6 °C/100 m is assumed because the Debeli Namet Glacier is faced northeast and is favored by shading. Besides temperature, precipitation is another important glacier mass balance variable. Average precipitation in accumulation and ablation season in two 30-year periods is presented in Table 2. Average precipitation increased for 13.5 mm (11%) in accumulation season and decreased for 11.5 mm (12%) in ablation season over two consecutive 30-year periods. For the glaciers in the Dinaric Mountains, the winter precipitation, not the temperature, has the leading role in the glacier existence (Gachev 2020).

4 Results

4. 1 The accumulation period

The NAO index for the accumulation period refers to December–March (DJFM). In Montenegro, the amount of precipitation in this period is correlated with the NAO; when DJFM NAO indices are negative, the amount of precipitation is above the average value, and vice-versa (Burić, Micev and Mitrović 2012). This could be disturbed by ENSO. Data from the meteorological station Žabljak show that years with very low precipitation, 30%–60% lower than average, were: 1991, 1992, 1993, 1998, 2002, 2008, 2014, 2017 and 2019. They are characterized by positive DJFM NAO indices for the accumulation season (Figure 2). Years with the highest precipitation, 20%–90% higher than average, were: 1996, 2001, 2005, 2006, 2009, 2010, 2011, 2013, 2018 and 2021. These years are mostly characterized by negative DJFM NAO indices (Figure 2). The exceptions are years 2005 and 2018 with small but positive DJFM NAO indices suggesting that the NAO does not affect climate variables much. In these years El Niño (in 2005) and La Niña (in 2018) events could influence the climate variables more than NAO (Figure 3). It is also known that switches from negative to positive NAO and vice versa are followed by noticeable changes in the average precipitation (Criado-Aldeanueva and Soto-Navarro 2020). In the last 30 years there is a moderate negative correlation (Spearman's correlation $rs = -0.55$, $p = 0.002$) between precipitation and DJFM NAO index. This means that the rising/declining precipitation trend in the Durmitor Massif is related to the negative/positive DJFM NAO index.

Relationship between temperatures in the accumulation period and DJFM NAO indices shows that the temperatures are mostly lower than average in the positive NAO phase. Namely, the years with the temperatures which are more than 1 °C lower than average for this period, were: 1992, 1993, 2000, 2003, 2005, 2006, 2012. In these years the DJFM NAO indices are mostly positive. The only exception is the year 2006 when the negative DJFM NAO was accompanied by the influence of La Niña. It seems that La Niña has a more significant impact on the temperature than on the precipitation because in 2006 the amount of precipitation was higher than average and in correlation with negative DJFM NAO index. The temperature in 2006 shows the opposite characteristic–it was lower than average in the accumulation period.

The highest temperatures in accumulation period should be expected in the years with the negative NAO, but this is not the case. Years with the highest temperatures in accumulation period, more than 1.5 °C higher than average for this period, were: 1994, 2001, 2007, 2014 and 2016. Only in 2001 a negative DJFM NAO was recorded while other years were with a positive DJFM NAO index. It seems that El Niño events in 1994, 2007 and 2014–2016, strongly influences the temperatures in the accumulation season (Figure 4). Correlation between temperatures and DJFM NAO index is low and statistically insignificant (Spearman's correlation, t-test shows $p = 0.52$). These temperatures are in connection not only with the NAO but also with the El Niño/La Niña events (Table 3).

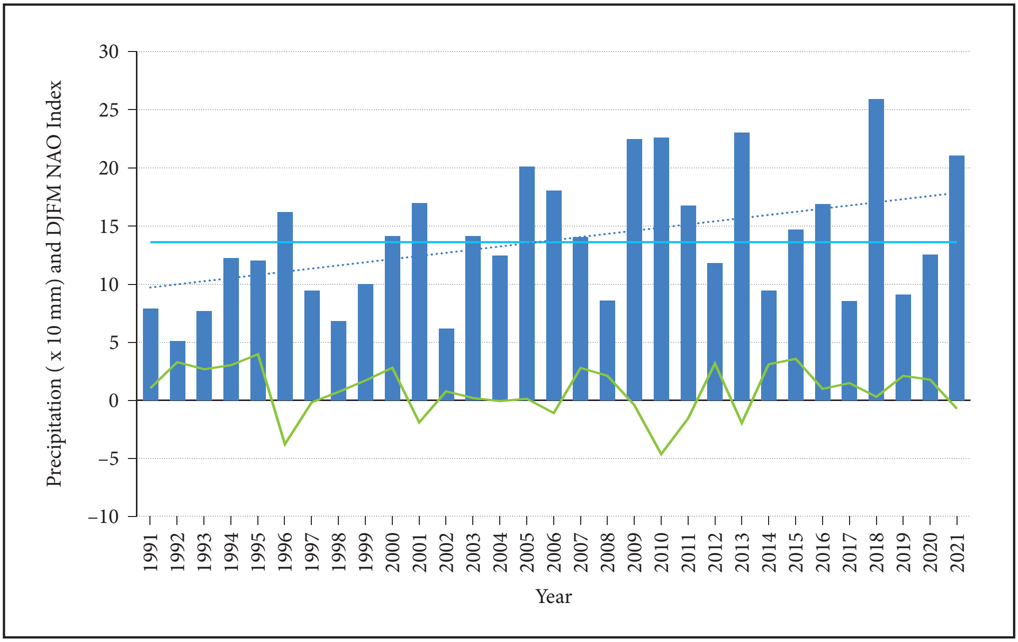

Figure 2: Precipitation for Žabljak meteorological station in accumulation period (blue columns) and DJFM NAO index (green line) for 1991–2021. The dashed blue line shows the trend of increasing precipitation, while the solid blue line represents the average precipitation (provided by the Institute for Hydrometeorology and Seismology of Montenegro 2022 and by the National Center for Atmosferic Research, USA 2022).

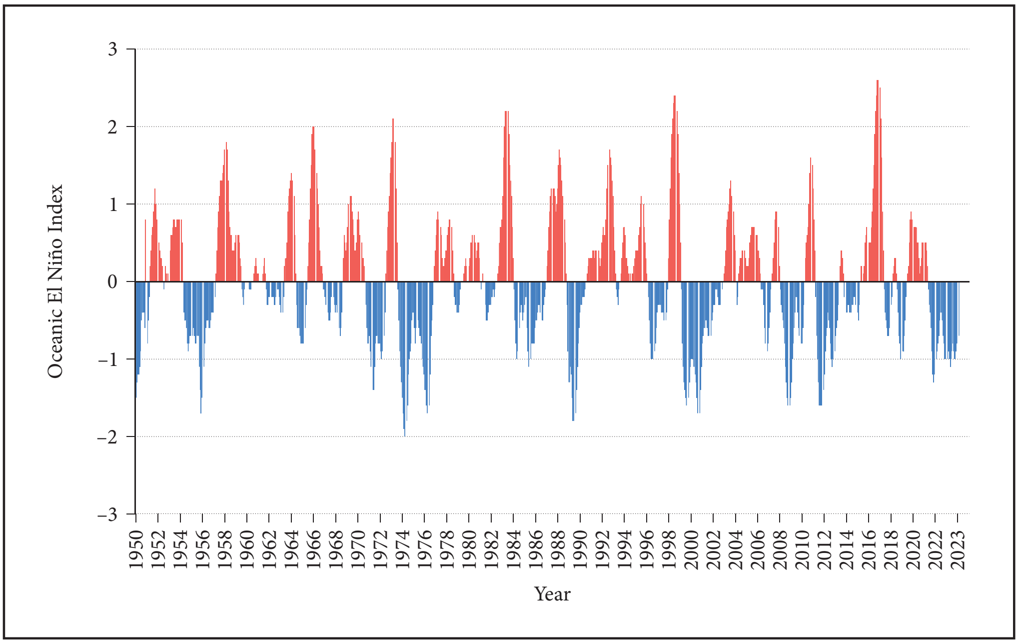

Figure 3: Warm (> +0.5 °C) and cold (< –0.5 °C) episodes for the Oceanic Niño Index_(ONI) in the period 1950–2022. The events are defined by ONI as weak (0.5–0.9), moderate (1.0–1.4) and strong (≥ 1.5) (provided by the National Center for Atmosferic Research, USA 2022 and National Weather Service, National Oceanic and Atmospheric Administration, USA 2022).

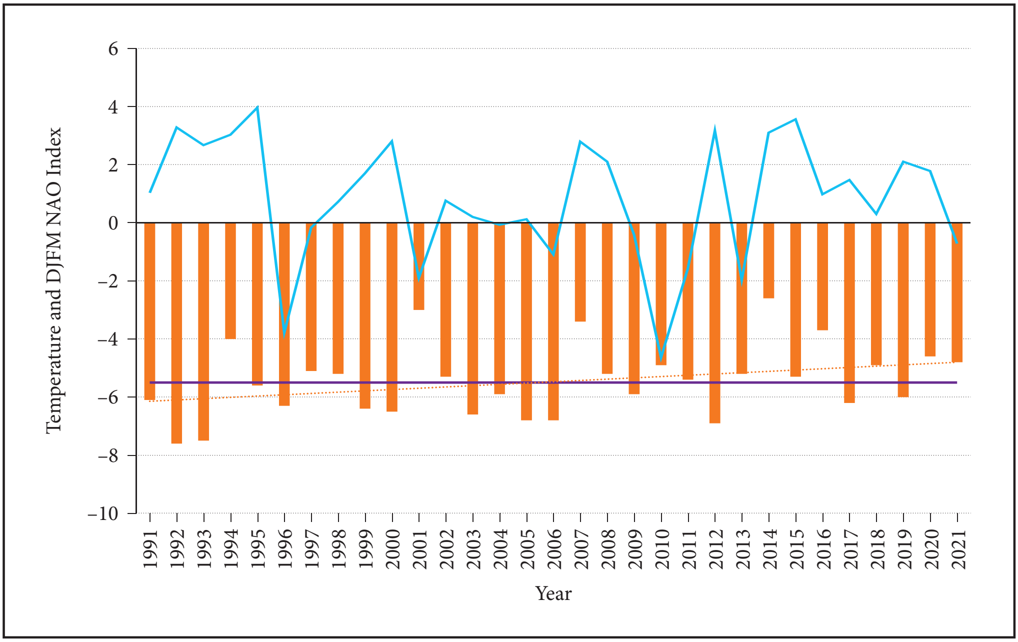

Figure 4: Temperatures for Žabljak meteorological station in accumulation period (orange columns) and DJFM NAO index (light blue line) for 1991–2021. The dashed orange line shows the trend of increasing temperature while the solid violet line represents the average temperature (provided by the Institute for Hydrometeorology and Seismology of Montenegro 2022 and by the National Center for Atmosferic Research, USA 2022).

Table 3: The influence of La Niña/ El Niño and DJFM NAO combinations on the precipitation and temperature in the Durmitor region for 1991–2021 (provided by the National Center for Atmosferic Research, USA 2022 and National Weather Service, National Oceanic and Atmospheric Administration, USA 2022).

		precipitation	temperature
La Niña	NAO +	↑	
	NAO –		↓
El Niño	NAO +		↑
	NAO –		

4. 2 The ablation period

Summer precipitation and summer temperatures are the main causes of the glacier shrinking. The NAO index for the ablation period refers to July–September (JAS). In the Mediterranean region the NAO influence in this period is less pronounced than in accumulation period. Years with precipitation above 110 mm or 30%–50% higher than average for ablation period, were: 1995, 2006, 2007, 2014 and 2020. Years with precipitation less than 70 mm, i.e. 20%–44% lower than average for ablation period, were: 1991, 1993, 1994, 1997, 2010, 2012, 2015, 2017 and 2021. These years are mostly characterized by negative JAS NAO indices (Figure 5). Exceptions are in 1997 with the strong El Niño and in 2017 and 2021 with moderate La Niña. It can be said that a negative JAS NAO is the leading factor that determines extreme precipitation in the ablation period. During the period 1991–2021 precipitation trend is almost constant.

Temperatures in the ablation season rose slightly in the considered 30-years period (Figure 6). For the temperatures above 11 °C, which are more than 0.5 °C higher than average in ablation season, the JAS NAO indices are mostly negative. Years with these temperatures were: 1998, 1999, 2003, 2007, 2010–2012, 2015,

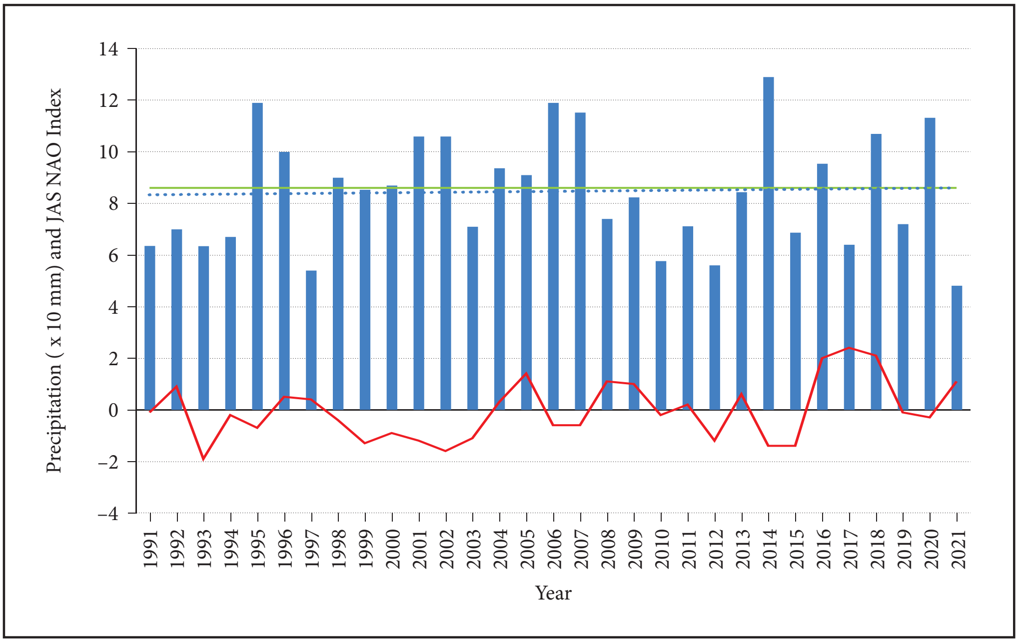

Figure 5: Precipitation for Žabljak meteorological station in ablation period (blue columns) and JAS NAO index (red line) for 1991–2021. The dashed blue line shows that precipitation tends to be almost constant, while the solid green line represents the average precipitation (provided by the Institute for Hydrometeorology and Seismology of Montenegro 2022 and by the National Center for Atmosferic Research, USA 2022).

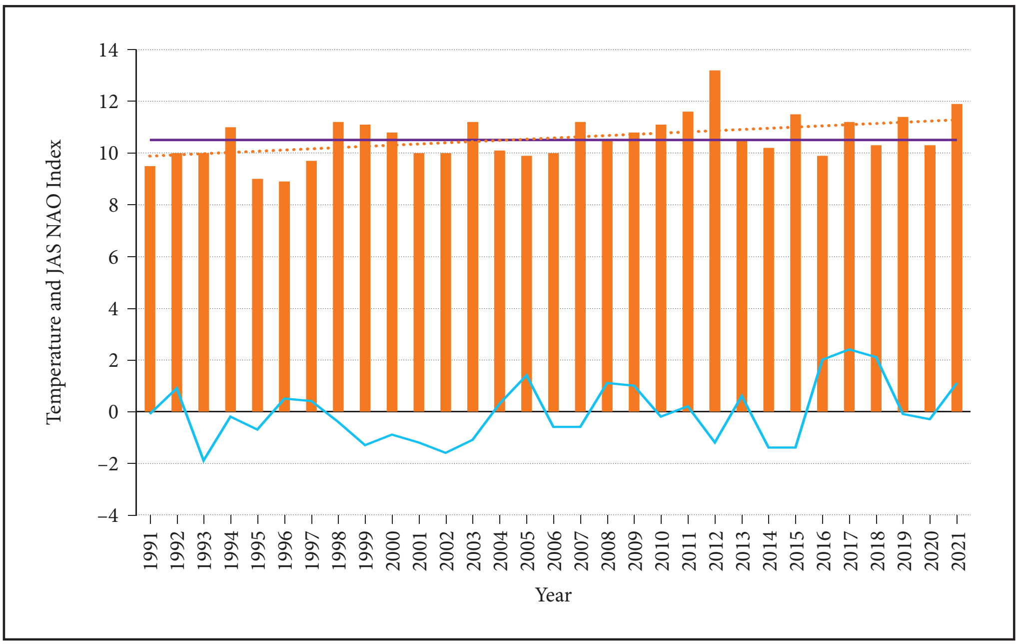

Figure 6: Temperatures for Žabljak meteorological station in ablation period (orange columns) and JAS NAO index (blue line) for 1991–2021. The dashed orange line shows the trend of increasing temperature while the purple line represents average temperature (provided by the Institute for Hydrometeorology and Seismology of Montenegro 2022 and by the National Center for Atmosferic Research, USA 2022).

2017, 2019 and 2021. Exceptions are the positive JAS NAO indices in the years 2011 (strong La Niña), 2017 and 2021 (moderate La Niña). Years with the temperatures lower than 10 °C, i.e. more than 0.5 °C less than average for this season, are mostly with the positive JAS NAO indices. These years were: 1991, 1995–1997, 2005 and 2016. In the 1991 and 1995 JAS NAO was negative and accompanied with El Niño.

Table 4 shows the exceptions when La Niña and a positive JAS NAO reduce precipitation below the average but increase the temperature above the average value as in the years 2011, 2017 and 2021. In the ablation period extreme precipitation and the highest temperatures are mainly characterized by the negative JAS NAO. On the other hand, El Niño has a great influence on the lowest temperatures regardless of the JAS NAO phase. Its influence on the precipitation is ambiguous.

Table 4: The influence of La Niña/ El Niño and JAS NAO combinations on the precipitation and temperature in the Durmitor region for Žabljak meteorological station for 1991–2021 (provided by the Institute for Hydrometeorology and Seismology of Montenegro 2022, the National Center for Atmosferic Research, USA 2022 and by the National Oceanic and Atmospheric Administration, USA 2022).

		precipitation	temperature
La Niña	NAO +	↓	↑
	NAO –		
El Niño	NAO +		↓
	NAO –		↓

4. 3 Influence of NAO on the Debeli Namet Glacier

For the further analysis, climate data were summarized in accordance with the glacier size. The size of the glacier was calculated empirically. The annual NAO index reflects both, the NAO influence in the glacier accumulation period and the NAO influence in the glacier ablation period. Therefore, it is convenient for comparison with the glacier size measured in autumn, mainly in October (Figure 7). A negative annual NAO is mainly related with the increase in glacier size, while a positive annual NAO is mainly related with the decrease in glacier size. The exceptions are years 2012, 2013 and 2018.

In the accumulation period size of the glacier increases when the DJFM NAO decreases and vice versa (Figure 8). This is in agreement with the correlation between NAO and precipitation in accumulation period. The lowest glacier size was in 2017 as a result of very low winter precipitation followed by hot and dry summer. The Spearman's correlation between glacier size and DJFM NAO index in the accumulation period is moderate negative correlation ($rs = -0.62$, $p = 0.019$).

5 Discussion

The NAO index is widely recognized as the one of the most important modes of the atmospheric variability in the northern hemisphere in the present and future (Rousi et al. 2020). There are indications that NAO is correlated not only with the geophysical phenomena but also with the solar cycle (Thiéblemont et al. 2015; Zharkova 2020; Drews et al. 2021).

In this article we present the NAO influence on climate variables in the Durmitor region. The focus is on temperature and precipitation especially in the accumulation period important for existence of the Debeli Namet Glacier. In the last 30 years there were 21 years with the positive NAO indices and only nine with the negative NAO index values. This means that about 2/3 of the considered period was characterized by the precipitation lower than average for the accumulation season. As the Žabljak meteorological station has a leeward position to the atmospheric advections from the southwest, which serve as the main sources of precipitation, it is worth to consider data from meteorological stations situated on the windward side like Nikšić and Šavnik (Figure 9). Not surprisingly, Nikšić and Šavnik receive more precipitation than Žabljak in the accumulation period but the trends are similar in all three cities, caused by the NAO influence (Burić, Micev and Mitrović 2012).

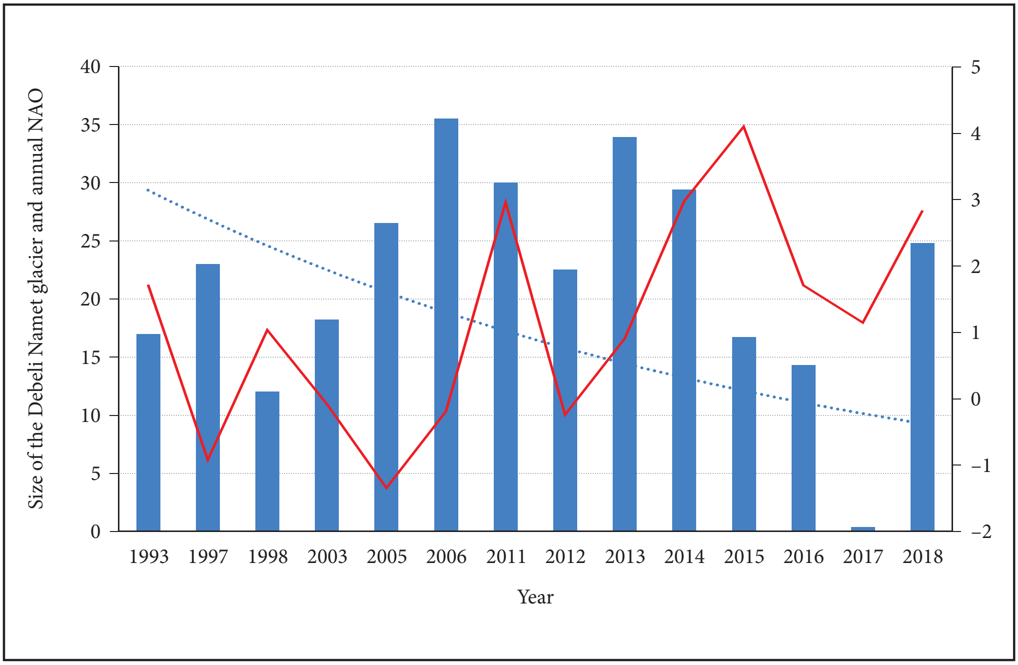

Figure 7: Size (in 106 m3) of the Debeli Namet Glacier (blue columns) and annual NAO index (red line) for the period 1993–2018. The dashed blue line shows that the glacier size tends to decrease (provided by the National Center for Atmosferic Research,USA 2022; Gachev 2020; Table 1).

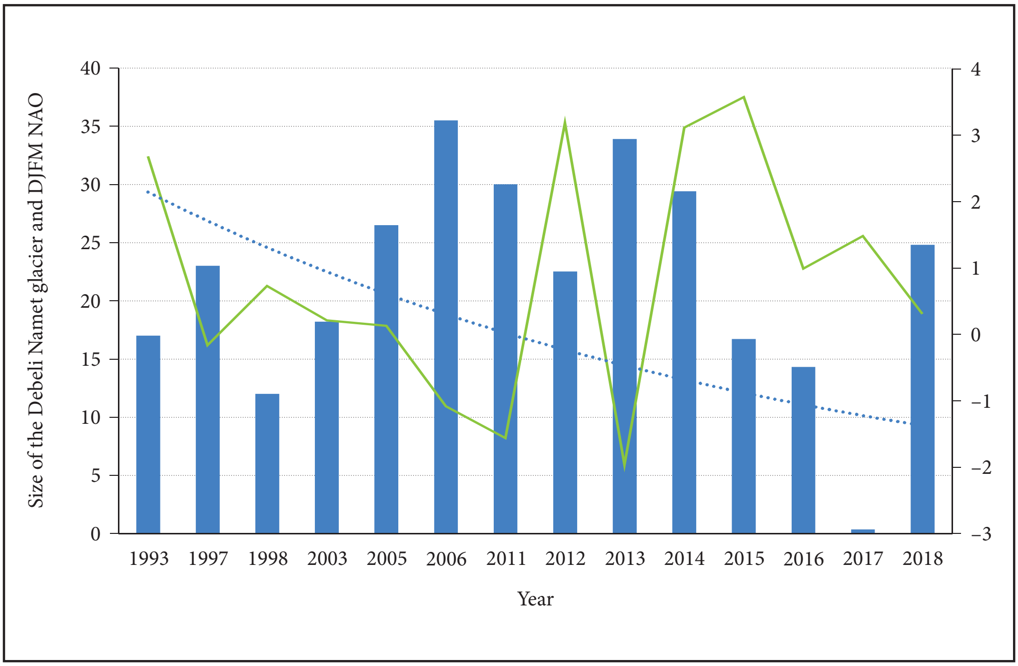

Figure 8: Size (in 106 m3) of the Debeli Namet Glacier (blue columns) and DJFM NAO index (green line) for the period 1993–2018. The dashed blue line shows that the glacier size tends to decrease (provided by the National Center for Atmosferic Research,USA 2022; Gachev 2020; Table 1).

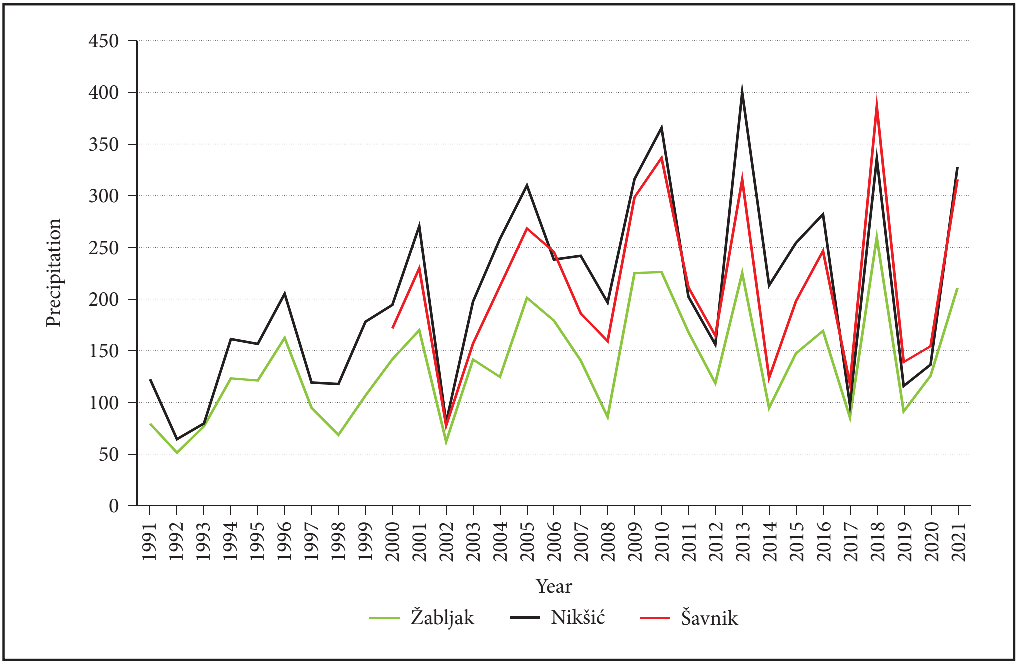

Figure 9: Precipitation in accumulation period for Žabljak, Nikšić and Šavnik meteorological stations for 1991–2021 (note that there is no data for Šavnik before the year 2000; provided by Institute of Hydrometeorology and Seismology of Montenegro).

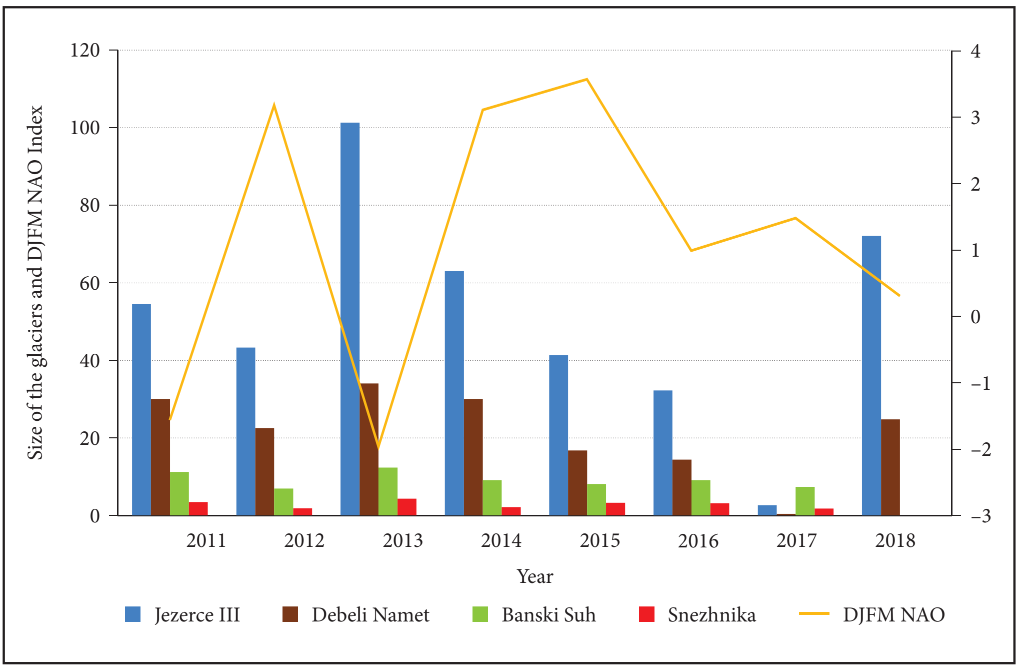

Figure 10: Size (in 106 m3) of the current glaciers in the Balkans: Jezerce III (Prokletije), Debeli Namet (Durmitor), Banski Suhodol and Snezhnika (Pirin) and DJFM NAO index for the period 2011–2018. There is no data for Banski Suhodol and Snezhnika for 2018 (Gachev 2020).

The nearest glaciers to the Debeli Namet Glacier are located in the Prokletije Mountains, Albania (Palmentola et al. 1995; Hughes 2009; Grunewalad and Scheithauer 2010; Gachev 2017). They are located below north-east-facing cliffs near the highest peak of this range, Maja Jezerce (2694 m). The largest (Jezerce III; Gachev 2020) was chosen for comparison with other current glaciers in the Balkans–Debeli Namet and glaciers in the Pirin Mountain, Bulgaria–Banski Suhodol and Snezhnika. Sizes of the glaciers are given in Figure 10.

Glaciers in the Pirin Mountain with a more continental climate are less sensitive on climate change than glaciers in the Dinaric Mountains. This is in accordance with previous studies (Gachev 2020). The heatwaves in the summers in 2012 and 2017 together with the low winter precipitation caused record minimum of those glaciers (Figure 2 and Figure 6). Periods of glacier advance are characterized by a negative DJFM NAO index, while periods of glacier retreat are characterized by a positive DJFM NAO index. This situation can be changed under the influence of La Niña like in 2018, especially when the NAO index has small value.

Small glaciers respond quickly to extreme weather conditions. If warm summers follow winters with few snowfalls over several years, they shrink until they reach a new equilibrium mass balance or melt completely. Also, phases with above-average winter precipitation and cooler summers are often sufficient to stabilize small glaciers or even produce re-advance. For example, at Debeli Namet Glacier, a new moraine developed between 1994 and 2003, and between 2004 and 2006, due to small glacier advances (Grunewald and Scheithauer 2010). In the Julian Alps recent increases in winter snowfall provide resilience to very small glaciers (Colucci et al. 2021). Gachev (2022) studied response of very small glaciers in the Pirin Mountains to climate variations and found that their short-term size fluctuations are mostly related to the temperature conditions during the ablation season. Twenty-first century glaciers and climate in the Prokletije Mountains have been studied by Hughes (2009).

6 Conclusion

We analyzed the climate variables in the region of Durmitor Massif over the last 30 years and their influence on the Debeli Namet Glacier. In the first part of the article we analyzed temperature and precipitation tendencies in the periods of accumulation and ablation. Average temperature in accumulation (ablation) period in the last 30 years is 1 °C (1.6 °C) higher than average temperature in accumulation (ablation) period in 1961–1990. The lowest temperatures in the accumulation period are mainly in the years with a positive DJFM NAO while the highest temperatures in this period are driven by the combined NAO and ENSO phenomena. In the last 30 years precipitation in accumulation (ablation) period increased 11% (decreased 12%) compared to the period 1961–1990.

The main mechanism that drives precipitation in accumulation period is the NAO measured by the DJFM NAO index. In the Durmitor region the lowest precipitation is in the years with the positive DJFM NAO index while the highest precipitation is mainly in the years with the negative DJFM NAO index. We suggest that this situation may change under the influence of ENSO events, especially in the years when the NAO index is low.

In ablation period the NAO influence, measured by the JAS NAO index, is less pronounced than in accumulation period. Almost every two years since 2010 has been a year with low precipitation and above average temperatures. This fact shows that the climate variables in the ablation period have moved towards higher temperatures and lower precipitation in the last 30 years. We found that the negative JAS NAO is the leading factor that determines extreme precipitation in the ablation period. Surprisingly, there is a good correspondence between the positive JAS NAO and the lowest temperatures and between the negative JAS NAO and the highest temperatures in the ablation period.

In the second part of the article, we compared the annual and DJFM NAO with the size of the Debeli Namet Glacier. The size of the glacier increases when DJFM NAO decreases and vice versa. The situation is the same with precipitation. This result suggests that there is no significant relationship between glacier size and ablation temperatures. We found that precipitation in accumulation period has the leading role in glacier size fluctuations. Glaciers located in the Prokletije Mountains, Albania and in the Pirin Mountain, Bulgaria show similar trend in the size variations. The fact is that glaciers in the Pirin Mountain with a more continental climate are less sensitive on climate change than glaciers in the Dinaric Mountains.

ACKNOWLEDGMENT: The research and writing of this work was funded by the Montenegrin National Project »Physics of Ionized Gases and Ionized Radiation«.

7 References

Burić, M., Micev, B., Mitrović, L. 2012: Atlas klime Crne Gore. Podgorica.

Cattiaux, J., Vautard, R., Cassou, C., Yiou, P., Masson-Delmotte, V., Codron, F. 2010: Winter 2010 in Europe: A cold extreme in a warming climate. Geophysical Research Letters 37-20. DOI: https://doi.org/10.1029/2010GL044613

Chen, J., Ohmura, A. 1990: Estimation of Alpine glacier water resources and their change since the 1870s. Hydrology in Mountainous Regions. International association of hydrological sciences 193.

Cohen, J. L., Furtado, J. C., Barlow, M. A., Alexeev, V. A., Cherry, J. E. 2012: Arctic warming, increasing snow cover and widespread boreal winter cooling. Environmental Research Letters 7-1. DOI: https://doi.org/10.1088/1748-9326/7/1/014007

Colucci, R. R., Žebre, M., Torma, C. Z., Glasser, N. F., Maset, E., Del Gobbo, C., Pillon, S. 2021: Recent increases in winter snowfall provide resilience to very small glaciers in the Julian Alps, Europe. Atmosphere 12-2. DOI: https://doi.org/10.3390/atmos12020263

Criado-Aldeanueva, F., Soto-Navarro, J. 2020: Climatic Indices over the Mediterranean Sea: A Review. Applied Sciences 10-17. DOI: https://doi.org/10.3390/app10175790

Cvijić, J. 1889: Glacijalne i morfološke studije o planinama Bosne, Hercegovine i Crne Gore. Beograd.

Cvijić, J. 1903: Novi rezultati o glacijalnoj eposi Balkanskog poluostrva. Beograd.

Cvijić, J. 1914. Eiszeitliche Vergletscherung der Gebirgsgruppen von Prokletije bis Durmitor. Maßstab 1:200,000. Des K.u.k. Militärgeographischen Institutes. Wien.

Cvijić, J. 1917: L'époque glaciaire dans la péninsule des Balkanique. Annales de Géographie 26-144.

Cvijić, J. 1920: Istorija geografije. Beograd.

Djurović, P. 2009: Reconstruction of the pleistocene glaciers of mount Durmitor in Montenegro. Acta geographica Slovenica 49-2. DOI: https://doi.org/10.3986/AGS49202

Djurović, P. 2012: The Debeli Namet glacier from the second half of the 20th century to the present. Acta geographica Slovenica 52-2. DOI: https://doi.org/10.3986/AGS52201

Drews, A., Huo, W., Matthes, K., Kodera, K., Kruschke, T. 2021: The Sun's role for decadal climate predictability in the North Atlantic. Atmospheric Chemistry and Physics 22-12. DOI: https://doi.org/10.5194/acp-22-7893-2022

Eshel, G., Farrell, B. F. 2000: Mechanisms of Eastern Mediterranean rainfall variability. Journal of the Atmospheric Sciences 57-19. DOI: https://doi.org/10.1175/1520-0469(2000)057<3219:MOEMRV>2.0.CO;2

Gachev, E. 2011: Inter-annual size variations of Snezhnika glacieret (the Pirin mountains, Bulgaria) in the last ten years. Studia Geomorphologica Carpatho-Balcanica 45-7.

Gachev, E. 2017: The unknown southernmost glaciers of Europe. Glacier Evolution in a Changing World. London. DOI: https://doi.org/10.5772/intechopen.68899

Gachev, E. 2020: Small glaciers in the Dinaric mountains after eight years of observation: On the verge of extinction? Acta geographica Slovenica 60-2. DOI: https://doi.org/10.3986/AGS.8092

Gachev, E. 2022: Response of Very Small Glaciers to Climate Variations and Change: Examples from the Pirin Mountains, Bulgaria. Atmosphere 13-6. DOI: https://doi.org/10.3390/atmos13060859

Grunewald, K., Scheithauer, J. 2010: Europe's southernmost glaciers: response and adaptation to climate change. Journal of Glaciology 56-195. DOI: https://doi.org/10.3189/002214310791190947

Hagedorn, J. 1969: Beiträge zur Quartarmorphologie griechischer Hochgebirge. Habilitation Thesis, Geographisches Institut der Universität. Göttingen.

Hughes, P. D. 2007: Recent behaviour of the Debeli Namet glacier, Durmitor, Montenegro. Earth Surface Processes and Landforms 32-10. DOI: https://doi.org/10.1002/esp.1537

Hughes, P. D. 2008: Response of a Montenegro glacier to extreme summer heatwaves in 2003 and 2007. Series A, Physical Geography 90-4. DOI: https://doi.org/10.1111/j.1468-0459.2008.00344.x

Hughes, P. D. 2009: Twenty-first century glaciers and climate in the Prokletije Mountains, Albania. Artic, Antarctic, and Alpine Research 41-4. DOI: https://doi.org/10.1657/1938-4246-41.4.455

Hughes, P. D., Woodward, J. C., van Calsteren, P. C., Thomas, L. E., Adamson, K. R. 2010:

Pleistocene ice caps on the coastal mountains of the Adriatic Sea. Quaternary Science Reviews 29-27/28. DOI: https://doi.org/10.1016/j.quascirev.2010.06.032

Hughes, P. D., Woodward, J. 2009: Glacial and periglacial environments. The Physical Geography of the Mediterranean. Oxford. DOI: https://doi.org/10.1093/oso/9780199268030.003.0024

Hughes, P. D., Woodward, J. C. 2016: Quaternary glaciation in the Mediterranean mountains: A new synthesis. Geological Society London Special Publications 433-1. DOI: http://doi.org/10.1144/SP433.14
Hughes, P. D. 2018: Little Ice Age glaciers and climate in the Mediterranean mountains: a new analysis. Geographical Research Letters 44-1. DOI: http://doi.org/10.18172/cig.3362
Hurrell, J. W. 1995: Decadal trends in the North Atlantic oscillation regional temperatures and precipitation. Science 269-5224. DOI: https://doi.org/10.1126/science.269.5224.676
Hurrell, J. W. 1996: Influence of variations in extratropical wintertime teleconnections on Northern Hemisphere temperature. Geophysical Research Letters 23-6. DOI: https://doi.org/10.1029/96GL00459
Hurrell, J. W., Deser, C. 2009: North Atlantic climate variability: The role of the North Atlantic Oscillation. Journal of Marine Systems 78-1. DOI: https://doi.org/10.1016/j.jmarsys.2008.11.026
Kern, Z., Surányi, G., Molnár, M., Nagy, B., Balogh, D. 2007: Investigation of natural perennial ice deposits of Durmitor mts, Montenegro. Proceedings of the 2nd International Workshop on Ice Caves. Demänovská Dolina.
Li, J. P., Sun, C., Jin, F. F. 2013: NAO implicated as a predictor of Northern Hemisphere mean temperature multidecadal variability. Geophysical Research Letters 40-20. DOI: https://doi.org/10.1002/2013GL057877
Li, J. P., Ruan, C. Q. 2018: The North Atlantic–Eurasian teleconnection in summer and its effects on Eurasian climates. Environmental Research Letters 13-2. DOI: https://doi.org/10.1088/1748-9326/aa9d33
Liedtke, H. 1962: Eisrand und Karstpoljen am Westrand Lukavica-Hochfläche. Erdkunde 16-4.
Louis, H. 1926: Glazialmorphologishche Beobachtungen im albanischen Epirus. Zeitschrift der Gesellschaft für Erdkunde 9-10.
Marengo, J. A. 2004: Interdecadal variability and trends of rainfall across the amazon basin. Theoretical and Applied Climatology 78,1–3. DOI: https://doi.org/10.1007/s00704-004-0045-8
Marović, M., Marković, M. 1972: Glacijalna morfologija šire oblasti Durmitora. Geološki anali Balkanskog poluostrva 37-2.
Messerli, B. 1967: Die eiszeitliche und die gegenwartige Vertgletscherung im Mittelemeeraum. Geographica Helvetica 22-3.
Mezzina, B., Garcia-Serano, J., Blade, I., Kucharski, F. 2019: Dynamics of the ENSO teleconnection and NAO variability in the North Atlantic–European late winter. Journal of Climate 33-3. DOI: https://doi.org/10.1175/JCLI-D-19-0192.1
Milivojević, M., Menković, L, Ćalić, J. 2008: Pleistocene glacial relief in the central part of Mt. Prokletije (Albanian Alps). Quaternary International 190-1. DOI: https://doi.org/10.1016/j.quaint.2008.04.006
Milojević, B. Ž. 1937: Visoke planine u našoj Kraljevini. Beograd.
Milojević, B. Ž. 1951: Durmitor-regionalno-geografska istraživanja. Zbornik radova 9-2. Beograd.
Mirković, M. 1983: Geološki sastav i tektonski sklop Durmitora, Pivske planine i Volujka. Geološki glasnik 5.
Mu, B., Li, J., Yuan, S., Luo, X. 2022: The NAO variability prediction and forecasting with multiple time scales driven by ENSO using machine learning approaches. Computational Intelligence and Neuroscience 2022. DOI: https://doi.org/10.1155/2022/6141966
Nadbath, M. 1999: Triglavski ledenik in spremembe podnebja. Ujma 13.
Nicod, J. 1968: Premières recherches de morphologie karstique dans le massif du Durmitor (Crna Gora: Montenegro). Meditérraneé 9-4.
Onaca, A., Ardelean, F., Aredelean, A., Magori, B., Sirbu, F., Voiculescu, M., Gachev, E. 2020: Assessment of permafrost conditions in the highest mountains of the Balkan Peninsula. Catena 185-1. DOI: https://doi.org/10.1016/j.catena.2019.104288
Onaca, A., Gachev, E., Ardelean, F., Ardelean, A., Perşoiu, A., Hegyi, A. 2022: Small is strong: Post-LIA resilience of Europe's Southernmost glaciers assessed by geophysical methods. Catena 213-3. DOI: https://doi.org/10.1016/j.catena.2022.106143
Palmentola G, Baboci K, Gruda GJ, Zito G. 1995: A note on rock glaciers in the Albanian Alps. Permafrost and Periglacial Processes 6-3. DOI: https://doi.org/10.1002/ppp.3430060306
Penck, A. 1900: Die Eiszeit auf der Balkanhalbinsel. Globus 78.
Rousi, E., Rust, H. W., Ulbrich, U., Anagnostopoulou, C. 2020: Implications of Winter NAO Flavors on Present and Future European Climate. Climate 8-1. DOI: https://doi.org/10.3390/cli8010013
Seager, R., Kushnir, Y., Nakamura, J., Ting, M., Naik, N. 2010: Northern Hemisphere winter snow anomalies: ENSO, NAO and the winter of 2009/10. Geophysical Research Letters 37-14. DOI: https://doi.org/10.1029/2010GL043830

Thiéblemont, R., Matthes, K., Omrani, N., Kodera, K., Hansen, F. 2015: Solar forcing synchronizes decadal North Atlantic climate variability. Nature Communications 6-1. DOI: https://doi.org/10.1038/ncomms9268
Veselinović, D., Kovačević, D., Rajšić, S., Vukmirović, Z., Djordjević, D., Stanković, S., Stanković, A. 2001. The metal amounts in ice stalagmite of »ice cave« snow and water at Durmitor mountains (Yugoslavia). Journal of Environmental Protection and Ecology 2-1.
Wang, C. Z., Liu, H., Lee, S. K. 2010: The record-breaking cold temperatures during the winter of 2009/2010 in the Northern Hemisphere. Atmospheric Science Letters 11-3. DOI: https://doi.org/10.1002/asl.278
Woodward, J. (ed.) 2009: The physical geography of the Mediterranean. Oxford. DOI: https://doi.org/10.1093/oso/9780199268030.001.0001
Zhang, W., Mei, H., Geng, X. 2018: A Nonstationary ENSO–NAO Relationship Due to AMO Modulation. Journal of Climate 32-1. DOI: https://doi.org/10.1175/JCLI-D-18-0365.1
Zharkova, V. 2020: Modern Grand Solar Minimum will lead to terrestrial cooling. Temperature 7-3. DOI: https://doi.org/10.1080/23328940.2020.1796243

Acta geographica Slovenica, 63-1, 2023, 23–34

RADICALLY LOCAL SUPPLY CHAINS THROUGH TERRITORIAL BRANDS: INSIGHTS FROM THE 100% LOCAL

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Signpost for the Bohinj cheese tour.

DOI: https://doi.org/10.3986/AGS.10581
UDC: 658.626:338.439(234.3)

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Radically local supply chains through territorial brands: Insights from the 100% Local project

ABSTRACT: The modernization of food supply chains has marginalized remote agricultural regions such as the Alps. As a result, local actors often adopt new ways of producing, promoting, and selling their products by differentiating them in the eyes of consumers. The labelling of quality local agri-food products through the development and promotion of territorial brands play an essential role in this respect. In the article we address the research question: What are the conditions for the creation, development and sustainability of territorial brands in the agri-food sector? What are the characteristics of some territorial brands, which are an essential development factor and the subject of local identities and local policies? We discuss cooperation between local, regional, and national actors. The aim of this article is to highlight the preparation and role of the 100% Local Model for the successful creation and development of territorial brands in the field of agro-food production in the Alps.

KEY WORDS: labelling, territorial brands, 100% Local, food, agriculture, Alps

Radikalno lokalne dobavne verige s teritorialnimi blagovnimi znamkami: Spoznanja iz projekta 100 % Local

POVZETEK: Modernizacija preskrbovalnih verig s hrano je potisnila oddaljena kmetijska območja kot so Alpe na obrobje. Zato lokalni akterji mnogokrat prevzamejo nove načine proizvodnje, promocije in prodaje svojih izdelkov, tako da jih v očeh potrošnikov ločijo od drugih. Pri tem ima bistveno vlogo označevanje kakovostnih lokalnih kmetijsko-živilskih proizvodov povezano z razvojem in s spodbujanjem teritorialnih blagovnih znamk.

V članku obravnavamo raziskovalni vprašanji: Kakšni so pogoji za oblikovanje, razvoj in trajnost teritorialnih blagovnih znamk v kmetijsko-živilskem sektorju? Kakšne so značilnosti nekaterih teritorialnih blagovnih znamk, ki so bistveni dejavnik razvoja ter predmet lokalnih identitet in lokalnih politik? Razpravljamo tudi o sodelovanju med lokalnimi, regionalnimi in nacionalnimi akterji. Namen tega članka je osvetliti pripravo in vlogo modela 100 % Local Model za uspešno oblikovanje in razvoj teritorialnih blagovnih znamk na področju kmetijsko-živilske proizvodnje v Alpah.

KLJUČNE BESEDE: označevanje, teritorialne znamke, 100 % Local, hrana, kmetijstvo, Alpe

The article was submitted for publication on 17th January, 2022.
Uredništvo je prejelo prispevek 17. januarja 2022.

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1 Introduction

The production and provision of food, its preparation, and consumption, are fundamental cultural practices because humans have created a range of cultural practices between hunger and its satisfaction (Mennell, Murcott and Otterloo 1994; Wiegelmann 2006; Finnis 2012). Before the Second World War, as in other non-urban areas of Europe, people in the Alpine region were still dependent on their own food production and subsistence, which was the purpose of most of their economic activities (Godina Golija 2008; Atkins, Amilien and Oddy 2009; Ledinek Lozej 2016). With increasing global food production and trade in food products in recent decades, subsistence food production has been abandoned and trade in cheap food products, which can come from very remote locations, has expanded, leading to a disconnect between the places of production and those of consumption. Contemporary agri-food supply chains have undergone a strong process of de-territorialisation due to the modernisation of agriculture and food production (Popkin and Gordon-Larsen 2004; https://www.alpine-space.eu/project/alpfoodway/). Food production has remained important in harder to reach, remote areas, for individuals with low purchasing power and for some elderly people who maintain the economic activities of their youth (Kos et al. 2000).

These are joined by individuals who, for ecological, worldview, political and other reasons, support local food production and greater self-sufficiency and sustainable development, which researchers have found to be a growing phenomenon in the European Union (Pratt 2007; Köstlin 2010; Grimaldi, Fassino and Porporato 2019). This group of consumers is paying attention to local supply chains and healthier food. They are willing to pay more for products embodying different values and logic, including the local production of ingredients, the involvement of small and medium-sized farms, the use of environmentally friendly production practices (Tschofen 2010; Bartsch and Lysaght 2017; Báti 2017; May et al. 2017; Godina Golijan and Ledinek Lozej 2018).

Although the Alps are a remote area, poorly connected by communication routes and new technologies, the last four decades have seen transformative changes and intensification of agriculture. These trends have resulted in the downsizing or disappearance of some agro-food supply chains and productive know-how, in standardisation and homogenisation of plant varieties and animal breeds, the mechanization of agriculture, the increased use of fertilizers and pesticides, and the industrialization of food production. These negative consequences of agriculture and food production are also linked to climate change. Agriculture in the Alps contributes to climate change, and at the same time, climate change affects the agricultural sector in a negative manner (Kienast, Ströbele and Schüpbach 2021). Just to mention the abandonment of small-scale livestock farming and the introduction of intensive cattle farming in some Alpine areas.

There are few in-depth studies on food production transformation and modern food supply in the Alps (Nussbaumer and Exenberger 2009; Rinallo and Luminati 2021). They are mostly concerned about the production, marketing, and heritage of some of the most characteristic agricultural products of the Alps, especially cheese (Grasseni 2011; Ledinek Lozej 2013; 2016; Grasseni 2017; Ledinek Lozej 2021). Less attention is paid to the current problems of agriculture, the need to restructure it and radically change supply chains in the Alps, and to modernised ways of producing food in the face of new social and climatic changes. The Alpine Convention's recent Climate Action Plan 2.0 (2021) also highlights these problems in the Alpine region. It encourages farmers to engage in climate action through »promotion of local Alpine products and increase of locally retained added value from marketing and distribution of climate-friendly products at a local and regional level« and »the set up of a scheme for low-CO_2 or CO_2-neutral agriculture in the Alps, based on a significant increase of the share of Alpine agriculture adopting climate-friendly and organic farming methods, which shall also significantly reduce the use of chemicals in farming« (Permanent Secretariat … 2021).

Territorial brands (TBs) are a collective marketing tool through which producers from a given area under the coordination of an umbrella organization can promote themselves, differentiate their products with respect to those from other areas, and retain local added value (Bardone and Kannike 2022; Ledinek Lozej and Razpotnik Visković 2022; see also AlpFoodway project and Territorial Brands in the Alpine Region workshop). They differ from the brands of individual producers because of their collective nature. Similar to TBs are destination brands, which focus on tourism promotion and geographical indications, which also can be thought of as collective brands linked to a territory, but which unlike territorial brands focus on one product category only (Rinallo and Pitardi 2019; Logar 2021a; 2021b; 2021c). TBs, destination brands and geographical indications act as a quality signal to consumers, by guaranteeing that recognized products are made within the boundaries of an area by respecting agreed-upon specifications.

Unlike geographical indications or short supply chains, which are much more investigated and recognized as territorial development tools (Rinallo and Pitardi 2019; Lešnik Štuhec 2021; Logar 2021a; 2021b; 2021c), TBs are understudied, little understood, and often confused with other types of brands (e.g., city brands, destination brands, individual brands promoting their place of origin) or with the collective image of an area (Charters and Spielmann 2014; Spielmann and Williams 2016). Limited work has instead looked at territorial brands 'from the inside'. One exception is Logar (2021a; 2021b; 2021c; 2022), whose analysis of Slovenian territorial brands concluded that they can effectively fulfil their functions only when adopting a long-term perspective. In Slovenia, many territorial brands were established through Common Agricultural Policy (CAP) funds or the European Regional Development Fund (ERDF); most however did not survive much longer the end of the projects through which they were funded, due to a lack of long-term strategy and management capabilities (Ledinek Lozej 2020; Lešnik Štuhec 2021; Logar 2021a; 2021b; 2021c). Clearly, more research is needed on how local support for territorial brands can help them grow and reach a maturity stage where initial investments are rewarded in terms of local economic and image impacts.

The goal of the article is to contribute to the sparse literature on territorial brand sustainability based on insights from the 100% Local financed by Alpine Regione Preparatory Action Fund (ARPAF) II, which developed a model of territorial branding based on radically local supply chains in the Alpine region. A radically local supply chains are defined as the supply and sale of products that are consistently made only from local raw materials and local ingredients. These products are based on only local resources throughout the entire production, distribution and sales process (Figure 1). The premise of the project was that territorial brands can indeed benefit from the signs of discontent and resistance to the intensive agro-business system, which often supplies less tasty food and of lower quality than the food obtained using extensive farming and more traditional production methods (Grasseni 2011; Godina Golija 2012; Kisbán 2016; West 2016; Rinallo 2019; Ledinek Lozej and Šrimpf Vendramin 2020; Logar 2021a; see also AlpFoodway project). As the name suggests, the project has developed a model for local territorial brands, focusing on products and services based on the area's cultural heritage, made with local ingredients and raw materials and entirely processed locally. This model has been tested in different pilot areas. The research question addressed


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Figure 1: Selling local products on a farm in Bohinj.

in the text is how the 100% Local Model was developed, how it was successfully or unsuccessful adopted, and whether the 100% Local Model is applicable in different Alpine regions.

2 Methodology and research area

This article is based on the results of the research and expert work within the 100% Local project (https://www.alpine-region.eu/projects/100-local) in five Alpine areas as a case study: Bohinj and Triglav National Park, Slovenia; Obervinschgau/Alta Val Venosta, Italy; Parco Prealpi Giulie, Italy; Pitztal, Austria and Valsot, Unterengadin, Switzerland (Figure 2). Qualitative research methods were used to prepare this article: analyses of documents and sources, semi-structured interviews, ethnographic fieldwork with cultural analysis (Löfgren 1981; May 2022) and thematic analysis (Braun and Clarke 2006).

Field material was collected during the 100% Local project through fieldwork and by conducting interviews in the study areas in 2020. Some of the field material on typical local products in the Alps used and presented in this article was collected before the start of the project, as some of the 100% Local collaborators were already active in the selected areas for other projects, e.g., the AlpFoodway project (https://www.alpine-space.org/projects/alpfoodway/en/home). We also collected data on the pilot areas through secondary online sources (e.g., territorial brands' product specifications; tourism statistics).

Besides the described qualitative methods, we also analysed the material from the workshops with stakeholders and the responses to an online questionnaire. The workshops with local stakeholders were held on June 2020 in these areas: Obervinschgau/Alta Val Venosta (3. 6. 2020), Valsot (4. 6. 2020), Pitztal (5. 6. 2020), Parco Prealpi Giulie (8. 6. 2020), Bohinj and Triglav National Park (TNP; 9. 6. 2020 and 16. 6. 2020). The workshops involved exchanging experiences, lessons learned and results of good and less successful practices and addressing the problems encountered in the production, sale, promotion, branding and distribution of local agricultural products and food. Before workshops in May 2020, an online questionnaire was addressed to stakeholders from the five Alpine areas. The stakeholders shared their perceptions

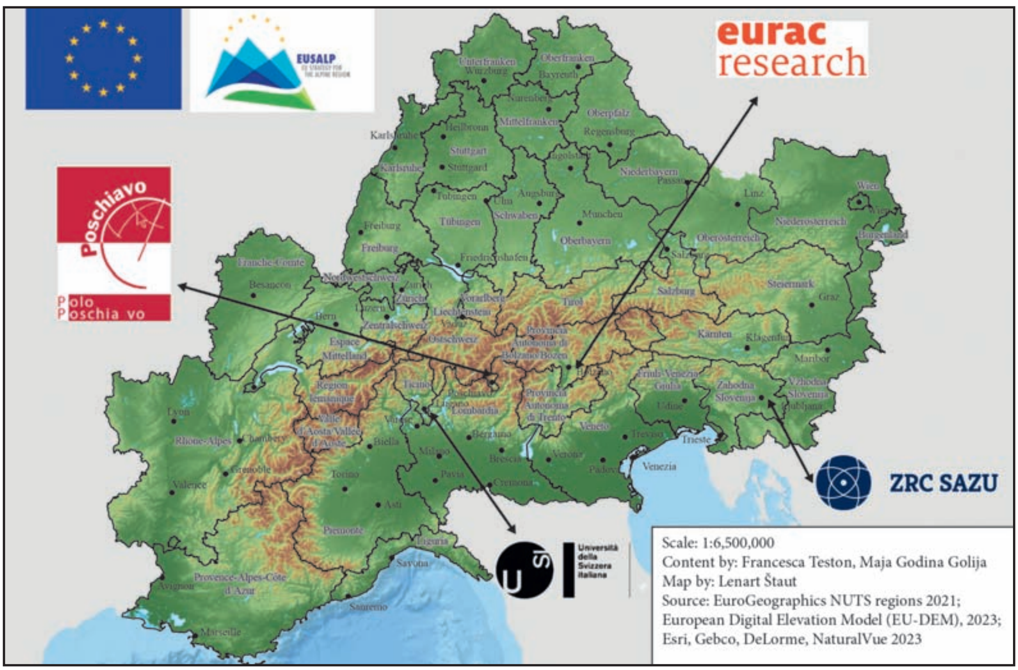

Figure 2: The project areas and partners.

on the most relevant megatrends for Alpine agri-food value chains (accelerating technological change, climate change and environmental degradation; continuing urbanization; growing consumerism; increasing demographic imbalances).

The earlier research results were tested in all five study areas and refined with suggestions discussed with local stakeholders. In doing so, the article's authors and other project researchers were aware of the importance of bottom-up methodology in participatory research (Nared and Bole 2020). In this article, we illustrate how the 100% Local Model, which was developed in the framework of the project work in 2020 and 2021 (Rinallo et al. 2021) was applied in the areas of Bohinj and the Triglav National Park, Slovenia, with a critical discussion of common problems, implementation difficulties, and future prospects.

3 Results

3.1 Construction and characteristics of the 100% Local Model

The 100% Local Model is a result of the European project Boosting the Alpine agri-food value chains with the »100% Local« (100% Local project in short), the project took place in 2019–2021. The project had the goal to develop a sustainable territorial development model based on territorial branding practices focused on agri-food products entirely produced and processed locally.

The project understood the term model as a simplified version of reality capable of reducing the complexity of strategic decision-making. Thanks to the 100% Local Model, local communities can design and manage teritrial brands and Territorial Brand Managing Organizations (TBMOs) that resonate with the characteristics of the local community, and to ensure its sustainability thanks to future-proofing techniques.

The 100% Local Model is based on a future envisioning participative methodology in three stages (see Figure 3). We refer to the 100% Local final report (Rinallo et al. 2021) for a more in-depth examination of elements to be included in the analysis and guiding questions. In the next paragraph, we illustrate how the 100% Local Model was applied in one of the project's pilot areas (Bohinj and the Triglav National Park), focusing specifically on Step 1 (Analysis of the current situation) and Step 2 (Participative future-envisioning and collective decision-making) of the methodology, as most initiatives are yet to be implemented. More specifically, background analyses were carried out in April–May 2020 with data provided by local stakeholders. Participative future envisioning workshops with local stakeholders took place online on June 9th and June 16th, 2020. Further online workshops were held on January 26th and April 2nd, 2021, thanks to which a tentative action plan was developed. During April–May 2021, project partner »Università della Svizzera italiana« accompanied local stakeholders in the model implementation through dedicated coaching sessions.

3.2 Applying the 100% Local Model in the case study area Bohinj and the Triglav National Park

The following chapter is based on material related to adapting the 100% Local Model in the municipality of Bohinj.

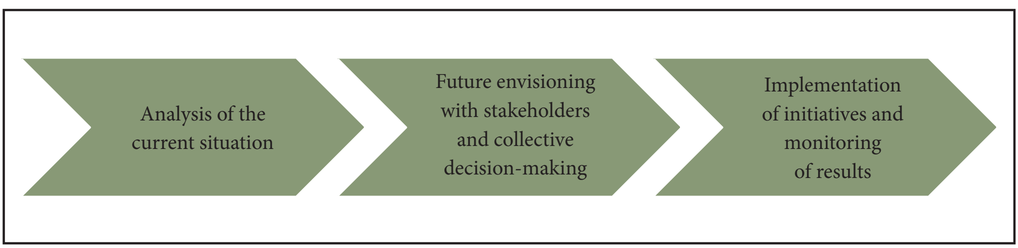

Figure 3: Steps in the application of the 100% Local Model (Rinallo et al. 2021).

3.2.1 Step 1: Analysis of the current situation

In testing the 100% Local Model, we asked local stakeholders to collect data on the economic, social and cultural characteristics of their regions from secondary sources and by interviewing community members. We tested the current situation in the regions using publicly available quantitative data and local actors' perceptions. Our research focused in particular on areas of relevance to the local economy: a description of the current local cooperation network, the existence of territorial brands and other quality certifications in the area, and an analysis of the basic rules (with a particular focus on membership criteria and rules for product inclusion); the state of the local economic system (agriculture, food production and crafts, tourism, etc.), other relevant systems (culture, education, civil society, etc.), as well as the available policy support at the local, regional, national and possibly EU level. We present the key findings from these activities for the municipality of Bohinj, partly for TNP.

The municipality of Bohinj is located in the Upper Carniola Region in northwestern Slovenia. According to the Statistical office of the Republic of Slovenia it covers an area of 333.7 km^2, 66% of which is in the TNP. The municipality has a population of 5,770 (approximately 2,910 males and 2,860 females, spread over an altitude of between 400 and 2,800 metres above sea level).

Bohinj is a well-known tourist destination and in 2019, there were 266,000 arrivals, and 710,000 overnight stays in Bohinj, mainly from Slovenia, Germany, the Czech Republic, the Benelux countries and the United Kingdom according to data of the Bohinj Tourist Board. In 2020, Bohinj had 157,135 guests, in 2021, 216,135 guests and a record number of 299,161 guests in 2022. That year, Bohinj recorded the highest number of overnight stays, 821,942. Tourist workers in Bohinj believe that the high number of visitors in 2022 was due to the Covid 19 epidemic and the introduction of tourist vouchers for the Slovenian population. The analysis of the structure of overnight stays also showed this consequence. The highest number of Slovenian overnight stays in Bohinj during the epidemic in 2020 and 2021, 62.8% and 49.7% respectively, significantly higher than before the epidemic, when the share of domestic overnight stays in Bohinj was only 23.2%. In 2022, 67% of guests visited Bohinj in the summer. In all municipalities covered by the park, tourism (especially foreign tourism) has increased from 2015 to 2021.

Agriculture in the area is concentrated in the lower plains. Crop production is therefore limited by the location of the land, its quality and the climatic characteristics of the area. Instead, livestock breeding and milk production are well-developed. Some radical pastoral and cheese-making practices were abandoned in the past due to the rise of industrial milk processing but have recently been revived (Ledinek Lozej 2016). The better-known products from the Bohinj are Mohant cheese (protected by a protected denomination of origin; Godina Golija 2017), dried meats, and local corn varieties. Some traditional crafts typical of the area have also been revitalised and promoted. Many territorial projects linked to the tri-territorial development were also aimed at passing on traditional skills to new generations. These projects have raised awareness of the local food heritage, linking producers to tourism operators, the market, and consumers, for example, through farm tourism, but much more needs to be done in this area (Razpotnik Visković and Komac 2021).

Bohinj is home to a well-developed territorial brand, Bohinjsko (From Bohinj), owned by the Municipality of Bohinj which registered in 2015 as a collective brand. Bohinjsko certifies agri-food products, crafts and design products, experiences, restaurants (more than 50% of the 30 in the municipality) and accommondation businesses. To be certified, products need to be produced in the municipality, use local ingredients and raw materials, and respect traditional values. The brand, currently counting 70 suppliers for a total of 400 products and services, is managed by the local destination management organization Turizem Bohinj, whose Quality Centre certifies new applicants and vigilates on the respect of quality standards. The territorial brand's activities include the collective promotion of certified products through traditional and digital media, the fostering of collaborations across the supply chain, the improvement of packaging and labels based on a heritage storytelling approach, and the stimulation of innovation (e.g., chocolate with Mohant cheese) and marginal (e.g., modern shapes for traditional products; smaller sizes for the souvenir market). Bohinjsko has been an inspiration for other Slovenian municipalities, who have attempted to create territorial brands based on its model, often without the same level of success (Logar 2021a; 2021b; 2021c). Also the TNP has developed a Park Quality Mark granted to producers of arts and crafts products or service providers in its territory and/or in the Julian Alps Biosphere Reserve. So far, only 11 tourism farms and other accommodation services have obtained the certification. Respect to other pilot areas in the 100% Local Model, Tourism Bohinj and the TNP already had a quite established territorial brand and cooperation network. By taking part in the 100% Local project activities, they hoped to involve a greater number of local actors, stimulating the adoption of local ingredients in food production and the restaurant business, increasing the number of market-oriented farms, and gaining broader support for some development ideas already circulating in the area.

3.2.2 Step 2: Participative future-envisioning and collective decision-making

We first carried out a participating macro-trend analysis to anticipate plausible, probable, and possible futures using the methodology developed by the European Commission's Competence Centre on Foresight. The Megatrend Engagement Tools we adopted are available at https://knowledge4policy.ec.europa.eu/foresight/megatrends-engagement-tools_en. Macrotrends bring with them risks and opportunities as they shape populations, the environment, science and technology, work, and consumption habits. Main insights from this stage were as follows: 1) available farmland is being abandoned or converted to housing uses. Thus limits the benefits in terms of jobs and business opportunities deriving from linking farming to food production and tourism services. Farms and farming land thus need to be safeguarded to ensure the sustainability of 100% Local strategies; 2) conflicts of interest overal land use, particularly in the case of new inhabitants, are to be expected; 3) farms are of limited size and their owner are aging, which makes generational turnover problematic; 4) technological change and hyper-connectivity can play a role in generating higher volumes of agricultural produce and foodstuffs, which are needed because of consumers' and tourists' greater interest in local food.

Another methodology we applied is the »Three Horizons« (3H) framework (Sharpe et al. 2016), which connects the present with desired futures and contributes to identifying conflicts and incompatibilitis between the present and envisioned futures. The 3H framework helps stakeholders to map different and often coexisting ways of thinking about the future, the so-called managerial, visionary, and entrepreneurial mindsets.

The first horizon of the 3H framework is linked to a managerial mindset, focused on the present and on running the current organization or system. In this step of the future envisioning process, local stakeholders were asked to identify current concerns, or the elements in the way things are managed that have been inherited from the past, are effective today, but could sooner or later enter in a crises and become increasingly dysfunctional. Building on the macrotrend analysis, stakeholders from the Bohinj and TNP identified various concerns. First, the Park could end up being a victim of its success, as increased tourist flows could be difficult to control; moreover, farmland could decline resulting in insufficient production of local produce and foodstuffs to satisfy tourism demand. Second, most farmers are aging and show limited interest in organic agriculture or collaboration with tourist activities; additionally, some are discouraged by the complex administrative requirements for organic production, farm tourism, or being part of territorial brands. Third, short supply chains (farmers to hotels, restaurants, or consumers) are under-developed from both the information and logistics points of view, thus limiting collaboration. Fourth, respect to cheaper imports from other areas, local ingredients and products are expensive and their origin is difficult to prove.

The third horizon of the 3H framework focuses on aspirations for the future. Local stakeholders are thus asked to develop a shared vision for the area (say, 20 years or more in the future) and identify the elements of innovation required to make the vision come true. Aspirations for Bohinj and the TNP in 2040 were the following:

1) More successful territorial brands, engaging more actors, resulting in a greater number of market-oriented farms and increased production volume, and decreases in prices of locally produced products thanks to economies of scale;
2) better marketing and distribution of local products, as well as greater restaurant adoption of local products and recipes;
3) heritage-based innovation in foodstuffs, recipes, and tourist attraction, including high-quality gastronomic experiences and themed festivals;
4) more cooperation among local stakeholders and municipalities in TNP. Crucial to the realization of this vision would be the establishment of an umbrella organization capable of coordinating individual territorial brands to exploit synergies towards a common cross-sectoral development strategies, financed by the municipalities and the Park, and the creation of a logistics and internal/external communication system.

The second horizon of the 3H framework, associated to an entrepreneurial mindset, encourages to reflect on how it will be possible to introduce innovations by deploying appropriate financial and organizational resources and facing the possible obstacles to the achievement of the vision. Participants of online workshops (on January 26 and April 2nd, 2021) were asked what they could concretely do to drive the system towards its aspired future, reflecting on what should be dismissed, maintained, or innovated in the 3-5 following years. In this stage, participants developed a tentative action plan at the scale of the entire Julian Alps. Crucial to their vision was the constitution in 2024 of a cross-sectoral, professionally managed umbrella organization responsible for business development, promotion, and the provision of a shared infrastructure for distribution, quality control, logistics, certification, and marketing.

4 Discusion

We argue that the results of the development and adaptation of the 100% Local Model are relevant for the wider Alpine region. The region combines natural wealth, agriculture, care for natural and cultural heritage and the rapid development of tourism, particularly rural tourism, in conjuction with local cuisine and the use of typical local products, such as different types of cheese (Ledinek Lozej 2013; 2016; 2021). In this area, some local communities have already developed territorial brands and implemented territorial development models based on the commercial valorisation of agri-food products produced and processed locally (Rinallo and Luminati 2021; Ledinek Lozej 2021; Logar 2022).

During the 100% Local Model development process the model was tested in all four project pilot areas. During this testing, it has been shown that using the model requires a certain amount of pre-preparation or preliminary activities. Nevertheless, the use of the model is also more successful in areas where some territorial branding or forms of local production and distribution of agri-food products have already been developed (e.g., the Territorial Brands in the Alpine Region workshop). In territories where activities to encourage local production and distribution of food are just beginning, e. g. Pitztal in Austria, the use of the 100% Local Model proved less appropriate. Less appropriation is linked to the fact that a deep analysis of the current situation is always required at the outset to apply a 100% Local Model. In local communities where activities to promote local food production and distribution are only at the beginning, there is a need for timely information, and relevant knowledge may be fragmented. In contrast, the successful adaptation of the 100% Local Model has been demonstrated in the Bohinj and TNP area. In this area, local stakeholders very well analysed their current situation, resources, and challenges. They also accelerate an inclusive process of mobilising other actors and increase the success rate of planned initiatives (Logar 2021c). Their activities considered essential factors such as: focus on locally produced and processed products, inclusive stakeholder engagement and participation, consideration of place-specificity, food heritage and futures-proofing.

The advantage of the 100% Local Model is its transferability, scalability and flexibility. The model is scalable and can be applied to different Alpine areas, regardless of their size and economic development, be they remote Alpine areas or more significant regions in the Alpine macro-region. Model 100% Local is also flexible. Flexible means that it can assist various territorial development initiatives in different stages of their life cycle. Notably, the model can also be well applied to various forms of cross-border cooperation between Alpine areas (Ledinek Lozej 2021). Due to the adoption of futures-proofing methodologies, the 100% Local Model very well considers macro-trends and minimises the effects of shocks and stresses of future events on the locally designed production and distribution of food. The model can positively impact the development of local initiatives in Alpine areas and better cooperation between agri-food businesses, tourism, civil society, cultural and educational institutions and policy actors.

5 Conclusion

The article discusses selected findings of the 100% Local project, its model and the conditions for creating territorial brands in agri-food production. In addressing this topic, we have used the results of fieldwork in the pilot areas, secondary and online sources, data collected through, and territorial brand workshops and workshops with local stakeholders in the study areas. We have considered EU and national policy objectives, targets and recommendations. According to recent research European consumers are increasingly interested in quality food, local products and territorial brands. The development of local food production and territorial brands is often linked to tourism, in particular rural, gastronomic and wine tourism, which has both positive and negative impacts on communities and space. The application of the 100% Local Model has shown the excellent applicability of this model in Alpine areas wishing to boost local food production and distribution. Territorial brands and the development of 100% Local food production are a crucial development factor and the subject of local identities and local policies, and, more recently, cooperation between local, regional and national actors.

ACKNOWLEDGMENTS: The author acknowledges the financial support of the European Alpine Region Preparatory Action Fund II (ARPAF II) for the project Boosting the Alpine agri-food value chains with the »100% Local« (100% Local), and of the research programm Cultural Spaces and Practices: Ethnology and Folklore Studies (P6-0088) funded by the Slovenian Research Agency. Special thanks go to Diego Rinallo, who contributed the material (Three Horizons framework, the results of workshops), and suggested some corrections to the article. Thank you also to the researchers Rocco Scolozzi, Francesca Teston, Cassiano Luminati, Daniele Isepponi, Špela Ledinek Lozej, Erik Logar, Umberto Bondi and Andrea Antonacci. Special thanks also to the communities involved as case study, for their time, interest and enthusiasm: municipality Bohinj and TNP (Slovenia), Obervinschgau/Alta Val Venosta and Parco Prealpi Giulie (Italy), Pitztal (Austria) and Valsot, Unterengadin (Switzerland).

6 References

Atkins, P., Amilien, V., Oddy, D. J. (eds.) 2009: The Rise of Obesity in Europe: A Twentieth Century Food History. Burlington.

Bardone, E., Kannike, A., 2022: The use of European Union instruments for branding and labelling regional foodproducts in Estonia. Acta geographica Slovenica 62-2. DOI: https://doi.org/10.3986/AGS.10504

Bartsch, S., Lysaght, P. (eds.) 2017: Places of Food Production. Origin, Identity, Imagination. Frankfurt am Main.

Báti, A., 2017. Organic Farm, Organic Food Steps Towards a Sustainable Agriculture (with Hungarian and Slovenian Examples). Acta Ethnographica Hungarica 62-2. DOI: https://doi.org/10.1556/022.2017.62.2.1

Braun, V., Clarke, V. 2006: Using thematic analysis in psychology. Qualitative Research in Psychology 3-2. DOI: https://doi.org/10.1191/1478088706qp063oa

Charters, S., Spielmann. N. 2014: Characteristics of strong territorial brands: The case of Champagne. Journal of Business Research 67-7. DOI: https://doi.org/10.1016/j.jbusres.2013.07.020Finnis, E. (eds.) 2012: Reimagining Marginalized Foods: Global Processes, Local Places. Tucson.

Finnis, E. (eds.) 2012: Reimagining Marginalized Foods: Global Processes, Local Places. Tuscon.

Godina Golija, M. 2008: Oblikovanje sodobnega potrošnika: O spremembah v preskrbi in pridelavi živil na Slovenskem. Etnolog 18-1.

Godina Golija, M. 2012: Contemporary appropriations of culinary tradition in Slovenia. Traditiones 41-2. DOI: https://doi.org/10.3986/Traditio2012410207

Godina Golija, M. 2017: Slovenian cheeses Mohant, Tolminc and Nanos, and their importance for local food production and regional identity. Places of Food Production: Origin, Identity, Imagination. Frankfurt am Main.

Godina Golija, M., Ledinek Lozej, Š. 2018: Pomen in cilji projektov ohranjanja dediščine prehrane. Register nesnovne kulturne dediščine, Etnofolk in AlpFoodway. Etnolog 28.

Grasseni, C. 2011. Re-inventing food: Alpine cheese in the age of global heritage. Anthropolgy of food 8. DOI: https://doi.org/10.4000/aof.6819

Grasseni, C. 2017: The heritage Arena: Reinventing cheese in the Italian Alps. New York, Oxford. DOI: https://doi.org/10.2307/j.ctvss40qp.6

Grimaldi, P., Fassino G., Porporato, D. 2019: Culture, Heritage, Identity and Food: A Methodological Approach. Milano. Internet: https://www.unisg.it/assets/Culture-Heritage-Identity-and-Food-A-Methodological-Approach.pdf (22. 3. 2023)

Kienast, F., Ströbele, M., Schüpbach, U. 2021: The Forum Landscape, Alps, Parks (FoLAP). Mountain Research and Development 41. DOI: https://doi.org/10.1659/MRD-JOURNAL-D-20-00074.1
Kisbán, E., 2016: Choose local, try organic, think ecological. Actions and ideas in the recent Hungarian food realm. Places of Food Production: Origin, Identity, Imagination. Frankfurt am Main.
Kos, D., Tivadar, B., Ule, M., Rener, T., Hočevar, M. 2000: Razvoj orodij in model za spremljanje rabe kmetijskih in živilskih proizvodov. Ljubljana.
Köstlin, K. 2010: A New Ascension of Regional Food. Food and Meals at Cultural Crossroads. Oslo.
Ledinek Lozej, Š. 2013: Paša in predelava mleka v planinah Triglavskega narodnega parka: Kulturna dediščina in aktualna vprašanja. Traditiones 42-2. DOI: https://doi.org/10.3986/Traditio2013420203
Ledinek Lozej, Š. 2016: Dairying in the mountain pastures in the Julian Alps: Heritages, utopias and realities. Studia ethnologica Croatica 28-1 DOI: https://doi.org/10.17234/SEC.28.5
Ledinek Lozej, Š. 2020: Tolminc cheese scuffles behind closed doors. Palaver 9-2.
Ledinek Lozej, Š., Šrimpf Vendramin, K. 2020: Food heritage-making between the Alps and the Adriatic. Traditiones 49-3. DOI: https://doi.org/10.3986/Traditio2020490301
Ledinek Lozej, Š. 2021: Labelling, certification and branding of cheeses in the southeastern Alps (Italy, Slovenia): Montasio, Bovec, Tolminc and Mohant cheese. Acta geographica Slovenica 61-1. DOI: https://doi.org/10.3986/AGS.8746
Ledinek Lozej, Š., Razpotnik Visković, N. 2022: Branding, labelling and certification: Geographical and anthropological insights. Acta geographica Slovenica 62- 2. DOI: https://doi.org/10.3986/AGS.11265
Lešnik Štuhec, T. (ed.) 2021: Podeželje in razvoj gastronomije v Sloveniji. Maribor. DOI: https://doi.org/10.18690/978-961-286-431-6
Logar, E. 2021a: The role of place brands in the development of rural areas in Slovenia. 34th International Geographical Congress. Istanbul University. Istanbul.
Logar, E. 2021b: Spatial patterns of territorial brands in Slovenian rural areas. 8th EUGEO Congress on the Geography of Europe. Faculty of Science of Charles University. Prague.
Logar, E. 2021c: Territorial brands in rural areas of Slovenia: An approach to stimulate territorial prosperity or stagnation? Doctoral Colloquium, Conference of the International Place Branding Association. Barcelona.
Logar, E. 2022: Place branding as an approach to the development of rural areas: A case study of the brand »Babica in Dedek« from the Škofja Loka Hills, Slovenia. Acta geographica Slovenica 62-2. DOI: https://doi.org/10.3986/AGS.10883
Löfgren, O. 1981: On the anatomy of culture. Ethnologia Europaea 12-1. DOI: https://doi.org/10.16995/ee.1860
May, S. 2022: Labelling local wood: On the valorization of regionality and sustainability in timbertrade. Acta geographica Slovenica 62-2. DOI: https://doi.org/10.3986/AGS.10507
May, S., Sidali, K. L., Spiller, A., Tschofen, B. (eds.) 2017: Taste, power, tradition. Geographical indications as cultural property. Göttingen Studies in Cultural property 10. DOI: https://doi.org/10.17875/gup2017-1004
Mennell, S., Murcott, M., van Otterloo, A. H. 1994: The Sociology of Food: Eating, Diet and Culture. London.
Nussbaumer, J., Exenberger, A. 2009: Century of Hunger, Century of Plenty: How Abundance Arrived in Alpine Valleys. The Rise of Obesity in Europe. Burlington.
Nared, J., Bole, D. 2020: Participatory research on heritage-and culture-based development: A perspective from South-East Europe. Participatory Research and Planning in Practice. Cham. DOI: https://doi.org/10.1007/978-3-030-28014-7_7
Permanent Secretariat of the Alpine Convention 2021: Climate action plan 2.0. Innsbruck.
Popkin, B. M., Gordon-Larsen, P. 2004: The nutrition transition: Worldwide obestiy dynamics and their determinants. International Journal of Obesity 28. DOI: https://doi.org/10.1038/sj.ijo.0802804
Pratt, J. 2007: Food values: The local and the authentic. Critique of Anthropology 27-3. DOI: https://doi.org/10.1177/0308275X07080357
Razpotnik Visković, N., Komac, B. 2021: Gastronomy tourism: A brief introduction. Acta geographica Slovenica 61-1. DOI: https://doi.org/10.3986/AGS.10258
Rinallo, D. 2019: Guidance Paper on the Successful Commercialization of the Alpine Food Heritage. Internet: https://www.alpine-space.eu/wp-content/uploads/2021/10/6-2-alpfoodway_Guidance-Paper-on-the-Successful-Valorisation-of-the-Alpine-Food-Heritage-output.pdf (12. 1. 2022).
Rinallo, D., Pitardi, V. 2019: Open conflict as differentiation strategy in geographical indications: The Bitto Rebels case. British Food Journal 121-12. DOI: https://doi.org/10.1108/BFJ-11-2018-0738

Rinallo, D., Luminati, C. 2021: The 100% Valposchiavo territorial brand: Case study and lessons learned. Mountain Farming Systems: Seeds for the Future. Sustainable Agricultural Practices for Resilient Mountain Livelihoods. Rome.
Rinallo, D., Scolozzi, R., Teston, F., Luminati, C., Isepponi, D., Ledinek Lozej, Š., Logar, E., Godina Golija, M., Bondi, U., Antonacci, A. 2021: 100% Local: A territorial development model based on the valorisation of agri-food products fully produced and processed locally. Internet: https://www.alpine-region.eu/sites/default/files/uploads/event/2411/attachments/100_local_report_final.pdf (2. 10. 2022).
Sharpe, B., Hodgson, A., Leicester, G., Lyon, A., Fazey, I. 2016: Three horizons: a pathways practice for transformation. Ecology and Society 21-2. DOI: https://doi.org/10.5751/ES-08388-210247
Spielmann, N., Williams, C. 2016: It goes with the territory: Communal leverage as a marketing resource. Journal of Business Research 69-12. DOI: https://doi.org/10.1016/j.jbusres.2016.03.071
Tschofen, B. 2010: Things, Senses, Practices: Experiencing Cultural Crossroads through Hospitality and the Culinary System. Food and Meals at Cultural Crossroads. Oslo.
West, H. G. 2016: Artisanal Foods and the Cultural Economy: Perspectives on Craft, Heritage, Authenticity and Reconnection. The Handbook of Food and Anthropology. London. DOI: https://doi.org/10.5040/9781474298407.0029
Wiegelmann, G. 2006: Alltags und Festspeisen in Mitteleuropa: Innovationen, Strukturen und Regionen vom späten Mittelalter bis zum 20. Jahrhundert. Münster.

Acta geographica Slovenica, 63-1, 2023, 35–54

NATIONAL GENIUSES' HERITAGE AS POTENTIAL FOR THE DEVELOPMENT OF CULTURAL TOURISM IN ROMANIA

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DOI: https://doi.org/10.3986/AGS.11032
UDC: 338.48-6:929(498)
719:338.48(498)

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National geniuses' heritage as potential for the development of cultural tourism in Romania

ABSTRACT: This article investigates how domestic tourists perceive the possibilities of boosting cultural heritage tourism in Romania, through the capitalization of national genius personalities. The methodology is based on the survey method. The research identified 22 geniuses, largely represented in national culture, and acknowledged and demanded by the market. The vast majority have been converted into tourist attractions, however those of international visibility are missing or are underrepresented in Romanian heritage tourism. An increased focus on geniuses would be highly valued by tourists and could reinforce the value of cultural heritage, consequently, boosting tourism resources. This would lead to multiple and sustainable benefits for destinations' development, but certain infrastructure and management gaps would need to be filled.

KEY WORDS: perception, cultural heritage, genius personalities, tourism, museums, Romania

Dediščina izjemnih osebnosti kot potencial za razvoj kulturnega turizma v Romuniji

POVZETEK: Avtorji v članku proučujejo mnenja domačih turistov o možnostih spodbujanja razvoja kulturnega turizma v Romuniji na podlagi izjemnih osebnosti iz romunske kulturne zgodovine. Uporabljena metodologija temelji na anketi, v kateri so vprašani izpostavili 22 romunskih kulturnih osebnosti, prepoznanih na trgu. Večina je bila preobražena v turistične zanimivosti, pri čemer pa v romunskem dediščinskem turizmu manjkajo mednarodno prepoznavne osebnosti ali so te slabo zastopane. Večji poudarek na tovrstnih osebnostih bi turisti zelo dobro sprejeli, hkrati bi se s tem povečala vrednost kulturne dediščine, kar bi posledično spodbudilo razvoj novih turističnih virov. Navedeno bi imelo različne trajnostne koristi za razvoj destinacij, treba pa bi bilo zapolniti nekatere vrzeli v infrastrukturi in upravljanju.

KLJUČNE BESEDE: mnenja, kulturna dediščina, izjemne osebnosti, turizem, muzeji, Romunija

The article was submitted for publication on October 5th, 2022.
Uredništvo je prejelo prispevek 5. oktobra 2022.

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1 Introduction

Cultural heritage tourism is the economic interface through which the preserved and protected material and immaterial assets of designated human communities are commodified in order to create experiences for visitors. The cultural heritage that sustains cultural tourism – or more specifically cultural heritage tourism (Hall 1991; Yale 1991; Kirshenblat-Gimblett 1995; Seal 1996) – was derived from different actions, namely, the initiatives of certain institutions or communities. Thus, it is recognized, restored and preserved, and the generation of today is able to adequately manage it as a defined benefit in the present and may potentially pass it on to future generations (Pelegrini 2008; Bitušíková 2021). Cultural heritage has encountered continuous development, as interest in the preservation of human values has increased (Bucurescu 2015). Therefore, many outstanding monuments of the past have been added to the list of protected monuments, each with a unique contribution to human history (Li, Wu and Cai 2008).

Cultural heritage has economic benefits, especially through the development of cultural heritage tourism. According to UNWTO (World Tourism Organisation), cultural heritage accounted for almost 40% of the global tourism market in 2018. The capitalization of cultural heritage in both material and immaterial forms has been criticized as »commoditization« wherein cultural heritage loses its intrinsic meaning, when considered primarily in terms of its monetary exchange value (Greenwood 1977). However, other scholars, such as Cohen (1988) and Kirshenblatt-Gimblett (1995) show that commoditization or capitalization can give new meaning and value to heritage. Even if statistically the employment rate in cultural heritage is low, its multiplier effects through tourism are more valuable (Vita 2018). For example, in 2018, in Italy, known as the country with the highest number of UNESCO sites (Canale et al. 2019), an impressive 57% of the revenue produced by cultural heritage came from tourism, comprising 73% of culture staff. Only 2.1% of the total country employment represented jobs directly related to cultural heritage. In the same year in Romania, direct jobs in cultural heritage constituted only 0.3% of the total employment (Lykogianni et al. 2019).

The heritage of geniuses has, in general, not been a distinct element of cultural attraction in relation to tourism, perhaps because attributing this characteristic to a person is debatable. However, clarifications related to the topic of *genius* are acknowledged by the disciplines of medicine (Robertson 2018), psychology (Simonton 2018) and philosophy (Ostaric 2012). These have focused on the explanation of specific aspects related to the conceptualization, manifestation and processes of being classified as a genius. Thus, the concept is associated with exceptional intellectual abilities (Möller-Recondo and D'Amato 2020), the eminence of individuals identified as geniuses (Simonton 1996), augmented by talent (Nerubasska and Maksymchuk 2020) and the way in which creative, original contributions warrant worldwide recognition (Wolff 2001). Beyond these aspects, many publications refer to geniuses as Nobel prize winners (Fahy 2018), with the addition of the title of academician (Nicolaie 2015); other papers are simple eulogies in memory of famous people during their celebrations (Buttimer 1995). However, all definitions highlight the fact that they provided progress of humankind, while geniuses all over the world have, over the centuries, enriched the legacy of the peoples from which they have ascended (Hu and Rousseau 2017).

Usually, the cultural heritage of famous people refers to historical personalities (kings, queens, leaders of states, leading artists, etc.) who have impacted humankind through broader or narrower leadership, and have imposed material or immaterial cultural values, used or continued by their dynasties or their nations. Some of these cultural landmarks have been transformed into tourist attractions (e.g., Nelson Mandela; see Mgxekwa, Scholtz and Saayman 2019) or framed in the architectural or cultural landscape of an era (e.g., Egypt, Turkey) (Yilmaz and El-Gamil 2018). Italy remains a famous destination, where clusters of attractions are branded by geniuses such as Michelangelo, Da Vinci, Alighieri and many others (Bellini et al. 2014). There are cases where such personalities are considered to belong equally to a nation and the world. For example, Albert Einstein, assumed to be the world's greatest genius, is valued not only in Germany, his native country, but also in countries across the globe (Switzerland, Spain, Japan, the US, etc.) (Owens 2012) where he worked or where the influence of his work was felt.

Often, heritage is recognized by UNESCO and consequently, becomes widely known and appreciated in cultural tourism. In this regard, Italy, China, Spain, France and India are leaders of UNESCO cultural heritage sites (Lushchyk 2021). Even in 2022, Romania benefitted from seven UNESCO cultural properties (see World Heritage List) yet none of these represent a legacy relating to famous people. However, on the tentative list, the Constantin Brâncuși's open-air sculptures complex in Târgu-Jiu was considered for nomination (Șerban 2018).

Among its cultural icons, Romania counts remarkable personalities, whose scientific and technical contributions have produced positive changes nationally or worldwide, yet some are not recognized as part of Romania's national heritage. Simmons (1996) ranked the top 100 scholars in world history and stated that Romania has an advantageous position in the list boasting 6% of the world's geniuses, with Germany, the UK and the USA occupying the top position, followed by France, etc.

Starting from the assumption that for all countries around the world, cultural heritage sites are elements of national identity and branding that continue to influence the current values of societies (O'Connor 1993), it should be the duty of each nation, as well as humankind, to develop them carefully and equitably, so as to synthesize all the valuable assets of their peoples. These values might also include genius personalities and their life and work, whether this be artistic, scientific or technical. Nevertheless, such untapped patrimonial resources, which could enrich the offer of tourist attractions, is not being fully capitalized on in Romania (Nicolaie 2015).

Therefore, the purpose of this research is to analyse domestic tourists' perceptions of the development of cultural attractions, related to the heritage of genius personalities within Romanian culture. The objectives of the research are: (1) to identify and create a ranked list of the most recognized Romanian geniuses; (2) to analyse the visitors' statistics and perceptions of Romanian personalities' heritage sites; (3) to explore the needs and benefits of developing heritage sites associated with genius personalities.

1.1 A brief theoretical background

The topic of cultural heritage has been addressed in many scientific publications, which cover several fields of research, including that of tourism. Thus, the search for the »cultural heritage« keyword in the Web of Science (WoS) database, for the period 1990 to 2022, revealed 40,000 publications, which address the topic separately or in the context of cultural tourism; »cultural heritage tourism« generated around 7,000 works, of which 71% were classified as (original) scientific research articles.

The concept of cultural heritage, repeatedly addressed over the last five decades by international and national bodies, as well as scientists (Vlase and Lähdesmäki 2023), was defined by UNESCO for a global purpose in terms of its material, intangible and environmental values, which are of considerable importance to humanity (Ahmad 2006). The preservation and valorization of cultural heritage must take into account its global spread (Lowenthal 1998), the potential of each site (Król 2021) and its multiple roles in society (Kesar, Matečić and Hodak 2018).

In the case of tourism, cultural heritage is linked to two types of tourism: cultural tourism and cultural heritage tourism (Bitušíková 2021). For McIntosh and Goeldner (1986), as well as Edson (2004), cultural tourism includes cultural heritage both as processes and products, while Goeldner and Richie (2000) consider that cultural heritage tourism means visits to historical attractions and that cultural tourism may or may not be associated with the current elements of cultural life.

Cultural heritage supports cultural tourism, but, at the same time, research highlights its role as a driving force in the development of the community (Kausar and Nishikawa 2010), and settlements for urban regeneration (Lak, Gheitasi and Timothy 2020), the revitalization of small towns (Matei et al. 2013; Munjal 2019) or rural sustainability (Hidalgo 2020; Zang et al. 2020). Alternatively, cultural tourism is commonly considered an effective way of expressing an educational function through different activities (Ashworth and Turnbridge 2000; Lowenthal 1998; Light 2000; Dean, Morgan and Tan 2002). It helps governments influence public opinion and gain support to promote national aspirations (Cohen-Hattab and Kerber 2004), create a positive country image (Urry 1990; O'Connor 1993; Hall 1995; Pretes 2003) and shape national branding in order to distinguish countries and cultures from one other.

Therefore, the lack of concern of municipalities in preserving (Ștefănică et al. 2021) or enriching local heritage and tourism development (Wei et al. 2021; Arisanty et al. 2019) should be alleviated. It may be the case that geniuses' heritage, whose »places and anniversaries can function as sites of memory« (Fara 2000, 407) may contribute to the overall visitors' experience (Poria, Reichel and Biran 2006), as their distinctive characteristics are necessary for tourism development (Truong, Lenglet and Mothe 2018). The genius personalities' heritage and museums studies showed that the tourist preference depends on the individual tourists' background and education. Thus, Yue, Bender and Cheung (2011) revealed that the Chinese are more focused on the heritage of meritorious personalities (science, technologies), while the research of Tang, Werner and Hofreiter (2018) on the Germans demonstrated that they are closer to the aesthetical domain (literature, arts, philosophy). In fact, all personalities, regardless of the field in which they excelled, must be valued, and the public's perception of who deserves to be invested in a museum, even at empirical level, should be taken into consideration (Schwartz 1998).

In the case of valuable products, tourists are willing to travel long distances (Panzera, de Graaff and de Groot 2020) or through rural surroundings (Bertacchini, Nuccio and Durio 2021). Cellini and Cuccica (2013) concluded that museums cannot influence the tourist flow, but can impact the length of their stay, while Carey et al. (2013) pointed out that museums attract tourists in urban areas and »star« sites, such as UNESCO, which can increase international visit flows (Panzera, de Graaff and de Groot 2020).

Research regarding the development of cultural tourism heritage highlights that local communities must be as sustainable as possible, but this depends on the economic and social background of each destination (Ngamsomsuke, Hwang and Huang 2018). Certain studies draw attention to the stimulation of over-tourism and the escalation of social, local conflicts (Murzyn-Kupisz and Hołuj 2020), while others emphasize the multiple opportunities for locals (Catrina 2015). Moreover, all stakeholders participating in the development of heritage sites contribute to their success, which directly constitutes a safe development (Balažič 2010).

In the case of Romania, publications relating to cultural tourism heritage are either general approaches or theoretical aspects (Cocean 2006; Busuioc 2008). Other researchers analyse the tourism potential of destinations (Iațu and Bulai 2011), historical (Muntean and Stremtan 2012) or religious attractions, as well as UNESCO registered sites (Maxim and Chasovschi 2021). Some authors have studied the heritage site trends for sustainable development (Stoica et al. 2022; Merciu, Petrişor and Merciu 2021) or a museum's dynamics (Bogan, Constantin and Grigore 2018). Thus, the research on Romania's cultural tourism focuses on certain general ideas, but none of these include the heritage of a genius' life, works or material values.

2 Data and methods

The study adopted both quantitative and qualitative analysis. Thus, in order to explore the opinions of domestic tourists, we conducted an online survey. The data collected were analysed through statistical methods, aiming to establish an association among variables, the p value significance, score and frequencies. In addition, qualitative analysis was used for the open-ended responses. The statistics on visitors were collected from museums and memorial houses' reports, and from the National Institute of Statistics (NIS); visitors could be tourists and local people. The data refer to 2019 and therefore, are not skewed by the Covid-19 pandemic, which changed tourist flows and tourism functionalities (Park, Kim and Ho 2022; Turtureanu et al. 2022), and consequently the number of museum visitors. Mathematical formulas were utilized to compute the share of museums' visitors among respondents and tourists.

The survey was semi-structured, created in Google Forms and was sent via email and WhatsApp, starting from the Romanian authors' social networks within the general population, in January and February 2022. Due to the context of the Covid-19 pandemic, the snowball technique was considered the most appropriate, being consistent with the respondents' ability to reply online or communicate using electronic devices (Matei et al. 2021). Therefore, in its introduction, there was a description of the aim of the research to encourage the voluntary participation of persons with the attribute in question, followed by instructions on how the questionnaire should be forwarded to at least one person of a different gender, age and profession. This technique improved population sampling and avoided keeping the configuration of the authors' social networks.

The sample size (385 respondents) was projected using Cochran's formula (1) to estimate the minimum sample for large populations, using a z score of 1.96 and, therefore, a confidence interval of 95% (Cochran 1977):

$$n_0 = \frac{Z^2 pq}{e^2} \tag{1}$$

where e is defined as the margin of error (0.05), p is the proportion of the estimated population, which relates to the attribute in question (0.5) and q is 1-p (Ryan 2013).

The specificity of theme and online snowballing of the survey explain the structure of the final sample, characterized by a large majority of graduates and post-graduates (88.6%), with 38.2% being current students and mainly inhabitants of urban centres (86.3%). Gender, age groups or income structure are almost balanced. All respondents were proven to be visitors of at least one of the geniuses' heritage sites identified in this research. Therefore, we named them tourist respondents.

The survey was composed of five open-ended questions, five questions on a five-point Likert scale and two multiple-choice questions (Table 2). We also asked respondents to provide six demographic variables (gender, age group, education, place of residence, profession, income (Table 1).

Table 1: Demographic characteristics of the sample.

Variables		%	Variables		%
Gender	M	54.8	Profession	Art and culture	0.12
	F	45.2		Economist	4.6
Place of residence	Urban	86.3		Education	4.1
	Rural	13.7		Employer	4.1
Education	Gymnasium	0.7		Engineer (IT)	6.8
	Lyceum	10.7		Health	6.2
	Faculty	50.0		Judicial	1.2
	Post graduate	38.6		Media	3.1
Income (€)	<400	10.5		NGO	3.0
	401–800	40.6		Other	8.4
	801–1200	34.7		Research	2.9
	>1200	14.2		Retail	4.0
Age groups	18–20	22.1		Retired	0.6
	31–45	39.5		Security and defence	5.8
	46–60	32.3		Civil servant	2.3
	60+	6.1		Student	38.2
				Tourism	3.5

Table 2: Content of the survey.

Type of question	Questions
Open-ended	Q1. Which personalities of Romanian culture (including science, technology, arts etc.) from any time period would you consider to be geniuses? Rank at least three names, please!
	Q2. Which tourist attractions, related to these personalities, have you visited? List them!
	Q3. Which of these attractions impressed you the most? Justify your choice.
	Q4. Which tourist attraction impressed you the least? Justify your choice.
	Q5. Did you identify any personality in your list with no tourist attraction? Name that personality and provide a brief comment!
Five-point Likert scale (score) 1 (very little) – 5 (very much)	Q6. How would you rate the start of a new tourist product, based on Romanian geniuses' heritage sites?
	Q7. How do you rate the quality of museum services (guide, information, etc.) in Romania?
	Q8. How do you rate the quality of road transport services in Romania for tourism?
	Q9. How do you rate the quality of tourist information points and services in Romania?
	Q10. How do you rate the quality of accommodation services in Romania?
Multiple choice	Q11. Who should implement the Romanian geniuses' heritage for tourism? a. Ministry of Culture and Ministry of Tourism; b. town halls; c. NGOs; d. county prefectures and county councils; e. custodians of these objectives united in an association; f. private entrepreneurial companies; g. other
	Q12. One of the principles in sustainable tourism development aims to involve the community in local business. How does this principle apply to capitalizing Romanian geniuses' heritage? Choose at least one option! a. local employment; b. boosting souvenir business; c. development of a project focusing on a genius; d. local guide qualification; e. renting a room for tourists; f. stimulating a project for tourism infrastructure; g. other

The demographic and multiple-choice answers were coded in SPSS (version 28) as nominal and ordinal scales. Questions based on the Likert scale (Q6→Q9) were weighted using a scoring scale between 1 and 5. The open-ended responses (Q1→Q5) were coded by the similarity of the contents considered as categorical data or selected manually for qualitative analysis.

The starting point was to use the open-ended responses to nominate at least three top genius personalities, ranking them according to their perceived importance (Q1). In this respect, nominations with at least 1% occurrence were considered, regardless of their rank (Figure 1) and were included in the correspondence analysis (CA) (Figure 2). The CA was applied to measure the association between the frequency of attributes (the first, the second, the third) and the nominations of personalities. As an exploratory method for categorical data, not based on specific hypotheses, CA explains the variance (inertia) in a model, breaking it down into the least number of dimensions (Doey and Kurta 2011). CA uses the Chi-square statistics or Euclidean distance measures for the association between variables ($p<0.5$) on the biplot graph (Figure 2).

Questions 2, 3, 4 and 5 were analysed quantitatively (frequency of occurrence of the key words), and for 3 and 4, a qualitative approach was added (manual text analysis) (Figure 4).

The Student test and the ANOVA procedure with the Fisher test were applied, in order to test the impact of the tourists' socio-demographic characteristics in relation to their perception of the importance of genius heritage and Romanian tourist attractions. This was based on Sullivan and Artino's findings (2013) regarding the robustness of results given by the parametric tests of the Likert scale, including the mean score for the scale items.

3 Results

3.1 Identifying famous personalities considered geniuses by Romanian tourist respondents

In compliance with the 385 respondents' answers (Table 1), a total number of 130 personalities were nominated as geniuses. Most are historical (127) with only a few from the present time (three). Thirty have a percentage of frequency greater than 1%, and among these, 22 were nominated at least once for each of the first three places (Figure 1).

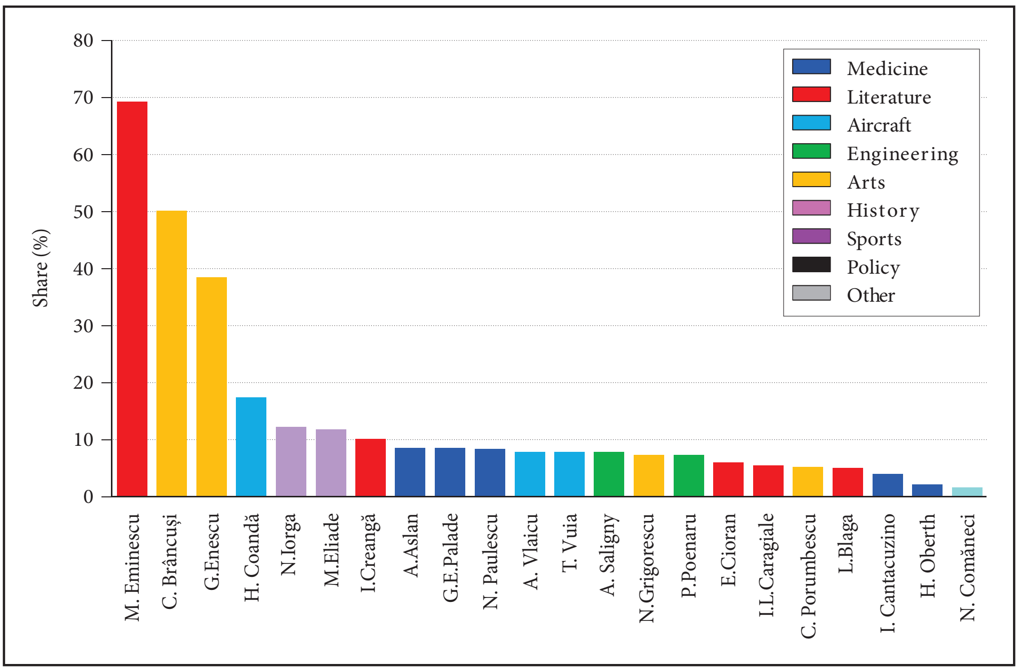


Figure 1: The frequency (more than 1%) of geniuses cited in respondents' nominations, based on the first three nominees.

The first three personalities are Mihai Eminescu (69.4%), Constantin Brâncuși (50.1%) and George Enescu (38.4%). The next four personalities, cited by respondents, with a frequency between 10% and 20% are Henri Coandă (17.4%), Nicolae Iorga (12.2%), Mircea Eliade (11.7%) and Ion Creangă (10.1%) (Figure 1).

In the field of medicine, the respondents listed academicians (each with 8.6%): Ana Aslan (geriatrist) and George Emil Palade, the winner of the Nobel Prize for Medicine in 1974 in modern cell biology (Bot 2009). Next was Nicolae Paulescu for insulin research, a discovery that generated controversies related to the Nobel Prize (Diem et al. 2022) and Ioan Cantacuzino (3.9%).

Another key group related to engineering, namely, Traian Vuia and Aurel Vlaicu (aircraft), Anghel Saligny (bridge builder) and Petrache Poenaru (stylus inventor) (Găină 2019).

Two other personalities that attracted attention were Herman Oberth, a pioneer of rocketry and astronautics (Neufeld 1996) and considered famous by only 2.1% of respondents, and Nadia Comăneci (gymnastics), possibly one of the country's most famous cultural icons outside of Romania (Miklowitz 1977).

The CA results of the association between the frequency of attributes (the first, the second, the third) and the nominations of personalities are acceptable for $p < 0.01$. They have a Chi-square value of 202.883 and are indicative in the case of total inertia. For the first dimension, the proportion of inertia accounting for this dimension is 79.4%, $\sigma = 0.030$, while the second dimension accounted for 20.6% of total inertia and $\sigma = 0.034$ (Table 3).

Figure 2 shows the popularity between M. Eminescu and the first place. C. Brâncuși corresponds equally to the first and second ranks. Enescu is associated both with the second and third ranks. M. Eliade, H. Oberth, P. Poenaru and I. Cantacuzino are closer to the second rank, while H. Coandă, T. Vuia, A. Vlaicu and N. Iorga are nearer to the third rank.

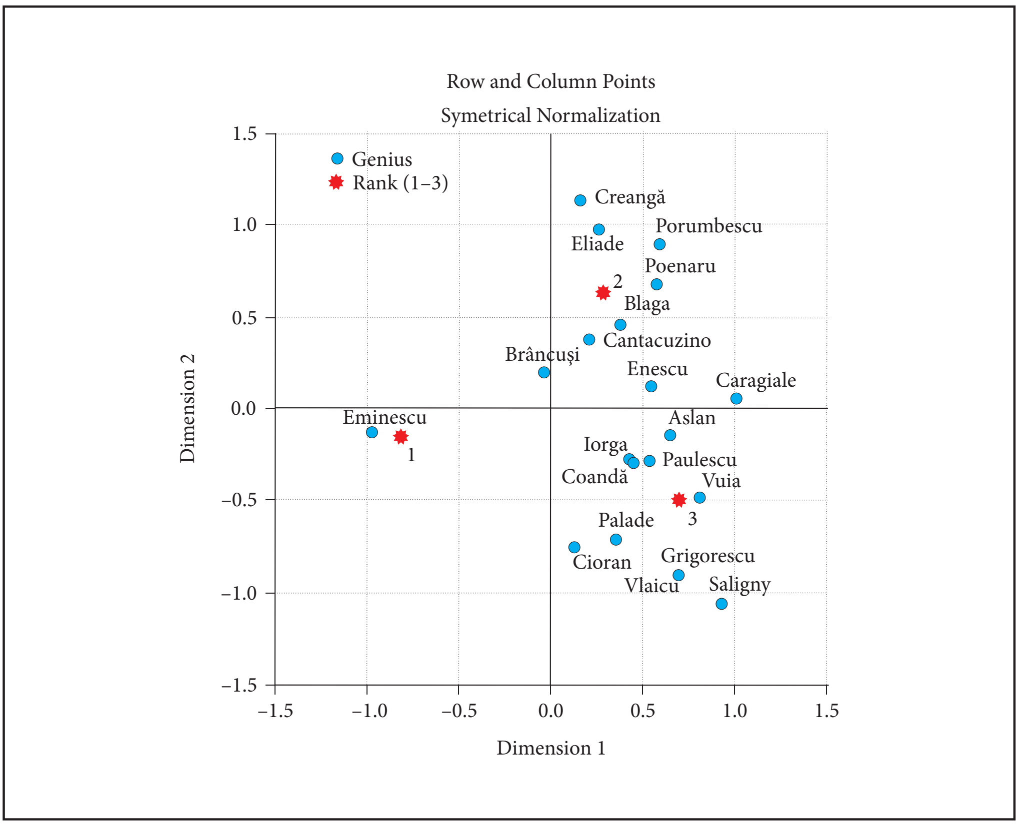


Figure 2: Correspondence map for the top 22 geniuses by frequency and rank from the perspective of the respondents.

Table 3: Summary of correspondence analysis of nominations and ranks.

Summary								
Dimension	Singular Value	Inertia	Chi Square	Sig.	Proportion of Inertia		Confidence Singular Value	
					Accounted for	Cumulative	Standard Deviation	Correlation 2
1	0.421	0.177			0.794	0.794	0.030	0.112
2	0.214	0.046			0.206	1.000	0.034	
Total		0.223	202.883	<.001[a]	1.000	1.000		

[a] 42 degrees of freedom

3.2 Heritage of Romanian genius personalities and tourist demand and perception

In 2022, Romania had 762 museums and collections, licensed as having national, regional, county or local importance. These include both public (state) and private museums and collections (Law 311/2003). Collectively, they attracted over 18 million visitors in 2019, in comparison with 13.3 million tourist arrivals registered in Romania in the same year (based on data provided by NIS).

Among Romania's museums and collections, 65 cultural sites connected with the 22 Romanian geniuses were identified by the respondents, but only 44.6% of the total were memorial houses and museums that capitalize on their assets, while others belonged to many personalities or vice versa.

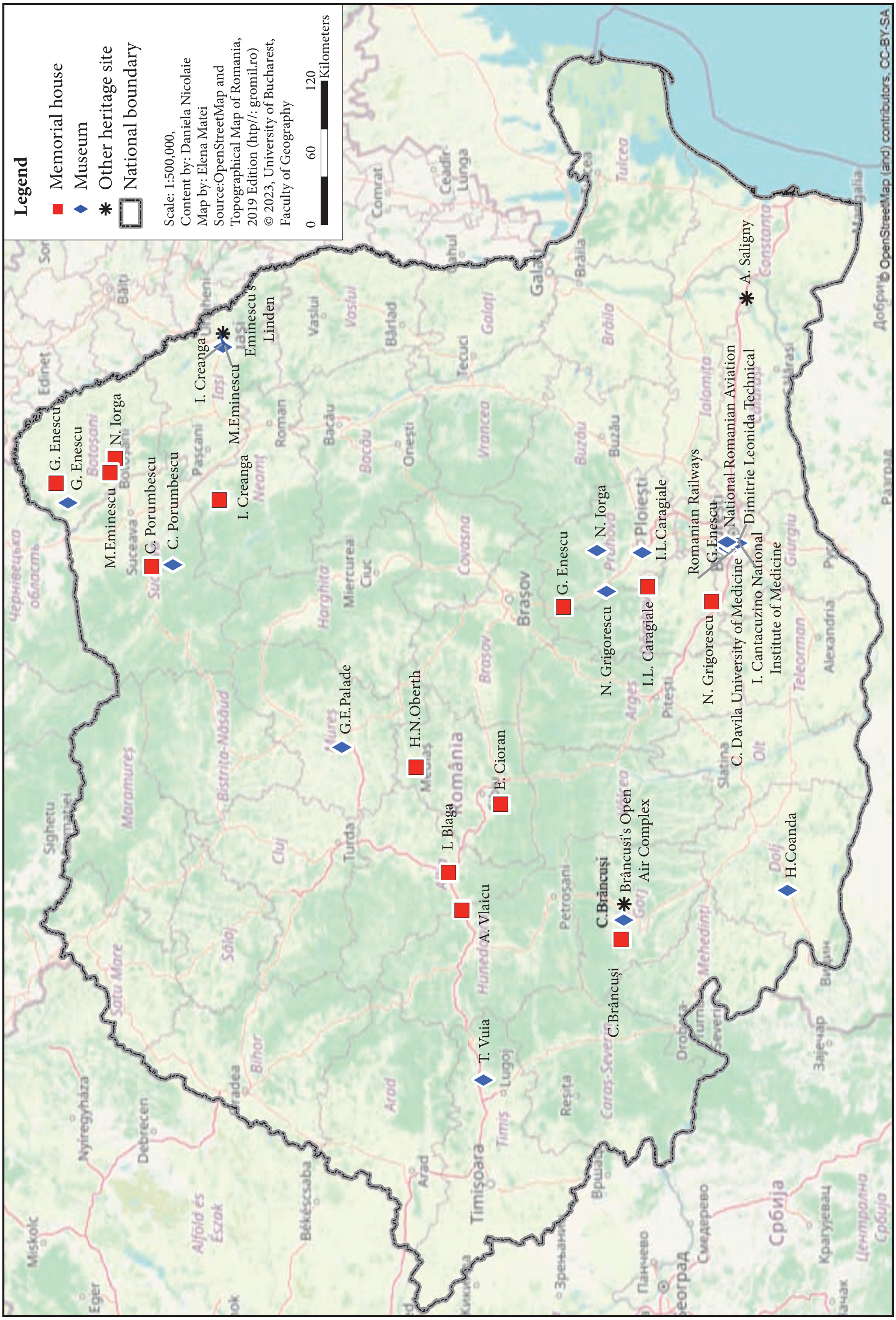
Memorial houses constitute the category of cultural attractions that evoke the life and activity of remarkable people, based on their native material assets. From the 22 chosen personalities, almost 60% of them

Table 4: The memorial houses of personalities: history, state, share of respondents and tourists' visits. Data collected from NIS and museums' reports.

Personality	Place of birth (county)	Establishment and state of memorial house	Share of respondents' visits (%)	No. of memorial visitors (their share among the tourist arrivals in the settlements), 2019
M.Eminescu	Ipotești (Botoșani)	1940, functioning	23.1%	16,536 (345.7%)
I. Creangă	Humulești (Neamț)	1951, functioning	6.4%	40,000 (237.5%)
G. Enescu	G. Enescu (Botoșani)	1968, poor condition	5.7%	1,046 (1,046%)
	Sinaia (Prahova)[1]	1995, functioning	6.7%	23,520 (7.7%)
C-tin Brâncuși	Hobița-Peștișani (Gorj)	1971, property conflicts	5.4%	11,292 (3,163%)
N. Grigorescu	Potlogi (Dâmbovița)	2019, functioning	2.5%	1,800 (186.9%)
N. Iorga	Botoșani (Botoșani)	1971, functioning	1.9%	1,719 (4.2%)
C. Porumbescu	Stupca (Suceava)	1953, functioning	1.8%	12,145 (391.3%)
E. Cioran	Rășinari (Sibiu)	1911, property conflicts	1.3%	600 (9.6%)
A. Vlaicu	Geoagiu (Hunedoara)	1952, functioning	1.0%	2,346 (4.5%)
L. Blaga	Lancrăm-Sebeș (Alba)	1998, functioning	1.3%	5,745 (21.5%)
H. Oberth	Mediaș (Sibiu)	1994, functioning	1.3%	1,005 (3.4%)
I. L. Caragiale	I. L. Caragiale (Dâmbovița)	1979, functioning	0.0%	1,174 (200%)
Romania's museum visitors:18,197,586 and tourist arrivals: 13,374,943 (2019)				95,408 (19.5%)

Note: [1]G. Enescu's residence during his life.

Figure 3. Famous heritage sites of personalities in Romania. ➤ p. 44


Legend
Memorial house
Museum
Other heritage site
National boundary
Scale: 1:500,000,
Content by: Daniela Nicolaie
Map by: Elena Matei
Source:OpenStreetMap and
Topographical Map of Romania,
2019 Edition (htp//: gromil.ro)
© 2023, University of Bucharest,
Faculty of Geography
0 60 120
Kilometers
G. Enescu
G. Enescu
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C. Porumbescu
C. Porumbescu
I. Creanga
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M.Eminescu
Eminescu's Linden
G.E.Palade
H.N.Oberth
E. Cioran
L Blaga
A. Vlaicu
T. Vuia
C.Brâncuși
C.Brâncuși
Brâncuși's Open Air Complex
G. Enescu
N. Iorga
N. Grigorescu
I.L.Caragiale
I.L. Caragiale
N. Grigorescu
Romanian Railways
G.Enescu
National Romanian Aviation
Dimitrie Leonida Technical
C. Davila University of Medicine
I. Cantacuzino National Institute of Medicine
A. Saligny
H.Coanda
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have such a heritage building. Not all recognized personalities are valorized in Romanian cultural heritage, with an identifiable building or other location, often due to conflicts relating to specific properties or houses, the physical degradation or even disappearance of some sites and other issues (Table 4; Figure 3).

All the geniuses' memorial houses were established over the last 110 years, most since the Second World War, yet tourist demand is still low, with only 0.5% of tourists visiting Romania's museums. However, in the present case study, more than half of the respondents (58.4%) confirmed past visits to these memorial houses. The frequency of visits to attractions, exemplified by the respondents in our survey is not in the same order as the nominations' rank (Figure 1) and differs from the number of museum visitors in the official statistics for 2019 provided by NIS. In particular, museum visitors showed a great interest in the Ion Creangă Memorial House, as Ion Creangă has remained in the collective memory of visitors as being the greatest narrator of his childhood in an authentic way (Diaconu 2002). The next site is the G. Enescu Memorial in Sinaia, a destination dependent upon the mountain tourism market, followed by the Eminescu Memorial in Ipotești village. By comparison, the respondents in this survey preferred the Mihai Eminescu Memorial House, followed by the Ion Creangă Memorial House, both with modern, interpretive-interactive amenities, destinations which registered a higher number of memorial visitors than tourist arrivals in 2019 (Table 4).

Museums are institutions in the service of society that play a crucial role in preserving local or national heritage assets for educative, research and leisure purposes (Foley and McPherson 2010). In the case of the 22 chosen geniuses, 50% benefit from fully customized cultural institutions, 30% have sections in museums

Table 5: The museums of personalities: history, location and share of respondents' and tourists' visits in 2019. Data collected from NIS and museum reports.

Personality	Foundation year	Location (county)	Share of respondents' visits (%)	No. of museum visitors, 2019 (their share among the tourist arrivals in the settlements)
M.Eminescu	1989	Iași (Iași)	2.3%	14,259 (4.6%)
G. Enescu	1956	Bucharest	7.3 %	56,668 (2.8%)
	1957	Dorohoi (Botoșani)	0.0%	1,201 (31.0%)
C-tin Brâncuși	2020	Târgu Jiu (Gorj)	0.0%	No data
H. Coandă	2007	Perișor (Dolj)	0.0%	380 (76.2%)
	1990	Bucharest[1]	1.6 %	17,892 (0.9%)
	1909	Bucharest[5]	1.8%	8,841 (0.4%)
T. Vuia	2012	Traian Vuia (Timiș)	1.0 %	1,764 (598%)
	1909	Bucharest[5]	1.8%	8,841 (0.4%)
N. Paulescu	2013	Bucharest[2]	0.3%	No data
Ioan Cantacuzino	2013	Bucharest[3]	0.6%	No data
Anghel Saligny	1969	Bucharest[4]	1.8%	15,582 (0.8%)
I. L. Caragiale	1962	Ploiești (Prahova)	1.0%	6,026 (9.9%)
N. Iorga	1997	Vălenii de Munte (Prahova)	5.7%	28,012[6] (375.4%)
P. Poenaru	1909	Bucharest[5]	1.8%	8,841 (0.4%)
H. Oberth	1909	Bucharest[5]	1.8%	8,841 (0.4%)
G.E. Palade	2022	Târgu Mureș (Mureș)	0.3%	No data
I. Creangă	1918	Iași (Iași)	2.3%	56,759[6] (18.3%)
N. Grigorescu	1957	Câmpina (Prahova)	2.3%	11,123 (74.0%)
C. Porumbescu	1971	C. Porumbescu (Suceava)	1.0%	12,145[6] (391.3%)
Romania's museum visitors: 18,197,586 and tourist arrivals: 13,374,943 (2019)				197,504 (1.2%)

[1]A section in the National Romanian Aviation Museum; [2]inside »Carol Davila« University of Medicine and Pharmacy; [3] inside »Ioan Cantacuzino« National Institute of Medicine; [4] a section in a Romanian railway museum; [5] a section in D. Leonida Technical Museum, Bucharest. [6]Based on NIS.

and 20% currently have no institutional representation (Table 5). As more complex cultural institutions, these museums attract a larger number of visitors than memorial houses, 1% from the total number of Romanian museum visitors and only 34.7% of the survey respondents. Museums dedicated to one personality attract more visitors and respondents than thematic institutions relating to science, technology and engineering.

Monuments, individual statues and cultural ensembles are tourist attractions mentioned and visited by the respondents. The monuments nominated most frequently by the respondents are, in fact, those located in well-known destinations (Bucharest, Iasi, Târgu Jiu etc.), either in cultural ensembles with the other genius heritage destinations of outstanding art value or positioned in cities, whose cultural life has been marked by them. Brâncuși's outdoor sculptures (The Gate of the Kiss, the Table of Silence and the Column of Infinity) from Târgu Jiu City are visited regularly by the respondents (34.5%). Of those interviewed, 12% had seen the Eminescu monument of the lime-tree in Iași. Less interest was shown in the Saligny Bridge (Carol I King) over the Danube River (Fetești-Cernavodă), designed by the engineer A. Saligny at the end of the 19th century (Băjenaru 2012). All these monuments are freely accessible, are subjected to mass tourism and are often affected by the negative behaviours of tourists (graffiti, garbage, scribbles, etc.) (Spiridon et al. 2017).

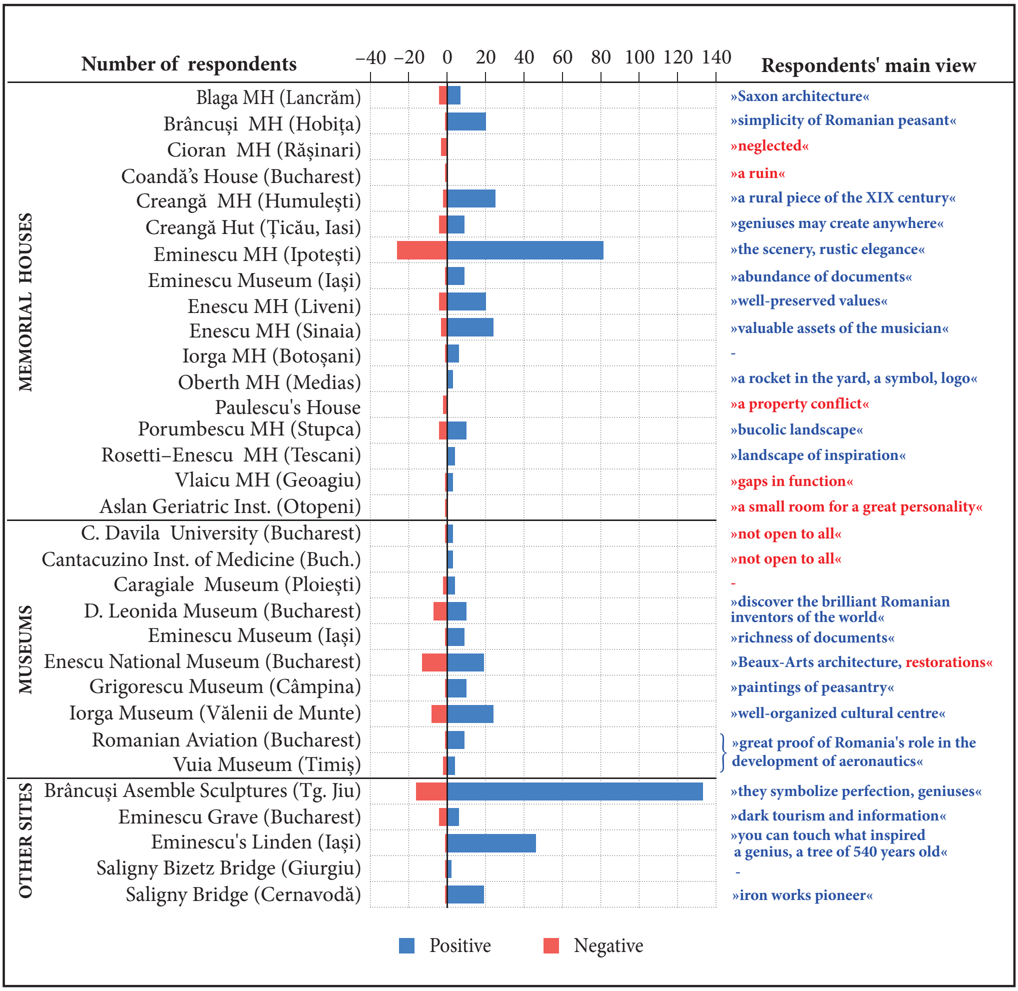

Figure 4: Frequency of positive and negative (red text) remarks regarding the visited sites from the tourist respondents' perspective.

The respondents' positive opinions outrank the negative opinions; 42% did not find anything they disliked, stating that »all were impressive«. On the other hand, there are sites that were neither mentioned as positive nor negative examples. Overall, the most exulted tourist attraction was Brâncuși's outdoor sculptures, open to the general public free of charge. The comments regarding each of the three exhibited pieces were exemplified by keywords, such as »uniqueness«, »greatness«, »perfection«, »genius«, »a sculptor of the modern art era, whose works are exhibited in the great museums of the world« (Figure 4).

Furthermore, both the M. Eminescu memorial house from Ipotești and his lime-tree, a secular tree in Copoul Park (Iași), were viewed positively, references to it being related to »the unique poetic vision about cosmic theory« and Eminescu's »role in the introduction of modern language in literature«. The respondents also identified the memorial houses of G. Enescu and I. Creangă, and the N. Iorga Museum, either for their organization, the preservation of their buildings or their representation of historic 19th and 20th century houses of different social categories, namely the peasantry (I. Creangă), the upper class (G. Enescu) and politicians (N. Iorga), all with a remarkable collection of assets.

Among the perceptions of those interviewed, negative issues were reported in the case of the G. Enescu Museum (Bucharest), organized in the Cantacuzino Palace and an impressive example of Beaux-Arts architecture, purchased by the artist (Beimel 2013). Controversially, this museum needed »urgent restoration works«, while the A. Vlaicu Memorial House had »poor guide services« or »insufficient road signage«. Unexploited heritage buildings were also reported, such as the N. Paulescu and H. Coandă houses, both in Bucharest City, as well as museums established within medical institutions but not open to the general public (Figure 4), such as Ana Aslan, I. Cantacuzino and N. Paulescu.

3.3 Heritage development of genius personalities: needs and benefits

Exploring the perception of a specific tourist product, which unifies the heritage dedicated to genius personalities, reveals a remarkably high rate of interest among respondents, with a mean score of 4.46 (on a scale from 1 to 5). The Student test and Fisher test (ANOVA method) results show that there is no difference among the groups of populations, except for three items relating to accommodation, as $p < 0.05$ (Table 6). The overall quality of the main components that characterize tourism: accommodation (3.39), access-transport (2.72), museum services (3.32) and tourist information (guidance, interpretation) (2.52) are considered satisfactory in terms of moderate values (Table 6). However, the higher the respondents' educational level, the more robust the incomes, and the more mature the groups, the lower the average scores. Therefore, when analysing the table of scores, the key expectations of the respondents regarding the new tourist package of geniuses, in the context of good museum services or accommodation, encompass needs such as the improvement of access-transport and tourist information services.

The establishment of a unified product of geniuses and the resolution of the identified needs are seen as equal prerogatives of the Ministry of Culture and the Ministry of Tourism (70%), then the responsibility of counties and local authorities (about 50%), followed by NGOs and other entities.

The benefits as a result of geniuses' heritage development would have multiplier effects on tourism, on settlements and on culture, etc. It is believed that initiating projects focused on adding to the heritage of geniuses, in particular, local personalities, would play a greater role in the education of the population (68.3%). Almost half of the respondents pay attention to the employment of positive inputs, either in relation to guiding (51.2%), museums' management (40%) or boosting local businesses based on souvenir stores (35.1%). Almost one fourth point to the augmentation of accommodation-based businesses, either by »rent a room« (28.1%) or through specific infrastructure (21.6%).

4 Discussion

Among the survey responses, 130 personalities were listed but only 22 were frequently nominated. This accords with the research of Schwartz (1998) whose empirical findings show that famous personalities are recognized by a large number of people. In the case of the Romanian personalities ranked in the first three places (M. Eminescu, C. Brâncuși and G. Enescu), it can be concluded that there is a stereotypical perception of geniuses, similar to the research results relating to Einstein and revealed in Smith and Wright's study (2000). Added to this is a statement by Smith and Wright (2000) that Mozart's nomination as a genius

Table 6: The results of testing the differences in genius heritage scores and the main tourism service scores in Romania, in relation to the respondents' socio-demographic characteristics.

Variables		Genius heritage		Museum services		Information services		Transport services		Accommodation		**Test**
Data tests		*Mean score*	Test value	*Mean score*	Test value	*Mean score*	Test value	*Mean score*	Test value	*Mean score*	*Test value*	
Overall sample		*4.46*		*3.32*		*2.52*		2.72		3.39		
Gender	M	4.51	198.209	3.28	252.11	2.44	197.604	2.75	197.60	3.28	0.84	t Test
	F	4.42	**(0.000)**	3.37	**(0.000)**	2.61	**(0.000)**	2.78	**(0.000)**	3.41	(0.772)	
Location	Urban	4.44	239.610	3.30	252.11	2.53	239.757	2.75	239.75	3.33	2.995	
	Rural	4.69	**(0.000)**	3.44	**(0.000)**	2.47	**(0.000)**	2.47	**(0.000)**	3.40	(0.084)	
Studies	Gymnasium	5.00	16.683	3.71	21.638	2.71	*9.261*	3.00	38.080	4.00	1.057	Fisher test (ANOVA)
	Lyceum	4.67	**(0.001)**	3.16	**(0.001)**	2.62	**(0.001)**	2.89	**(0.001)**	3.22	(0.367)	
	Faculty	4.40		3.41		2.57		2.81		3.35		
	Post gr.	4.48		3.23		2.43		2.54		3.34		
Income (€)	<400	4.42	17.553	3.07	27.222	2.86	24.613	2.98	28.844	3.38	0.265	
	401-800	4.42	**(0.001)**	3.42	**(0.001)**	2.51	**(0.001)**	2.72	**(0.001)**	3.37	(0.851)	
	801-1200	4.43		3.33		2.47		2.73		3.29		
	>1200	4.69		3.17		2.42		2.47		3.33		
Age groups	18-20	4.43	14.738	3.28	6.250	2.46	18.819	2.98	25.245	3.36	0.666	
	31-45	4.46	**(0.001)**	3.31	**(0.001)**	2.46	**(0.001)**	2.72	**(0.001)**	3.32	(0.573)	
	46-60	4.54		3.38		2.67		2.73		3.39		
	60+	4.60		3.16		2.34		2.47		3.15		
Profession	Art	3.75	12.782	2.50	12.965	3.00	11.926	3.00	16.779	3.60	1.622	
	Cults	4.50	**(0.001)**	3.50	**(0.001)**	2.50	**(0.001)**	3.50	**(0.001)**	3.50	**(0.045)**	
	Economist	4.06		3.13		2.63		2.98		3.24		
	Education	4.46		2.95		2.80		3.20		3.41		
	Employer	4.51		3.15		2.37		2.51		3.46		
	Engineer	4.44		3.30		2.48		2.89		3.13		
	Health	4.26		3.10		2.05		2.29		3.35		
	IT	4.56		3.22		2.39		2.91		2.72		
	Judicial	4.17		3.08		2.08		2.58		2.67		
	Media	4.58		3.19		2.48		2.97		3.00		
	NGO	5.00		2.87		2.33		2.20		3.30		
	None	4.27		3.40		2.53		2.60		3.50		
	Other	4.87		3.34		2.92		2.81		3.25		
	Research	4.34		3.59		2.79		2.76		3.67		
	Retail	4.54		3.10		2.60		2.67		3.80		
	Retired	4.27		3.00		1.67		1.33		3.33		
	Security	4.00		3.56		2.64		2.78		2.75		
	Servant	4.75		3.43		2.78		2.74		3.32		
	Student	4.30		3.48		2.53		2.64		3.33		
	Tourism	4.54		3.20		2.17		2.83		3.29		
	Worker	4.84		3.05		2.57		3.14		3.50		

Note: the significance level (p) of the test in the brackets.

is boosted during national cultural events. The three famous Romanians from this survey benefit from celebrations, such as the National Day of Culture organized on the 15th January since 2010 (Eminescu's birthday), Brâncuși Day, held on the 19th February since 2015 (Brâncuși's birthday) and the George Enescu Festival (established in 1958, on 4th September).

Considering their domains of excellence, geniuses of the arts, literature and philosophy (areas of aesthetic salience) are first nominated, followed by inventors and scientists (meritorious areas). This pattern was also highlighted by Yue, Bender and Cheung et al. (2011) and Tang, Werner and Hofreiter (2018) and was explained by popular educational orientation towards culture and then towards technical information or vice-versa.

The undisputed first place of M. Eminescu is explained by his mythification as a national poet, a genius of Romanian literature (Mironescu 2018). Otherwise, the works of M. Eminescu, C. Brâncuși, G. Enescu, M. Eliade, I. Creangă, L. Blaga, I. L. Caragiale and C. Porumbescu are taught during school education in Romania (see Ministry of Education national curricula; https://edu.ro). By comparison, the inventors and scientists' list, despite including a Nobel prize winner (G. E. Palade) or a contribution to the development of humankind (H. Coandă, T. Vuia, A. Vlaicu, N. Paulescu, P. Poenaru, H. Oberth, I. Cantacuzino, A. Aslan, A. Saligny) is mentioned mostly by health personnel and IT engineers, probably due to the ease of accessing information (Tang, Werner and Hofreiter 2018).

Concerning the capitalization of the heritage of genius personalities in relation to tourism, the results converge on several characteristics. For this reason, each situation (personality, region, nation and so forth) will require its own approaches. In this regard, the present study shows that the Romanian genius nominations are overlaid with the spread of their attractions (M. Eminescu, three landmarks; G. Enescu, four sites, etc.).

Museums dedicated to famous people outnumber memorial houses, as they are usually large public cultural institutions, designated to a group (Railway Museum, Technical Museum) or a single personality (G. Enescu) and are established in city settings, mainly Bucharest (Bogan, Constantin and Grigore 2018). Memorial houses are often private initiatives (foundations, family properties etc.) and are smaller in size, as many are linked to the native places of the subjects in rural or remote areas. In some cases, their setting up or function are influenced by legal processes of buildings restitution after the communist period (Bejtja and Bejtja 2015). Therefore, certain initiatives were blocked by ownership conflicts (E. Cioran and C. Brâncuși) or changed into residencies by descendants (P. Poenaru), while others were demolished and replaced by blocks of flats during communism (M. Eliade). In other cases, the accomplishments of outstanding personalities were organized exclusively within the institutions in which they worked, and information about them is not accessible to the general public (e.g., Palade, Paulescu, Cantacuzino and Aslan).

The data covering the visits to museums include both tourists and some residents, as official statistics do not differentiate between the two. This explains why the museum visitors outnumber tourist arrivals in our study. On the other hand, research has revealed that tourists in rural destinations tend to visit residential surroundings first (Bertacchini, Nuccio and Durio 2021 2021), while cities capture large numbers of visitors, due to the significant concentration of tourist attractions (Bogan, Constantin and Grigore 2018). These two findings could be used to explain why tourists and respondents visit memorial houses and museums in Bucharest or Iași with greater frequency. Furthermore, Cellini and Cuccica (2013) demonstrated that museums may influence the length of a tourist stays in particular destinations. Additionally, offers such as free entrance during the Museums Night event is a modifier of tourist numbers. Similarly, free access to open-air heritage sites, such as Brâncuși's outdoor sculptures and Eminescu's lime-tree in Iași, never captured in tourism statistics, could to a certain extent be comparable with the higher visitor rate noted by respondents.

The above ideas explain the partial overlapping of people with genius ranking and the statistics of visited sites, respectively, in the case of those personalities who are more generally promoted in Romanian culture and whose heritage is more adequately preserved and presented to the general public.

Moreover, respondents revealed the need for an improved valorization of famous personalities' heritage as a UNESCO site, which would bring multiple benefits to cultural tourism. Panzera, de Graaff and de Groot (2020) demonstrated that national and international (UNESCO) added values play the role of pull factors and may reduce the distance decay effect.

The frequently chosen strengths (accommodation, museum services) or needs (conservation, signage in the territory, promotion, the quality of the guidance, the maintenance or organization and the spatial accessibility) influence the demands of cultural heritage. Thus, more careful exploitation and the implicit preservation of heritage related to genius personalities is clearly perceived as increasing tourism resources and the number of direct and indirect jobs, as well as revenues in the field of culture and tourism or heritage-oriented activities (Murzyn-Kupisz 2012). These are targets of the local sustainable tourism development, increasingly often argued for in tourism studies (Lanzinger and Garlandini 2019; Pop et al. 2019). The specificity and the spatial dispersion of such objectives requires the mitigation of certain deficiencies related to transport accessibility and signage (Wu and Guo 2013). The implementation of such a concept of tourism capitalization requires the combined and consistent effort of all stakeholders, from NGOs to local and national authorities, and even the EU in relation to the country's spaces (Surugiu and Surugiu 2013).

5 Conclusions

This article analysed the way in which Romanian tourists perceive the opportunities to boost cultural heritage tourism in Romania, by capitalizing on famous personalities at national and international level. According to the tourists, 22 geniuses were validated from different fields and were recognized and requested by the national tourist market.

Regarding the heritage of genius personalities from the perspective of visitors, around 60% of the personalities identified by respondents were represented by one or more heritage buildings (Eminescu, Brâncuși, Enescu). These were either visited regularly and were well preserved or required certain conservation work, extra signage or information. The remaining 40% of personalities, identified by the respondents, are not commemorated in Romanian cultural heritage with memorial houses for several reasons, such as conflicts related to properties, the physical degradation of the building or the disappearance of the sites.

In relation to the development of the heritage of genius personalities and the consideration of needs and benefits, it was found that setting up special projects based on their heritage and improving the quality of museum services were greatly appreciated among the respondents, while tourist information (guidance, interpretation) and the accessibility of these objectives to tourists required improvement. Moreover, the respondents regard that the development of the heritage of famous personalities would generate socio-economic benefits for the members of local communities.

ACKNOWLEDGMENTS: All authors have made an equal contribution. We thank all museum officers who understood the importance of the research and provided us with the requested data regarding visitors. We also thank the anonymous reviewers for their valuable suggestions in finalizing the article.

6 References

Ahmad, Y. 2006: The scope and definitions of heritage: From tangible to intangible. International Journal of Heritage Studies 12-3. DOI: https://doi.org/10.1080/13527250600604639

Arisanty, D., Normelani, E., Putro, H. P. N., Anis, M. Z. A. 2019: The role of local government for local product processing: The implication for tourism sustainability in Lok Baintan Floating Market. Journal of Indonesian Tourism and Development Studies 7-1. DOI: https://doi.org/10.21776/ub.jitode.2019.07.01.02

Ashworth, G. J., Tunbridge, J. E. 2000: The tourist-historic city. Retrospect and prospect of managing the heritage city. London. DOI: https://doi.org/10.4324/9780080519470

Balažič, G. 2010: Integrating socialist cultural heritage into the tourism offer of the Municipality of Koper. Sustainable Tourism 4. DOI: https://doi.org/10.2495/ST100321

Băjenaru, I. 2012: Anghel Saligny: Omul și monumentul. Urbanism. Arhitectură. Construcții 3-1.

Beimel, T. 2013: Cantacuzino Palast: Die Geschichte des rumänischen Komponistenverbands. Musicology Today: Journal of the National University of Music Bucharest 13-4.

Bejtja, S. and Bejtja, D. 2015: Comparative study in Central and Eastern Europe regarding restitution/compensation process. European Journal of Economics and Business Studies 1-1. DOI: https://doi.org/10.26417/ejes.v1i1.p31-45

Bellini, N., Baratta, V., Loffredo, A., Rovai, S. 2014: Chinese tourists in Tuscany: Redefining the relationship between heritage and authenticity. Proceedings of the Heritage. Tourism and Hospitality International Conference. Istanbul.
Bertacchini, E., Nuccio, M., Durio, A. 2021: Proximity tourism and cultural amenities: Evidence from a regional museum card. Tourism Economics 27-1. DOI: https://doi.org/10.1177/1354816619890230
Bitušíková, A. 2021: Cultural heritage as a means of heritage tourism development. Muzeologia A Kulturne Dedicstvo/Museology and Cultural Heritage 9-1. DOI: https://doi.org/10.46284/mkd.2021.9.1.5
Bogan, E., Constantin, D. M., Grigore, E. 2018: The museum tourism in Bucharest, Romania. Quality – Access to Success 19.
Bot, A. 2009: Dr George Emil Palade (1912–2008). International Reviews of Immunology 28-1-2. DOI: https://doi.org/10.1080/08830180902721041
Bucurescu, I. 2015: Managing tourism and cultural heritage in historic towns: examples from Romania. Journal of Heritage Tourism 10-3. DOI: https://doi.org/10.1080/1743873X.2014.968162
Busuioc, M. F. 2008: Strategii de dezvoltare şi promovare a turismului cultural în România. Bucharest.
Buttimer, A. 1995: Vidal de la Blache: 1845–1918. Un GéAnie de la Géographie. Sanguin, A. L. Annals of The Association of American Geographers 85-2.
Canale, R. R., De Simone, E., Di Maio, A., Parenti, B. 2019: UNESCO World Heritage sites and tourism attractiveness: The case of Italian provinces. Land Use Policy 85-C. DOI: https://doi.org/10.1016/j.landusepol.2019.03.037
Carey, S., Davidson, L., Sahli, M. 2013: Capital city museums and tourism flows: An empirical study of the museum of New Zealand Te Papa Tongarewa. International Journal of Tourism Research 15-6. DOI: https://doi.org/10.1002/jtr.1874
Catrina, S. 2015: Local heritage interpretation by private »cultural agents« from Maramureș. Procedia – Social and Behavioral Sciences 188. DOI: https://doi.org/10.1016/j.sbspro.2015.03.361
Cellini, R., Cuccia, T. 2013: Museum and monument attendance and tourism flow: A time series analysis approach. Applied Economics 45-24. DOI: https://doi.org/10.1080/00036846.2012.716150
Cocean, P. 2006: Turism cultural. Cluj-Napoca.
Cochran, W. G. 1977: Sampling techniques. New York.
Cohen, E. 1988: Authenticity and commoditizationin tourism. Annals of Tourism Research 15. DOI: https://doi.org/10.1016/0160-7383(88)90028-X
Cohen-Hattab, K., Kerber, J. 2004: Literature, cultural identity and the limits of authenticity: A composite approach. International Journal of Tourism Research 6-2. DOI: https://doi.org/10.1002/jtr.470
Dean, A., Morgan, D., Tan, T. 2002: Service quality and customers' willingness to pay more for travel services. Journal of Travel and Tourism Marketing 12-2-3. DOI: https://doi.org/10.1300/J073v12n02_06
Diaconu, A. M. 2002: Ion Creangă – Nonconformism și gratuitate. Cluj-Napoca.
Diem, P., Ducluzeau, P. H., Scheen, A. 2022: The discovery of insulin. Diabetes Epidemiology and Management 5. DOI: https://doi.org/10.1016/j.deman.2021.100049
Doey, L., Kurta, J. 2011: Correspondence analysis applied to psychological research. Tutorials in Quantitative Methods for Psychology 7-1. DOI: https://doi.org/10.20982/TQMP.07.1.P005
Edson, G. 2004: Heritage: Pride or passion, product or service. International Journal of Heritage Studies 10-4. DOI: https://doi.org/10.1080/1352725042000257366
Fahy, D. 2018: The laureate as celebrity genius: How Scientific American's John Horgan profiled Nobel Prize winners. Public Understanding of Science 27-4. DOI: https://doi.org/10.1177%2F0963662518762663
Falk, J. H., Dierking, L. D. 1992: The museum experience. Washington DC.
Fara, P. 2000: Isaac Newton lived here: sites of memory and scientific heritage. British Journal for The History of Science 33-4. DOI: https://doi.org/10.1017/S0007087400004192
Foley, M., McPherson, G. 2010: Museums as leisure. International Journal of Heritage Studies 6-2. DOI: https://doi.org/10.1080/135272500404205
Găină, D. 2019: Ctitor al învățământului românesc – Petrache Poenaru (1799-1875) 220 de ani de la naştere. Confluențe bibliologice: Revista de biblioteconomie şi ştiința informării 1.
Goeldner, C. R., Ritchie, J. R. B. 2000: Tourism: Principles. Practices. Philosophies. New Jersey.
Greenwood, D. J. 1977: Culture by the pound: An anthropological perspective on tourism as cultural commoditization. Hosts and Guests: The Anthropology of Tourism. Oxford. DOI: https://doi.org/10.9783/9780812208016.169

Hall, D. R. 1991: Tourism opportunities. Tourism and Economic Development in Eastern Europe and the Soviet Union. London.
Hall, D. R. 1995: Tourism and Economic Development in Eastern Europe. European Tourism: Regions, Spaces and Restructuring. Chichester.
Hidalgo, B. 2020: Cultural Heritage as a factor of resilient territorial development in rural areas. The case of Mértola (Portugal). Pasos: Revista de Turismo y Patrimonio Cultural 1.
Hu, X. J., Rousseau, R. 2017: Nobel Prize winners 2016: Igniting or sparking foundational publications? Scientometrics 110-2. DOI: https://doi.org/10.1007/s11192-016-2205-x
Iatu, C., Bulai, M. 2011. New approach in evaluating tourism attractiveness in the region of Moldavia (Romania). International Journal of Energy and Environment 5.
Kausar, D. R., Nishikawa, Y. 2010: Heritage tourism in rural areas: Challenges for improving socio-economic impacts. Asia Pacific Journal of Tourism Research 15-2. DOI: https://doi.org/10.1080/10941661003629995
Kesar, O., Matečić, I., Hodak, D. F. 2018: The role of intangible cultural heritage in differentiation of cultural tourism products – The case of Zagreb. Proceedings of the Congress on the Tourism and Hospitality Industry: Trends and Challenges. Opatija.
Kirshenblatt-Gimblett, B. 1995: Theorizing Heritage. Ethnomusicology 39-3.
Król, K. 2021: Assessment of the cultural heritage potential in Poland. Sustainability 13-12. DOI: https://doi.org/10.3390/su13126637
Lak, A., Gheitasi, M., Timothy, J. D. 2020: Urban regeneration through heritage tourism: cultural policies and strategic management. Journal of Tourism and Cultural Change 18-4. DOI: https://doi.org/10.1080/14766825.2019.1668002
Lanzinger, M., Garlandini, A. 2019: Local development and sustainable development goals: A museum experience. Museum International 71-3,4. DOI: https://doi.org/10.1080/13500775.2019.1706945
Li, M., Wu, B., Cai, L. 2008: Tourism development of World Heritage Sites in China: A geographic perspective. Tourism Management 29-2. DOI: https://doi.org/10.1016/j.tourman.2007.03.013
Light, D. 2000: Gazing on communism: Heritage tourism and post-communist identities in Germany, Hungry and Romania. An International Journal of Tourism Space, Place and Environment 2-2. DOI: https://doi.org/10.1080/14616680050027879
Lowenthal, D. 1998: The heritage crusade and the spoils of history. Cambridge.
Lushchyk, M. 2022: Geographical systematization of UNESCO World Heritage Sites. Journal of Geology, Geography and Geoecology 31-2. DOI: https://doi.org/https://doi.org/10.15421/112233
Lykogianni, E., Mobilio, L., Procee, R., Airaghi, E., Kern, P. H., Le Gall, A., Krohn, C., Vanhoutte, C. 2019: Material cultural heritage as a strategic territorial development resource: Mapping impacts through a set of common european socio-economic indicators, Targeted analysis. Luxembourg.
Matei, E., Dumitrache, L., Manea, G., Vijulie, I., Tîrlă, L., Matei, D. 2013: Urban sustainable development of the Romanian small towns in the local communities and authorities' perception. SGEM, Bulgaria 2.
Matei, E., Ilovan, O. R., Sandu, C. B., Dumitrache, L., Istrate, M., Jucu, I. S., Gavrilidis A. A. 2021: Early Covid-19 pandemic impacts on society and environment in Romania. Perception among population with higher education. Environmental Engineering and Management Journal 20-2.
Maxim, C., Chasovschi, C. E. 2021: Cultural landscape changes in the built environment at World Heritage Sites: Lessons from Bukovina, Romania. Journal of Destination Marketing and Management 20. DOI: https://doi.org/10.1016/j.jdmm.2021.100583
McIntosh, R. W., Goeldner, C. R. 1986: Tourism: Principles, practices, philosophies. New York.
Merciu, F. C., Petrişor, A. I., Merciu, G. L. 2021: Economic valuation of cultural heritage using the travel cost method: The historical centre of the Municipality of Bucharest as a Case Study. Heritage 4-3. DOI: https://doi.org/10.3390/heritage4030133
Mgxekwa, B. B., Scholtz, M., Saayman, M. 2019: A typology of memorable experience at Nelson Mandela heritage sites. Journal of Heritage Tourism 14-4. DOI: https://doi.org/10.1080/1743873X.2018.1527339
Miklowitz, G. 1977: Nadia Comaneci. New York.
Mironescu, A. 2018: Remembering the »National Poet«: From memoirs to postmemory. Philobiblon. Transylvanian Journal of Multidisciplinary Research in the Humanities 23. 197-210. DOI: https://doi.org/10.26424/philobib.2018.23.2.04

Möller-Recondo, C., D'Amato, J. P. 2020: New genius-entrepreneurs: Itinerary and trajectories of university educational excellence. Comunicar 28-64. DOI: https://doi.org/10.3916/C64-2020-07

Munjal, P. G. 2019: Enhancing heritage tourism in small and medium towns by leveraging their cultural heritage, traditional knowledge and skills. Worldwide Hospitality and Tourism Themes 11-1. DOI: https://doi.org/10.1108/WHATT-11-2018-0067

Muntean, A. C., Stremtan, F. 2012: Tourists satisfaction with the tourist offer of Alba Iulia historical fortress. Journal of Environmental Protection and Ecology 13-4.

Murzyn-Kupisz, M. 2012: Cultural, economic and social sustainability of heritage tourism: Issues and challenges. Economic and Environmental Studies 12- 2.

Murzyn-Kupisz, M., Hołuj, D. 2020: Museums and coping with overtourism. Sustainability 12-5. DOI: https://doi.org/10.3390/su12052054

Nerubasska, A., Maksymchuk, B. 2020: The demarkation of creativity, talent and genius in humans: A systemic aspect. Postmodern Openings 11-2. DOI: https://doi.org/10.18662/po/11.2/172

Neufeld, M. J. 1996: The Rocket and the Reich. Cambridge.

Nicolaie, D. 2015: Sustainable tourism destinations: Cultural sites generated by Romanian geniuses as a potential resource for cultural tourism. Journal of Environmental and Tourism Analysis 3-1.

Ngamsomsuke, W., Hwang, T. C., Huang, C. J. 2018: Sustainable cultural heritage tourism indicators. International Conference on Social Science and Humanity. Singapore.

O'Connor, B. 1993: Myths and mirrors: Tourist images and national identity. Tourism in Ireland: A critical analysis. Cork.

Ostaric, L. 2012: Kant on the normativity of creative production. Kantian Review 17-1. DOI: https://doi.org/10.1017/S1369415411000343

Owens, T. 2012: Tripadvisor rates Einstein: Using the social web to unpack the public meanings of a cultural heritage site. International Journal of Web Based Communities 8-1. DOI: https://doi.org/10.1504/IJWBC.2012.044681

Panzera, E., de Graaff, T., de Groot, H. L. F. 2021: European cultural heritage and tourism flows: The magnetic role of superstar World Heritage Sites. Papers in Regional Science 100-1. DOI: https://doi.org/10.1111/pirs.12562

Park, S., Kim, Y. R., Ho, C. S. T. 2022: Analysis of travel mobility under Covid-19: Application of network science. Journal of Travel and Tourism Marketing 39-3. DOI: https://doi.org/10.1080/10548408.2022.2089954

Pelegrini, S. 2008: World heritage sites, types and laws. Encyclopedia of Archaeology. Paris.

Pop, I. L., Borza, A., Buiga, A., Ighian, D., Toader, R. 2019: Achieving cultural sustainability in museums: A step toward sustainable development. Sustainability 11-4. DOI: https://doi.org/10.3390/su11040970

Poria, Y., Reichel, A., Biran, A. 2006: Heritage site management: Motivations and expectations. Annals of Tourism Research 33-1.DOI: http://doi.org/10.1016/j.annals.2005.08.001

Pretes, M. 2003: Tourism and nationalism. Annals of Tourism Research 30-1. DOI: https://doi.org/10.1016/S0160-7383(02)00035-X

Robertson, P. 2008: What is musical genius? Clinical Medicine Journal 8-2. DOI: https://doi.org/10.7861/clinmedicine.8-2-178

Ryan, T. 2013: Sample size determination and power. New Jersey.

Schwartz, B. 1998: Postmodernity and historical reputation: Abraham Lincoln in late twentieth-century America memory. Social Forces 77-1. DOI: https://doi.org/10.1093/sf/77.1.63

Seal, G. 1996: Consuming outlaws, the common good and heritage from below. Heritage, Culture and Identity: Heritage from Below. Gloucestershire.

Simmons, J. 1996: The 100 Most Influential Scientists. Bucharest.

Simonton, D. K. 1996: Individual genius within cultural configurations – The case of Japanese civilization. Journal of Cross-Cultural Psychology 27-3. DOI: https://doi.org/10.1177%2F0022022196273007

Simonton, D. K. 2018: Creative genius as causal agent in history: William James's 1880 theory revisited and revitalized. Review of General Psychology 22-4. DOI: https://doi.org/10.1037/gpr0000165

Smith, C. D., Wright, L. 2000: Perceptions of genius: Einstein, lesser mortals and shooting stars. The Journal of Creative Behavior 34-3. DOI: https://doi.org/10.1002/j.2162-6057.2000.tb01208.x

Spiridon, P., Sandu, I., Stratulat, L. 2017: The conscious deterioration and degradation of the cultural heritage. International Journal of Conservation Science 8-1.

Stoica, G. D., Andreiana, V. A., Duică, M. C., Ștefan, M. C., Susanu, I. O., Coman, M. D., Iancu, D. 2022: Perspectives for the development of sustainable cultural tourism. Sustainability 14-9. DOI: https://doi.org/10.3390/su14095678

Sullivan, G. M., Artino, A. R. Jr. 2013: Analyzing and interpreting data from Likert-type scales. Journal of Graduate Medical Education 5-4. DOI: https://doi.org/10.4300/JGME-5-4-18

Surugiu, C., Surugiu, M. R. 2013: Is the tourism sector supportive of economic growth? Empirical evidence on Romanian tourism. Tourism Economics 19-1. DOI: https://doi.org/10.5367/te.2013.0196

Șerban, O. 2018: The primitive intangible heritage behind Brancusi's modernist tangible forms of culture. Hermeneia 21.

Ștefănică, M., Sandu, C. B., Butnaru, G. I., Haller, A. P. 2021: The nexus between tourism activities and environmental degradation: Romanian tourists' opinions. Sustainability 13-16. DOI: https://doi.org/10.3390/su13169210

Tang, M., Werner, C. H., Hofreiter, S. 2018: Creativity alone does not make a star – social attributes of the nomination of creative icons: Results of a trend study in Germany. Frontiers in Psychology 9. DOI: https://doi.org/10.3389/fpsyg.2018.01944

Truong, T. L. H., Lenglet, F., Mothe, C. 2018: Destination distinctiveness: Concept, measurement, and impact on tourist satisfaction. Journal of Destination Marketing & Management 8. DOI: https://doi.org/10.1016/j.jdmm.2017.04.004

Turtureanu, A. G., Pripoaie, R., Crețu, C. M., Sîrbu, C. G., Marinescu, E. Ş., Talaghir, L. G., Chițu, F. A. 2022: Projection approach of tourist circulation under conditions of uncertainty. Sustainability 14-4. DOI: https://doi.org/10.3390/su14041964

Urry, J. 1990: The tourist gaze: Leisure and travel in contemporary societies. London.

Vita, C. 2018: Cultural tourism: the »minor« art center in Italy. African Journal of Hospitality, Tourism and Leisure 7-6.

Vlase, I., Lähdesmäki, T. 2023: A bibliometric analysis of cultural heritage research in the humanities: The Web of Science as a tool of knowledge management. Humanities and Social Sciences Communications 10. DOI: https://doi.org/10.1057/s41599-023-01582-5

Wei, W., Heerema, H., Rushfeld, R., Van der Lee, I. 2021: Issues in conservation-three value moments in the public perception of cultural heritage objects in public spaces. Collabra: Psychology 7-1. DOI: https://doi.org/10.1525/collabra.21935

Wolff, C. 2001: Defining genius: Early reflections of J.S. Bach's self-image. Proceedings of The American Philosophical Society 145-4.

Wu, X., Guo, X. 2013: The investigation of the competitiveness of tourism industry in Romania. Proceedings of the 2013 International Academic Workshop on Social Science. Changsha. DOI: https://doi.org/10.2991/iaw-sc.2013.55

Yale, P. 1991: From Tourist Attractions to Heritage Tourism. Huntingdon.

Yilmaz, Y., El-Gamil, R. 2018: Cultural heritage management in Turkey and Egypt: A comparative study. Advances in Hospitality and Tourism Research 6-1. DOI: https://doi.org/10.30519/ahtr.446254

Yue, X. D., Bender, M., Cheung, C. K. 2011: Who are the Best-known national and foreign creators – A comparative study among undergraduates in China and Germany. The Journal of Creative Behavior 45. DOI: https://doi.org/10.1002/j.2162-6057.2011.tb01082.x

Zang, Y., Liu, Y., Yang, Y., Woods, M., Fois, F. 2020: Rural decline or restructuring? Implications for sustainability transitions in rural China. Land Use Policy 94. DOI: https://doi.org/10.1016/j.landusepol.2020.104531

FIRE AND FLOOD OCCURRENCE IN THE HABITATS OF THE ENDANGERED BUTTERFLY *COENONYMPHA OEDIPPUS* IN SLOVENIA

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Habitat of *Coenonympha oedippus* in 2020, ten months after the fire in Cerje.

DOI: https://doi.org/10.3986/AGS.11028
UDC: 504.4:574.2:595.78(497.4)

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Fire and flood occurrence in the habitats of the endangered butterfly *Coenonympha oedippus* in Slovenia

ABSTRACT: In Slovenia the False ringlet *Coenonympha oedippus* uniquely occurs both on wet (Ljubljana Marsh and surroundings) and dry grasslands (Slovenian Istria, Karst, Gorica Hills). Natural hazards that threaten its habitats include fires and floods; the frequency of their occurrence in the former and existing habitats of *C. oedippus* was determined using the χ^2-test. We showed that habitats on wet grasslands are less threatened by fire than those on dry grasslands. Among the latter, habitats in the Karst and Slovenian Istria are the most threatened. Habitats of *C. oedippus* are threatened by flooding only in Slovenian Istria and Ljubljana Marsh. Considering the extent of fire and flood risk and fragmentation of *C. oedippus* habitats in Slovenia, we assume that such natural hazards may lead to local extinction of the species.

KEY WORDS: natural hazards, fires, floods, threats, butterfly, False ringlet, *Coenonympha oedippus*, western and central Slovenia

Prisotnost požarov in poplav v življenjskih okoljih ogrožene vrste metulja barjanski okarček (*Coenonympha oedippus*) v Sloveniji

POVZETEK: Barjanski okarček se v Sloveniji edinstveno pojavlja tako na vlažnih (Ljubljansko barje z okolico) kot na suhih traviščih (slovenska Istra, Kras, Goriška brda). Med naravnimi nesrečami, ki ogrožajo njegove habitatne krpe, so požari in poplave. Njihovo pogostost pojavljanja v nekdanjih in obstoječih bivališčih barjanskega okarčka smo ugotavljali s χ^2-testom. Pokazali smo, da so življenjska okolja na vlažnih traviščih požarno manj ogrožena kot na suhih traviščih. Med slednjimi so najbolj ogrožene habitatne krpe na Krasu in v slovenski Istri. Habitatne krpe barjanskega okarčka so poplavno ogrožene le v slovenski Istri in na Ljubljanskem barju. Glede na stopnjo požarne in poplavne ogroženosti ter razdrobljenosti življenjskih okolij barjanskega okarčka v Sloveniji domnevamo, da lahko tovrstne naravne nesreče povzročijo lokalno izumrtje vrste.

KLJUČNE BESEDE: naravne nesreče, požari, poplave, ogroženost, barjanski okarček, *Coenonympha oedippus*, zahodna in osrednja Slovenija

The paper was submitted for publication on 8th August, 2022.
Uredništvo je prejelo prispevek 8. avgusta 2022.

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1 Introduction

Human activities have an exceptional impact on the distribution of species and their populations. Many butterfly species now live in increasingly degraded environments due to habitat loss and fragmentation (Čelik 2003; Hanski and Gaggiotti 2004; Rakar 2016; Crawford and Keyghobadi 2018; Nowicki et al. 2018; Jeliazkov et al. 2019). Habitat fragmentation and isolation reduce connectivity of habitat patches and have a negative effect on species establishment and on the species' genetic pool (Nowicki et al. 2018). The term natural hazard, which includes floods, droughts, fires, landslides, torrential deposition, subsidence, hail, frost, and earthquakes, is used primarily to describe and assess impacts on society (Komac, Zorn and Pavšek 2010), and less often on nature. The synergy of human interventions that degrade or even destroy species' habitats and natural hazards can greatly increase the probability of extinction of small local populations of a species (Hanski 1997).

The False ringlet, *Coenonympha oedippus* (Fabricius 1787) (Nymphalidae: Satyrinae, Figure 1), is one of the 15 most threatened butterfly species in Europe (van Swaay et al. 2010). The species inhabits two different types of habitats: wet grasslands (in most of its range in Europe) and dry grasslands up to later successional stages at the southern limit of its European distribution (Slovenia, Italy, and Croatia; Habeler 1972; Čelik and Rebeušek 1996; Šašić 2010; Čelik 2015b). Populations of the two ecotypes of *C. oedippus* in Slovenia differ morphologically and genetically (Jugovic et al. 2018; Zupan et al. 2021). The remaining populations on wet meadows are found only in central Slovenia in the Ljubljana Marsh (*Ljubljansko barje*). Populations on dry habitats live in Slovenian Istria, in the Karst (*Kras*), in Gorica Hills (*Goriška brda*), and in the southern outskirts of Banjšice and Trnovo Forest plateau (*Trnovski gozd*). Despite the high regional diversity of Slovenia (Perko and Ciglič 2020) and the disjunct geographic distribution of *C. oedippus*, the species is most threatened due to agricultural intensification on the one hand and abandonment of land use on the other (Zupan et al. 2020). The distribution and presence of *C. oedippus* in habitat patches is determined, among other things, by the height of grass litter and the density of the herbaceous vegetation, the adequate representation of host and nectar plants, and the management of grasslands (Čelik 2015a; Čelik et al. 2015; Čelik, Šilc and Vreš 2018; Čelik 2020; 2021; Čelik et al. 2021). Natural hazards have always been part of natural variability (Komac, Zorn and Pavšek 2010). Occasional natural disturbances typical of the species' distribution area do not affect the survival of stable populations. Natural hazards particularly threaten rare species with small populations inhabiting fragmented habitats and specialized species with low dispersal ability (Keyghobadi 2007; Devictor and Julliard 2008). Because of its short generation time, *C. oedippus* responds quickly to unfavourable changes in the environment (Čelik 2007). The habitat of *C. oedippus* in Slovenia is extremely spatially fragmented; its abundance has declined throughout the range in recent years (Verovnik et al. 2009; Čelik and Verovnik 2010; Čelik 2015b; Verovnik et al. 2015). In 2019, only one population was still living in the Ljubljana Marsh (Škofljica - Mostišče); and in 2019–2022, a new population was established in Ig Marsh (*Iški morost*) by rearing *C. oedippus* (Čelik 2020; 2021). Both populations in Ljubljana Marsh are below the probability threshold for long-term survival of the species. *C. oedippus* on wet grasslands is threatened by hydromelioration, agromelioration, agro-chemicalization, frequent mowing, abandonment of land use, and urbanization (Čelik 2015a; 2020; 2021); while populations on dry habitats are threatened primarily by the overgrowing of grasslands into forests and their conversion into intensive grassland and permanent plantations (Zakšek and Verovnik 2020; Zupan et al. 2020). *C. oedippus* is a protected species in Slovenia (Uredba o zavarovanih prostoživečih živalskih vrstah, Uradni list RS št. 46, 2004) and is classified as endangered in the Slovenian Red List of endangered butterflies (Pravilnik o uvrstitvi ogroženih rastlinskih in živalskih vrst v Rdeči seznam, Uradni List RS 2002; 2010). *C. oedippus* is also listed as a Natura 2000 species and must be protected under the Habitats Directive (Council Directive 92/43/EEC, 1992) in and outside special areas of conservation.

The impact of natural hazards on *C. oedippus* in Slovenia has not yet been studied, but its potential impact was detected in 2010 in the area southeast of Ljubljana Marsh in the Duplica Stream Valley near Grosuplje. A heavy hailstorm in 2010, at the time of emergence of the adult butterflies, is the most likely reason for the local extinction of the species. The size of the population in this area was estimated at 400 individuals in 2009 (Verovnik et al. 2009), in 2011 it decreased to about 20 individuals (Verovnik et al. 2011), and in 2014 the species was no longer confirmed in this area (Čelik 2015a).


Figure 1: Male (left) and female (right) of *Coenonympha oedippus*.

The significant effects of natural hazards on changes in species composition and population dynamics are confirmed by studies of other butterfly species (Swengel 2001; Cleary and Genner 2004; Ricouart et al. 2013). In the last twenty years, the lack of precipitation has led to frequent and intense droughts, which increases the risk of fires in the natural environment (Sušnik and Gregorič 2017). Droughts dry out vegetation, reducing the amount of nectar available to butterflies and the nutritional value of the plant parts on which the caterpillars feed. Fires reduce the abundance of invertebrate species in affected areas and result in lower butterfly populations (Fleishman 2000; Huntzinger 2003; Cleary and Genner 2004; Pryke and Samways 2012; Ricouart et al. 2013; Moranz, Fuhlendorf and Engle 2014; Henderson, Meunier and Holoubek 2018). After fire, the species composition changes, and the empty space may first be colonized by non-native species. The recovery time of areas affected by natural hazards is difficult to predict (Jackson and Sax 2009).

In this study, we investigated the occurrence of natural hazards in *C. oedippus* habitats in Slovenia. We compared differences in fire and flood risk between wet and dry habitats and between different geographic regions.

2 Study area and methods

There are differences between geographical areas in terms of knowledge and quality of data on the occupancy of habitat patches of *C. oedippus* in Slovenia: wet habitats are much better studied than dry ones. We included 56 habitat patches from the entire distribution range of *C. oedippus* in Slovenia in the period 2002–2016 in the analysis (Table 1, Figure 2). All occurrence data published before 2012 were verified in the field in 2013–2016 and supplemented with data from fieldwork. Later published data on the distribution of the species (after 2016; Zakšek and Verovnik 2020) were not included (see also Verovnik et al. 2009; Verovnik et al. 2015).

C. oedippus habitat patches were defined as individual meadows, where the species was detected during 2002–2016. The size of the patch was defined on site according to: i) the boundaries surrounding these meadows, and ii) the adequate representation of plant species (host plants for caterpillars). We then drew polygons of habitat patches with ArcGIS 10.4.1. and calculated the areas (in hectares) of each patch (Table 1).

Depending on the type of habitat, we divided habitat patches into wet (seven habitat patches; Ljubljana Marsh with surroundings of Grosuplje) and dry (49 habitat patches; Slovenian Istria, Karst, Gorica Hills, Banjšice, and Trnovo Forest plateau) (Čelik 2003; Čelik and Verovnik 2010). Based on the geographically defined management units for the conservation of *C. oedippus* populations in Slovenia (Zupan et al. 2021), we divided the habitat patches into four groups: Slovenian Istria (25 habitat patches), Karst (13 habitat patches), Gorica Hills (with Trnovo Forest plateau and Banjšice; 11 habitat patches), and the Ljubljana Marsh with the surroundings of Grosuplje (seven habitat patches; Figure 2).

We have reviewed all available data on exceptional natural events in Slovenia that fall under the definition of natural hazards and at the same time have at least an indirect connection with the habitat patches of *C. oedippus*. In karst areas, these events are mainly soil subsidence and sinkholes, slope movements, and flash flooding (inability to drain rainwater) (Parise 2015). Flysch areas are characterized by landslides, with soil erosion occurring more frequently in areas of greater slope where agricultural use and forest clearing are intensive (Zorn and Komac 2009; Ravbar 2010). Floods are the most apparent natural hazard in Ljubljana Marsh (Gašperič 2004). For the entire study area, we also considered the risk of forest fires as a natural hazard, which is greater when there is seasonal water scarcity that causes vegetation to dry out (Turlure et al. 2013).

After reviewing data on natural hazards from the Slovenian Environment Agency (*Agencija Republike Slovenije za okolje: Geoportal* and *Atlas okolja*) and Agricultural Institute of Slovenia (*Kmetijski inštitut Slovenije: eTLA portal*), we included only floods and forest fires in the analysis of threats to species' habitats; for other natural hazards available data were insufficient for a detailed analysis.

2.1 Floods in the distribution area of *Coenonympha oedippus*

Despite the construction of numerous drainage ditches, flooding still occurs regularly in Ljubljana Marsh (Gašperič 2004; Komac, Natek and Zorn 2008). The extent of regular flooding has decreased most in the south-eastern part of this area (Kolbezen 1985). According to the Slovenian Environment Agency data flooding is frequent in autumn and winter, rare in spring, and extremely rare in summer, depending on the distribution and amount of precipitation. Frequent floods affect the central (lowest) parts of Ljubljana Marsh (about 15% of the area). During extremely large floods (karstic or torrential in origin), the floodplain extends from the Ljubljanica River along its tributaries, so that a good half of the area is under water (Gašperič 2004; Komac, Natek and Zorn 2008). The reason for the occurrence of floods is the extremely long retention of water on the surface due to impermeable and poorly permeable layers. The subsidence of the Ljubljana Marsh leads to the formation of depressions where flood waters are retained for a long time (Gams 1990; Zajc 2010). The Duplica Stream drainage basin is a hydrographic system separate from the Ljubljana Marsh.

In Slovenian Istria, the only surface water in close proximity to *C. oedippus* habitats that is occasionally flooded is the Dragonja River with its tributaries. There are no surface waters in the Karst. In the distribution areas of the species in the Gorica Hills, there are watercourses belonging to the catchment areas of the Pevmica Stream, Reka Stream, Idrija Stream, and Soča River.

2.2 Fires in the distribution area of *Coenonympha oedippus*

The Primorska region is the area with the highest fire risk in Slovenia, especially in the hot and dry periods of the summer months (Veble and Brečko Grubar 2016; see also Slovenia Forest Service; *Zavod za gozdove Slovenije*). Fire risk can be high already in early spring, when the intensity of solar radiation increases and there is an excess of dry, dead vegetation, while at the same time human activities in nature are very high (Pečenko 2005). Fires can be caused by traditional agricultural practices (prescribed burning, e.g., in Ljubljana Marsh), carelessness (accidental fire), or simply by the drying of vegetation during the summer months (self-combustion). The bora wind in Primorska further dries out vegetation and dead organic material and, in the event of a fire, accelerates its spread by providing the oxygen necessary for combustion and carrying sparks to new areas (Pečenko 2005). Pine forests and deciduous forests in warm and dry habitats are most susceptible to fire (Prebevšek 1998).

Occasional small fires occur frequently in the Karst (Veble and Brečko Grubar 2016). One of the largest fires occurred in the summer of 1994 in the area between Renče, Opatje selo, and Lokvica, burning 575 ha of pine forest (Zoratti 1995). The second major fire occurred in August 2019, when 85 ha of land burned in Cerje (near Lokvica and Opatje selo) (Komac 2022). The last, largest fire in July 2022 in the Karst burned 3,707 ha of land (Košiček 2022).

Table 1: List of habitat patches with at least one confirmed occurrence of *Coenonympha oedippus* in 2002–2016, and dates of flood events in a period since 1980. Patches located outside Natura 2000 sites are marked with a dash (–).

	Geographical area / Habitat patch	Natura 2000 site code and name	Area (ha)	Flood event
	Ljubljana Marsh (*Ljubljansko barje*)		16,03	
1	Škofljica - Mostišče	3000271–Ljubljansko barje	2,69	18.–20. 9. 2010
2	Škofljica - Podvin	3000271–Ljubljansko barje	1,78	18.–20. 9. 2010
3	Grosuplje - Skobčev mlin 1, Duplica	3000141–Duplica	5,01	18.–20. 9. 2010
4	Grosuplje - Skobčev mlin 2, Duplica	3000141–Duplica	0,38	18.–20. 9. 2010
5	Grosuplje - Skobčev mlin 3, Duplica	3000141–Duplica	2,58	18.–20. 9. 2010
6	Želimlje	3000271–Ljubljansko barje	2,68	18.–20. 9. 2010
7	Pijava Gorica - Podblato	3000271–Ljubljansko barje	0,91	
	Slovenian Istria (*slovenska Istra*)		45,90	
8	Izola - Cetore	–	2,47	
9	Baredi - Repka farm	–	0,63	
10	Parecag - Šorgo farm	–	0,13	
11	Dovin 1	3000212–Slovenska Istra	0,40	
12	Dovin 2	3000212–Slovenska Istra	0,20	
13	Dovin 3	3000212–Slovenska Istra	0,75	18.–20. 9. 2010
14	Abrami	3000212–Slovenska Istra	1,25	
15	Draga	3000212–Slovenska Istra	1,21	
16	Dragonja - Supot	3000212–Slovenska Istra	0,11	18.–20. 9. 2010
17	Čupinje	3000212–Slovenska Istra	0,82	
18	Gradišče - Krkavče	3000212–Slovenska Istra	3,38	
19	Koštabona	3000212–Slovenska Istra	0,11	
20	Jamnjek - Krkavče	3000212–Slovenska Istra	6,14	18.–20. 9. 2010
21	Nova vas nad Dragonjo	3000212–Slovenska Istra	0,51	
22	Padna	3000212–Slovenska Istra	0,54	
23	Petrinjevica	3000212–Slovenska Istra	0,97	18.–20. 9. 2010
24	Planjave	3000212–Slovenska Istra	2,10	
25	Plešivica	3000212–Slovenska Istra	0,17	
26	Solne - Krkavče	3000212–Slovenska Istra	2,15	
27	Sveti Maver	3000212–Slovenska Istra	1,31	
28	Sveti Peter	3000212–Slovenska Istra	1,12	
29	Smokvica - Velika vala	3000276–Kras	0,79	
30	Dolgo Brdo	–	1,14	
31	Upper course of Rakovec Stream	3000276–Kras	0,60	
32	Rovance	–	16,91	
	Karst (*Kras*)		6,51	
33	Opatje selo 1	3000276–Kras	0,14	
34	Opatje selo 2	3000276–Kras	0,07	
35	Opatje selo 3	3000276–Kras	0,20	
36	Opatje selo 4	3000276–Kras	1,21	
37	Opatje selo 5	3000276–Kras	0,59	
38	Opatje selo 6	3000276–Kras	0,24	
39	Opatje selo 7	3000276–Kras	0,17	

40	Opatje selo 8	3000276–Kras	0,60	
41	Opatje selo 9	3000276–Kras	0,80	
42	Brestovica pri Komnu	3000276–Kras	0,18	
43	Vojščica	3000276–Kras	0,66	
44	Gorjansko	3000276–Kras	1,11	
45	Tublje pri Komnu	3000276–Kras	0,55	
	Gorica Hills (*Goriška brda*)		13,93	
46	Golo Brdo - Idrija Stream Valley	–	2,89	
47	Plave - Strmec	3000379–Vrhoveljska planina	0,42	
48	Senik - Kajenca	–	0,30	
49	Vrhovlje pri Kožbani	–	0,32	
50	Gonjače - Vrhovec	3000290–Goriška brda	4,01	
51	Podsabotin	3000290–Goriška brda	5,83	
52	Solkan	–	0,16	25. 12. 2009, 5. 11. 2012*
	Banjšice and Trnovo Forest plateau (*Banjšice and Trnovski gozd*)		3,51	
53	Banjšice	3000034–Banjšice	0,15	
54	Ravnica 1	–	1,09	
55	Ravnica 2	–	1,04	
56	Ravnica 3	–	1,22	

*The habitat patch (Euclidean distance of 60 m from the Soča riverbed) was not flooded due to the difference in elevation between the height of the flood and the location of the habitat patch.

2.3 Data selection on the occurrence of fires and floods in *Coenonympha oedippus* habitat patches

Fire risk in *C. oedippus* habitat patches was determined based on the 2011–2020 Forest management plans for forest management areas (*Gozdnogospodarski načrti gozdnogospodarskih območij*), where the Slovenia Forest Service's Forest fire risk map classifies fires into four categories (Table 2). We compared the geographic data (shp layer) of forest fire threat with the layer of *C. oedippus* habitat patches in the ArcGIS 10.4.1 program. The threat to an individual habitat patch from the confirmed occurrence of a species (regardless of threat level) was defined as direct or indirect. A habitat patch is directly threatened if it is itself an open, light fire-prone forest or directly adjacent to a fire-prone forest. A habitat patch is indirectly threatened if the edge of the nearest fire-prone forest is no more than 1000 m (Euclidean distance) from the edge of the habitat patch.

For the statistical analysis of the distance to the nearest fire-prone forest, we used two classes: 0–200 m and 201–1000 m. We chose the upper limit of the first class at 200 m because the vast majority of *C. oedippus* flights are less than 200 m (> 85%, Vereš 2022). We chose the upper limit of the second class at 1000 m because this corresponds to the longest recorded flight length of this species in the Karst (Čelik and Verovnik 2010).

Flood risk data were obtained from documents describing the frequency and extent of flooding. The data on the frequency of flood occurrence, which were obtained from the eTLA portal (provided by Agricultural Institute of Slovenia), were divided into three categories: non-flooded areas, areas with very rare floods, and areas with frequent floods. Data on the flooded area at return periods of ten, one hundred and five hundred years were obtained from the databases *Geoportal* and *Atlas okolja* (provided by Slovenian Environment Agency). We then compared the geographic layer of the extent of floods with different return periods with the layer of habitat patches of *C. oedippus* in the program ArcGIS 10.4.1 and with the location of each habitat patch in the display of flood frequency in the *Atlas okolja*.

Table 2: Analyzed parameters of natural hazards in the distribution area of *Coenonympha oedippus* in Slovenia.

Parameters of natural hazards	Parameter type	Parameter categories	Source
Fires			
Forest fire risk	Ordinal	Level 1 – very high risk, Level 2 – high risk, Level 3 – medium risk, Level 4 – low risk	Slovenia Forest Service
Distance to the nearest fire-prone forest	Ordinal	0–200 m, 201–1000 m	Slovenian Environment Agency (*Atlas okolja*)
Floods			
Frequency of flood occurrence	Ordinal	non-flooded areas, areas with very rare floods, areas with frequent floods	Agricultural Institute of Slovenia (*eTLA*)
Flooded area at different return intervals*	Ordinal	return period of 10 years, return period of 100 years, return period of 500 years	Slovenian Environment Agency (*Geoportal* and *Atlas okolja*)

* We did not compare the parameter »Flooded area at different return intervals« between habitat types/management units, because for this parameter we have data only for Ljubljana Marsh.

We also determined the presence of individual flood events in the species' habitat patches. In this analysis, we included 15 flood events that have occurred since 1980: 6.–15. 11. 2014, 5.–6. 11. 2012, 27.–28. 10. 2012, 18.–20. 9. 2010, 25. 12. 2009, 23. 12. 2009, 3.–4. 8. 2009, 30. 3. 2009, 18.–19. 9. 2007, 5.–8. 10. 1998, 10. 12. 1990, 1.–2. 11. 1990, 5. 8. 1987, 15. 6. 1987, 9. 10. 1980. For data on individual flood events obtained from the *Atlas okolja*, we manually entered the coordinates of each habitat patch into the search engine and verified whether flooding occurred.

If we detected the presence of several different flooding categories in a habitat patch (e.g., very rare and frequent floods; Table 2), we included all categories of the individual habitat patch in the statistical analysis.

2.4. Data analyses

Frequencies of individual fire and flood risk parameters (Table 2) were analysed for each management unit (Slovenian Istria, Karst, Gorica Hills and Ljubljana Marsh) and for both habitat types (wet, dry). To determine whether management units/habitat types differ in terms of flood and fire risk (fire risk of the forests in Slovenia, distance to nearest fire-prone forest, frequency of flood occurrence; Table 2), we used the χ^2-test for association with the likelihood ratio statistic (LR). Standardized residuals (SR) were used to determine which class of each fire and flood parameter contributed most to the overall difference between management units or between habitat types. SR values > |2| were considered statistically significant ($p < 0.05$). We did not compare the parameter »Flooded area at different return intervals« with the χ^2-test for association, neither between habitat types nor between management units, because for this parameter data are available only for Ljubljana Marsh.

Using the χ^2-test for homogeneity of frequencies, we determined the uniformity of occurrence for three parameters of natural hazards (forest fire risk, distance to the nearest fire-prone forest, frequency of flood occurrence; Table 2) in habitat patches for each management unit and habitat type. For the parameter »Distance to the nearest fire-prone forest«, where we compared the homogeneity of frequencies between two classes, we used χ^2-test with Yates correction.

SPSS ver. 27 was used for the χ^2-test of association and homogeneity.

Most of the heterogeneity in relief was encompassed within the selected habitat patches in each management unit (Figure 2). We also considered the following parameters when interpreting the results: elevation difference between flooded and non-flooded habitats, distance from flooded habitats/forest fires, and different hydrologic systems.

3 Results

More than half (55.6%) of the surveyed habitat patches are smaller than 1 ha and 75.0% of them are smaller than 1.5 ha. The total area of the studied habitat patches in Slovenian Istria (25 patches) was 45.90 ha, in the Karst (13 patches) 6.51 ha, in Gorica Hills (11 patches) 17.44 ha and in Ljubljana Marsh (seven patches) 16.03 ha. The management units differ in terms of forest fire risk, with Gorica Hills and Ljubljana Marsh contributing the most to the overall difference (Table 3a). Gorica Hills has significantly more habitat patches with high fire risk (level 2: 72.7%) than the other units, while Ljubljana Marsh has more habitat patches with medium fire risk (level 3: 57.1%) and significantly fewer habitat patches with very high fire risk (level 1: 0%) compared to the other three management units. In the most fire-prone parts of Primorska (Karst and Slovenian Istria) more than 90% of habitat patches fall within category of very high fire risk (level 1), which corresponds to 6.38 ha of the species' habitat in the Karst and 41.20 ha in Slovenian Istria (Table 3a, Figure 2).

The two habitat types differ in their fire risk, as the number of habitat patches with very high fire risk (level 1) is significantly lower and with medium fire risk (level 3) is significantly higher in wet habitats (Table 3b). In wet habitats, 57.1% of habitat patches (8.06 ha) have medium fire risk (level 3) and 42.9% of patches (7.97 ha) have high fire risk (level 2). In dry habitats, more than three-quarters (77.6%) of habitat patches have a very high fire risk (level 1).

Habitat patches in management units also differ according to their distance from forest fires (Table 3a). Compared to the other units, there are significantly more habitat patches (20.0%) in Slovenian Istria at a distance of more than 200 m from fire-prone forests. The remaining 80.0% of habitat patches (or 38.01 ha) are located in close proximity (distance > 200 m) to fire-prone forests. In the other three management units, all habitat patches are less than 200 m from fire-prone forests. There is no statistically significant difference between the two habitat types in terms of distance of habitat patches from forest fires (Table 3b).

The frequency of flooding in the habitat patches differs between the four management units (Table 3a) and between the two habitat types (Table 3b). Slovenian Istria and Ljubljana Marsh contribute the most to the differences between management units. Compared to the other management units, the former has more areas with very rare floods (52.0% of habitat patches, corresponding to an area of 18.39 ha), while the latter has more habitat patches at risk of frequent floods (18.2%, corresponding to an area of 4.47 ha). The two habitat types differ in the frequency of flooding, as wet habitat patches are typically more exposed to frequent flooding than dry habitat patches.

The distribution of fire risk in habitat patches is uniform only in Ljubljana Marsh; in Gorica Hills, fire risk level 2 (72.7%) predominates, while in Slovenian Istria and Karst most habitat patches (> 90%) are exposed to the fire risk level 1 (Table 4). Accordingly, the highest fire risk (level 1) also prevails in the dry habitat type. In all management units and in both habitat types, habitat patches located less than 200 meters from fire-prone forests prevail. The frequency of flood occurrence in habitat patches is uniform only in Ljubljana Marsh (all three categories of flood occurrence are present); in Slovenian Istria habitat patches with very rare flood occurrences dominate (52.0%). In the Karst, all patches are located in non-flooded areas, as are the majority (90.9%) of habitat patches in Gorica Hills. Overall, non-flooded habitat patches predominate in the dry habitat type, while habitat patches subject to frequent flooding were not recorded in this habitat type.

A review of the individual flood events shows that the September 18-20, 2010, flood inundated 10 habitat areas, four in Slovenian Istria (with an area of 7.97 ha) and six in Ljubljana Marsh (with an area of 15.12 ha; Table 1). In Gorica Hills, only one habitat patch (Table 1) was located in close proximity to the flood events of December 25, 2009, and November 5, 2012, but even this was not flooded due to the difference in elevation between the flood level and the habitat location.

Analyzing the data describing the extent of floods with return periods of 10, 100 and 500 years in Slovenia, we found that such floods threaten only the habitats of *C. oedippus* in the Ljubljana Marsh. Floods with return periods of 100 and 500 years reach all habitat patches there, floods with a return period of 10 years threaten only habitat patches in Želimlje Valley (2.68 ha) and near Grosuplje (Skobčev mlin 3: 2.58 ha), both of which were inhabited by the species in the past.

Figure 2: Slovenia Forest Service Forest fire risk map and illustration of studied habitat patches of *Coenonympha oedippus* in Slovenia (Note: Due to close geographic proximity of habitat patches, the number of symbols in the figure may differ from the number of habitat patches in Table 1). Habitat patches are classified by management units. D – dry habitats, W – wet habitats. ➤ p. 66

Table 3. Categories of natural hazard parameters that contribute most to differences between management units (a) and habitat types (b) according to χ2-test for association with the likelihood ratio statistic (LR). LR with standardized residuals (SR > |2|, in bold). N - the number of *Coenonympha oedippus* habitat patches, df - degrees of freedom; p - statistical significance.

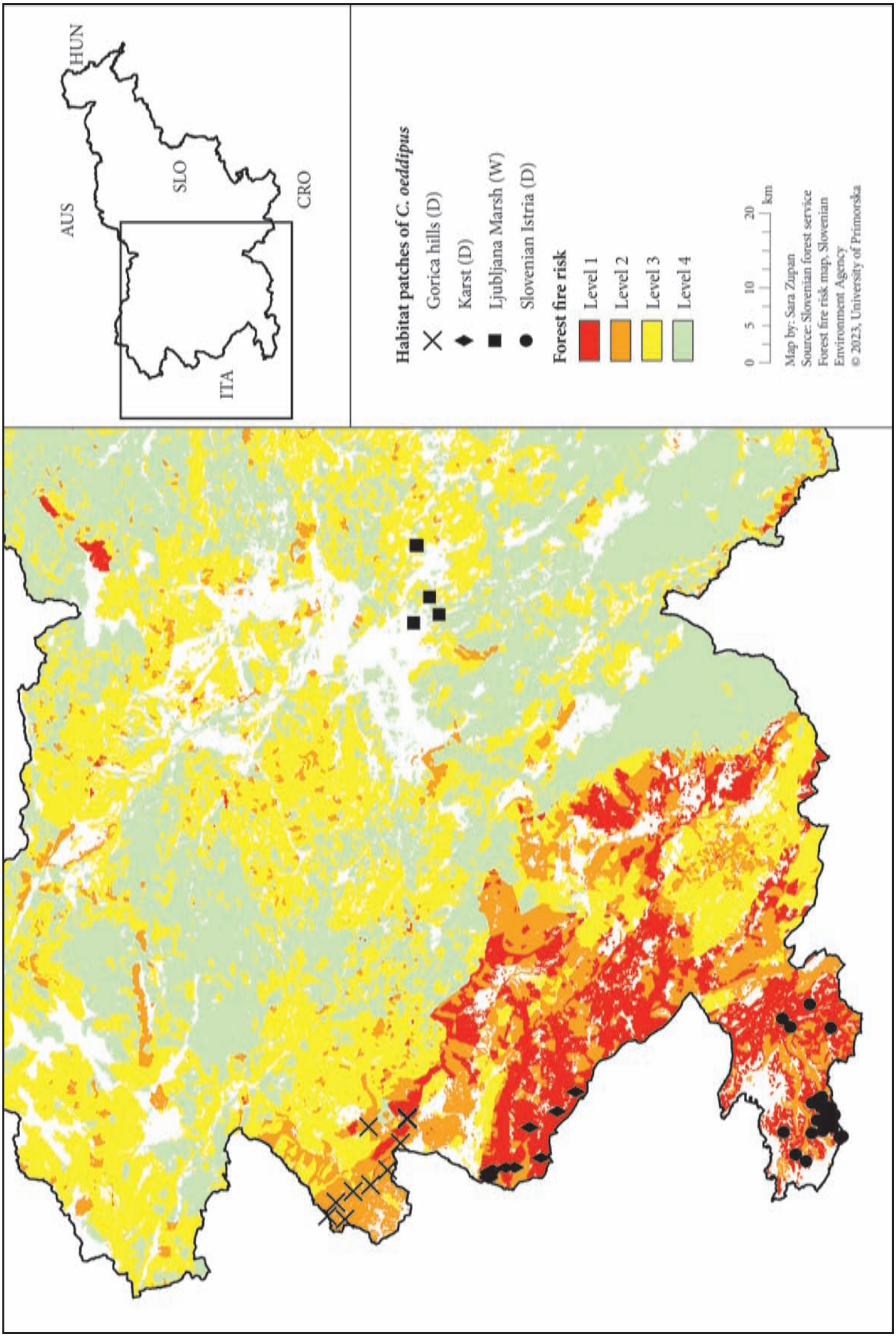
(a) Management units	Slovenian Istria			Karst			Gorica Hills			Ljubljana Marsh		
Parameters of natural hazards1	N	%	SR	N	%	SR	N	%	SR	N	%	SR
Forest fire risk[3] (LR = 45,96, df = 6, p < 0,001)												
Level 1	23	92,0	1,5	12	92,3	1,1	3	27,3	−1,6	0	0	−2,2
Level 2	2	8,0	−1,7	1	7,7	−1,2	8	72,7	3,2	3	42,9	0,9
Level 3	0	0	−1,3	0	0	−1	0	0	−0,9	4	57,1	4,9
Distance to the nearest fire–prone forest (LR = 8,68, df = 3, p < 0,05)												
0–200 m	20	80,0	−0,6	13	100	0,3	11	100	0,3	7	100	0,2
201–1000 m	5	20,0	1,9	0	0	−1,1	0	0	−1	0	0	−0,8
Frequency of flood occurrence (LR = 24,50, df = 6, p < 0,001)												
areas with frequent floods	0	0	−0,9	0	0	−0,7	0	0	−0,6	2	18,2	2,7
areas with very rare floods	13	52,0	2,2	0	0	−1,9	1	9,1	−1,2	3	27,3	−0,1
non–flooded areas	12	48,0	−1,2	13	100	1,4	10	90,9	0,9	6	54,5	−0,6
(b) Habitat type					Dry habitats[2]						Wet habitats	
Parameters of natural hazards[1]				N	%	SR				N	%	SR
Forest fire risk[3] (LR = 27,65, df = 2, p < 0,001)												
Level 1				38	77,6	0,8				0	0	−2,2
Level 2				11	22,4	−0,4				3	42,9	0,9
Level 3				0	0	−1,9				4	57,1	4,9
Distance to the nearest fire–prone forest (LR = 1,40, df = 1, NS)												
0–200 m				44	89,8	−0,1				7	100	0,2
201–1000 m				5	10,2	0,3				0	0	−0,8
Frequency of flood occurrence (LR = 7,19, df = 2, p < 0,05)												
areas with frequent floods				0	0	−1,3				2	18,2	2,7
areas with very rare floods				14	28,6	0				3	27,3	−0,1
non–flooded areas				35	71,4	0,3				6	54,5	−0,6

[1] The parameter »Flooded area at different return intervals« is commented in the text.
[2] The dry habitat type includes 3 management units: Slovenian Istria, Karst and Gorica Hills.
[3] The fourth level of fire risk was not represented in the studied habitat patches and is therefore not shown.
NS – not statistically significant.

Table 4: Representation of habitat patches in each management unit and habitat type for the three considered parameters of natural hazards in the distribution area of *Coenonympha oedippus* in Slovenia, calculated with the χ2-test for homogeneity of frequencies. Predominant = the predominant category of the natural hazard parameter and the percentage of habitat patches in this category. p – statistical significance (*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; NS – not statistically significant).

Management unit / Parameters of natural hazards	Slovenian Istria		Karst		Gorica Hills		Ljubljana Marsh/ Wet habitat		Dry habitat[2]	
	p	Predominant	*p*	Predominant	*p*	Predominant	*p*	Predominant	*p*	Predominant
Forest fire risk	***	Level 1 (92,0%)	***	Level 1 (92,3%)	*	Level 2 (72,7%)	NS	Level 3 (57,1%)	***	Level 1 (77,6%)
Distance to the nearest fire-prone forest	**	0–200 m (80,0%)	***	0–200 m (100%)	**	0–200 m (100%)	*	0–200 m (100%)	***	0–200 m (89,8%)
Frequency of flood occurrence	**	very rare floods (52,0%)	***	non-flooded areas (100%)	***	non-flooded areas (90,9%)	NS	non-flooded areas (54,5%)	***	non-flooded areas (71,4%)

[1] Calculated with Yates correction.
[2] The dry habitat type includes three management units: Slovenian Istria, Karst and Gorica Hills.


HUN
AUS
SLO
CRO
ITA
Habitat patches of *C. oeddipus*
Gorica hills (D)
Karst (D)
Ljubljana Marsh (W)
Slovenian Istria (D)
Forest fire risk
Level 1
Level 2
Level 3
Level 4
0 5 10 20 km
Map by: Sara Zupan
Source: Slovenian forest service
Forest fire risk map, Slovenian
Environment Agency
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4 Discussion

4. 1 The fire risk to the habitat of *Coenonympha oedippus*

According to the Slovenia Forest Service forests cover 58.2% of the land area in Slovenia. The risk of forest fires is present in four different levels nationwide. Fire risk in *C. oedippus* habitat patches falls in one of the three highest levels of fire risk. The distance of habitat patches from fire-prone forests is less than 200 m in all management units studied; except for five habitat patches in Slovenian Istria with an area of 7.89 ha. According to the guidelines of the Firefighters Association of Slovenia (*Gasilska zveza Slovenije*; see https://gasilec.net/) the speed of fire spread on levelled terrain at a wind speed of 20 km/h is 600 m/h and increases with increasing wind speed. This means that after igniting dry grass at the forest edge, fire can spread extremely quickly to dry grassland, which represents the majority of habitat patches suitable for *C. oedippus* in Slovenia. Fire risk to *C. oedippus* habitat is very high in the management units of Slovenian Istria and Karst, high in Gorica Hills, and medium in Ljubljana Marsh. However, in the latter management unit, prescribed burning of grassland and/or other plant biomass in early spring or autumn increases the fire risk.

In Slovenia populations on wet habitats are genetically unique (Zupan et al. 2021); only two populations currently live in Ljubljana Marsh. One of them was established by reintroducing individuals reared in nurseries in 2019–2022 (Čelik 2020; 2021; 2022). Both populations are vulnerable to extreme natural events. Prescribed burning of grasslands does not directly threaten them because the conservation measures and habitat management of both populations are adapted to the ecological needs of the species and do not allow activities that are harmful to the species. Prescribed fires of plant biomass threaten them indirectly, if the fire spreads to nearby areas and then encroaches on the populations' habitat. The same is true for areas that are being restored with the aim of creating a habitat suitable for the species, which could potentially be inhabited by individuals of both existing populations in the future (Čelik, Šilc and Vreš 2018).

Researchers from Poland, however, advocate burning wet habitats of *C. oedippus* (Sielezniew et al. 2010). There, sporadic fires in early spring, before caterpillars begin feeding after winter dormancy, limit succession in the habitat and maintain grasslands. However, the effects of fires on the abundance of *C. oedippus* were not examined in the above study.

In western Slovenia, forest fires pose a greater direct threat to the species' habitat than in Ljubljana Marsh. In the northwestern part of the Karst, the population of *C. oedippus* is one of the largest on dry habitats (Čelik et al. 2005), the size of which has been monitored since 2009 as part of the national monitoring of selected Natura 2000 species (Verovnik et al. 2009). The fire on Cerje in August 2019 destroyed 46.1% (10.88 ha) of the habitat of this population included in the national monitoring area as of 2019 (Vereš 2022). At the time of the fire, the species was in the stage of young caterpillars which were unable to move away from the burning meadows. The result of the fire was a drastic decline in the population by 56% in 2020 compared to the previous year when the pre-fire size was estimated (Vereš 2022). Only consecutive monitoring years of the local population, which is currently being conducted by researchers from the University of Primorska, will provide a realistic assessment of the consequences of the fire. The process of natural grassland recovery in the Karst after the 2019 fire was interrupted by another fire in July 2022, when 3,707 ha of land burned (Košiček 2022). This fire covered almost the entire monitoring area of this population (see Map 1 in Košiček 2022). In the north western part of the Karst, *C. oedippus* was also found scattered outside the area burned in the 2022 fire (Verovnik et al. 2009; 2015; Zakšek et al. 2019), increasing the likelihood that one of the once-largest populations in the Karst will be restored by spontaneous immigration from areas not affected by the fire into the burned area as the land naturally regenerates into habitat suitable for *C. oedippus*. Preliminary results of vegetation surveys on Cerje between the last two fires (2019 and 2022), conducted by researchers from Research Centre of the Slovenian Academy of Sciences and Arts, Jovan Hadži Institute of Biology, indicate that autochthonous herbaceous vegetation on some grasslands recovered to suitable habitat in just three years. Fires can have extremely devastating effects on *C. oedippus* throughout the year, as non-mobile (eggs: June–July; pupae: May–June) or low-mobile (caterpillars: June–May) developmental stages are always present in the population (Čelik 2015a; 2015b). If the fire is not too large and does not spread too rapidly during the period of adult emergence (June–July), butterflies that are not trapped in the fire zone may retreat to nearby unburnt areas. If the fire occurs during the last part of the butterfly flight season, fertilized females that predominate in the population, may move away from the fire area to establish a new generation. In organisms exposed to the threat of fire, there is increased selection pressure on the evolution of strategies to survive such events, but fire survival mechanisms other than escape/retreat have not been extensively studied in animals (Nowicki, Marczyk and Kajzer-Bonk 2015). Also, during large fires, small areas remain unaffected and can serve as refugia for butterflies (Swengel and Swengel 2007). Suitable refugia for the myrmecophilous butterfly species *Phengaris teleius* and *P. nausithous* (Lycaenidae) also include ant nests, where caterpillars and pupae may survive in the event of fire during this developmental phase (Nowicki, Marczyk and Kajzer-Bonk 2015). The authors note that the results should not be generalized to all habitats and species, as this case is a distinctive feature of myrmecophilous butterfly species.

Prescribed burning, sometimes used to limit grasslands succession (Swengel 1996; Robel et al. 1998; Lyet et al. 2009), has been suggested by some authors as a positive management measure (Middleton 2013). However, fire inevitably reduces landscape mosaicity, has variable and often unknown effects in terms of the timing of restoration of suitable habitat for different species (Swengel and Swengel 2007), and could lead to the establishment of non-native species that are often more successful in pioneer habitats than native species (Allen, Steers and Dickens 2011).

4.2 The flood risk to the habitat of *Coenonympha oedippus*

The habitat patches at highest risk of flooding are located in Ljubljana Marsh, followed by the habitat patches in Slovenian Istria in the immediate vicinity of the Dragonja River. The first area is characterized by very rare to frequent flooding, the second only by very rare flooding. The studied habitat patches in Gorica Hills and in the Karst are not at risk of flooding.

Short-term flooding does not usually affect the survival of caterpillars of Nymphalidae butterflies: *Neptis rivularis* (Konvička, Nedved and Fric 2002) and *Coenonympha tullia* (Joy and Pullin 1997; 1999) can survive flooding for up to three days without consequences, but as the duration of flooding increases, the survival rate of *N. rivularis* caterpillars decreases. Caterpillars of *C. tullia* can survive flooding for up to 52 days, but a flood of seven days results in mortality of up to 50% in the further developmental stages of the caterpillars (Joy and Pullin 1997; 1999). Flooding of ant nests hosting caterpillars of *P. teleius* and *P. nausithous* for three weeks had no negative effect on their population size the following year (Kajzer-Bonk et al. 2013). Prolonged flooding (over 28 days) resulted in the death of 65% of *Lycaena dispar* (Lycaenidae) caterpillars; and increased mortality among survivors at the end of overwintering (Nicholls and Pullin 2003). Flooding in the area of *C. oedippus* habitat patches included in this study occurs most frequently in spring and autumn, when the species is in the stage of less mobile young caterpillars. Considering that survival is highly dependent on the duration of flooding, we hypothesize that at least prolonged flooding may have a detrimental effect on the survival of *C. oedippus* caterpillars. Shorter floods do not adversely affect the related butterfly *C. tullia* (Joy and Pullin 1997; 1999; Konvička, Nedved and Fric 2002). Based on the similarity of the habitats of the two species, we can conclude that short floods do not have a negative impact on the studied species (e.g., floods between September 18 and 20, 2010, in Slovenian Istria and Ljubljana Marsh). High soil humidity following an exceptional amount of precipitation can also have a positive effect (Kajzer-Bonk et al. 2013) by reducing the intensity of agricultural use. The persistent soil humidity in Ljubljana Marsh in summer and autumn 2014 made it impossible for farmers to perform regular activities; the wet meadows with one of the last *C. oedippus* populations in this area were not mowed, which resulted in a 2.5-fold increase of the population the following year (Čelik 2015a).

The invertebrates best adapted to flooding are Annelida and some insect larvae (Plum and Filser 2005). For species that do not have specific physiological adaptations retreat, migration from flooded areas, and recolonization are important survival strategies after disturbance ceases (Plum and Filser 2005). Determinants that can significantly affect survival of populations during floods are heterogeneity of (micro)relief, the flood extent, and available suitable habitat outside of flooded area. Diverse micro-relief is important for hibernating caterpillars, which become active at high water levels and retreat to non-flooded plant parts (Joy and Pullin 1997). If topography is heterogeneous, elevated habitat parts may not be inundated and may provide refuge from high water for a part of the population (Nicholls and Pullin 2003); these areas serve as population sources for previously impacted areas (Konvička, Nedved and Fric 2002). A population exposed to flooding can survive if suitable habitat is available within its flight range. The flight ability of *C. oedippus* butterflies in Ljubljana Marsh is low, up to a maximum of 340 m (Čelik and Verovnik 2010), but they can travel longer distances (up to 1000 m) with the help of the wind (Verovnik et al. 2009; Čelik and Verovnik 2010; Čelik, Vreš and Seliškar 2010). During prolonged flooding, the viability of populations could be further compromised by the lack of suitable habitat outside the flooded area to which the butterflies can retreat. Also, in the Dragonja River Valley (Slovenian Istria) distances between flood-prone habitat patches and other areas are generally greater than the flight ability of *C. oedippus*.

5 Conclusions

This study is the first to address fire and flood risk in *Coenonympha oedippus* habitats. The use of publicly available spatial data combined with data on the exact geographic location of habitat patches contributes to knowledge based on which we can plan better conservation measures. However informative, this approach cannot fully replace field work, which, despite its time-consuming nature, provides invaluable information on the condition of a specific habitat patch. Because of its ecological duality (populations in wet and dry habitats) and fragmented distribution, *C. oedippus* is an extremely intriguing species from an evolutionary and ecological perspective. In Slovenian Istria, Karst and Gorica Hills, the probability of fires in the species' habitats is high, while in Ljubljana Marsh habitats are safer from naturally occurring fires, but more vulnerable to prescribed fires. Thus, the overall natural fire risk is lower in wet habitats than in dry habitats. The opposite is true for flood risk, to which populations in wet grasslands are more exposed. Species living in areas of natural disturbance have adapted to these using different strategies. Widespread species with stable populations recovers quickly after such events, but for endangered species such as *C. oedippus*, natural disturbance can lead to local extinction. With this review study, we have shown that *C. oedippus* habitats in Slovenia are threatened by both floods and fires.

ACKNOWLEDGMENT: We would like to thank the Slovene Science Foundation, which supported the research with a grant (in 2016), and all the students who participated in the fieldwork (Conservation Biology and Nature Conservation Studies Program, Faculty of Mathematics, Natural Sciences and Information Technology, University of Primorska).

6 References

Allen, E. B., Steers, R. J., Dickens, S. J. 2011: Impacts of fire and invasive species on desert soil ecology. Rangeland Ecology and Management 64-5. DOI: https://doi.org/10.2111/REM-D-09-00159.1

Cleary, D. F. R., Genner, M. J. 2004: Changes in rain forest butterfly diversity following major ENSO-induced fires in Borneo. Global Ecology and Biogeography 13-2. DOI: https://doi.org/10.1111/j.1466-882X.2004.00074.x

Crawford, L. A., Keyghobadi, N. 2018: Flight morphology corresponds to both surrounding landscape structure and local patch conditions in a highly specialized peatland butterfly (*Lycaena epixanthe*). Ecological Entomology 43-5. DOI: https://doi.org/10.1111/een.12639

Čelik, T. 2003: Population Structure, Migration and Conservation of *Coenonympha oedippus* Fabricius, 1787 (Lepidoptera: Satyridae) in a Fragmented Landscape. Ph.D. thesis, University of Ljubljana. Ljubljana.

Čelik, T. 2007: Dnevni metulji (Lep.: Papilionoidea in Hesperioidea) kot bioindikatorji za ekološko in naravovarstveno vrednotenje Planinskega polja. Varstvo narave 20.

Čelik, T. 2015a: Monitoring tarčnih vrst: barjanski okarček (*Coenonympha oedippus*). LJUBA Ljudje Za Barje - ohranjanje biotske pestrosti na Ljubljanskem barju. Končno poročilo, Biološki Inštitut Jovana Hadžija ZRC SAZU. Ljubljana.

Čelik, T. 2015b: Stanje vlagoljubnih populacij barjanskega okarčka (*Coenonympha oedippus*) v Sloveniji. Invited lecture/vabljeno predavanje na 10. strokovnem posvetu z naslovom Ogrožene vrste nature 2000 - stanje in izzivi. Ljubljana.

Čelik, T. 2020: Povečanje velikosti populacije in izboljšanje stanja ohranjenosti vrste barjanski okarček (*Coenonympha oedippus*) na Ljubljanskem barju s suplementacijo in reintrodukcijo osebkov. Prvo poročilo, Biološki Inštitut Jovana Hadžija ZRC SAZU. Ljubljana.

Čelik, T. 2021: Povečanje velikosti populacije in izboljšanje stanja ohranjenosti vrste barjanski okarček (*Coenonympha oedippus*) na Ljubljanskem barju s suplementacijo in reintrodukcijo osebkov. Drugo poročilo, Biološki Inštitut Jovana Hadžija ZRC SAZU. Ljubljana.

Čelik, T. 2022: Povečanje velikosti populacije in izboljšanje stanja ohranjenosti vrste barjanski okarček (*Coenonympha oedippus*) na Ljubljanskem barju s suplementacijo osebkov. Končno poročilo, Biološki Inštitut Jovana Hadžija ZRC SAZU. Ljubljana.

Čelik, T., Bräu, M., Bonelli, S., Cerrato, C., Vreš, B., Balletto, E., Stettmer C., Dolek, M. 2015: Winter-green host-plants, litter quantity and vegetation structure are key determinants of habitat quality for *Coenonympha oedippus* in Europe. Journal of Insect Conservation 19-2. DOI: https://doi.org/10.1007/s10841-014-9736-3

Čelik, T., Küzmič, F., Behrič, S., Šilc, U., Vreš, B. 2021: Raziskava stanja potencialnih izvornih populacij vrste barjanski okarček (*Coenonympha oedippus*) in stanja njihovega habitata s smernicami za ustrezno upravljanje. Končno poročilo, Biološki Inštitut Jovana Hadžija ZRC SAZU. Ljubljana.

Čelik, T., Rebeušek, F. 1996: Atlas ogroženih vrst dnevnih metuljev Slovenije. Ljubljana.

Čelik, T., Šilc, U., Vreš, B. 2018: Raziskava stanja potencialnih izvornih populacij vrste barjanski okarček (*Coenonympha oedippus*) in stanja njihovega habitata s smernicami za ustrezno upravljanje. Prvo poročilo, Biološki Inštitut Jovana Hadžija ZRC SAZU. Ljubljana.

Čelik, T., Verovnik, R. 2010: Distribution, habitat preferences and population ecology of the False Ringlet *Coenonympha oedippus* (Fabricius, 1787) (Lepidoptera: Nymphalidae) in Slovenia. Oedippus 26.

Čelik, T., Verovnik, R., Gomboc, S., Lasan, M. 2005: Natura 2000 v Sloveniji. Metulji (Lepidoptera). Ljubljana.

Čelik, T., Vreš, B., Seliškar, A. 2010: Determinants of within-patch microdistribution and movements of endangered butterfly *Coenonympha oedippus* (Fabricius, 1787) (Nymphalidae: Satyrinae). Hacquetia 8-2. DOI: https://doi.org/10.2478/v10028-009-0007-x

Devictor, V., Julliard, R. 2008: Distribution of specialist and generalist species along spatial gradients of habitat disturbance and fragmentation. Oikos 117-4. DOI: https://doi.org/10.1111/j.0030-1299.2008.16215.x

Fleishman, E. 2000: Monitoring the response of butterfly communities to prescribed fire. Environmental Management 26-6. DOI: https://doi.org/10.1007/s002670010125

Gams, I. 1990: Neotektonska pogojenost večjih poplavnih področij Jugoslavije. Geomorfologija in geoekologija: Zbornik referatov 5. znanstvenega posvetovanja geomorfologov Jugoslavije. Ljubljana.

Gašperič, P. 2004: The expansion of Ljubljana onto the Ljubljansko barje moor. Acta Geographica Slovenica 44-2. DOI: https://doi.org/10.3986/AGS44201

Habeler, H. 1972: Zur Kenntnis der Lebensraüme von *Coenonympha oedippus* F. (Lepidoptera, Satyridae). Nachrichtenblatt Der Bayerischen Entomologen 21.

Hanski, I. 1997: Metapopulation dynamics: From concepts and observations to predictive models. Metapopulation Biology: Ecology, Genetics, and Evolution. San Diego. DOI: https://doi.org/10.1016/B978-012323445-2/50007-9

Hanski, I., Gaggiotti, O. E. 2004: Ecology, Genetics, and Evolution of Metapopulations. San Diego. DOI: https://doi.org/10.1016/B978-0-12-323448-3.X5000-4

Henderson, R. A., Meunier, J., Holoubek, N. S. 2018: Disentangling effects of fire, habitat, and climate on an endangered prairie-specialist butterfly. Biological Conservation 218. DOI: https://doi.org/10.1016/j.biocon.2017.10.034

Huntzinger, M. 2003: Effects of fire management practices on butterfly diversity in the forested Western United States. Biological Conservation 113. DOI: https://doi.org/10.1016/S0006-3207(02)00356-7

Jackson, S. T., Sax, D. F. 2009: Balancing biodiversity in a changing environment: extinction debt, immigration credit and species turnover. Trends in Ecology & Evolution 25-3. DOI: https://doi.org/10.1016/j.tree.2009.10.001

Jeliazkov, A., Lorrillière, R., Besnard, A., Garnier, J., Silvestre, M., Chiron, F. 2019: Cross-scale effects of structural and functional connectivity in pond networks on amphibian distribution in agricultural landscapes. Freshwater Biology 64-5. DOI: https://doi.org/10.1111/fwb.13281

Joy, J., Pullin, A. S. 1997: The effects of flooding on the survival and behaviour of overwintering large heath butterfly *Coenonympha tullia* larvae. Biological Conservation 82-1. DOI: https://doi.org/10.1016/S0006-3207(97)00006-2

Joy, J., Pullin, A. S. 1999: Field studies on flooding and survival of overwintering large heath butterfly *Coenonympha tullia* larvae on Fenn's and Whixall Mosses in Shropshire and Wrexham. Ecological Entomology 24-4. DOI: https://doi.org/10.1046/j.1365-2311.1999.00208.x

Jugovic, J., Zupan, S., Bužan, E., Čelik, T. 2018: Variation in the morphology of the wings of the endangered grass-feeding butterfly *Coenonympha oedippus* (Lepidoptera: Nymphalidae) in response to contrasting habitats. European Journal of Entomology 115. DOI: https://doi.org/10.14411/eje.2018.034

Kajzer-Bonk, J., Nowicki, P., Bonk, M., Skorka, P., Witek, M., Woyciechowski, M. 2013: Local populations of endangered *Maculinea* (*Phengaris*) butterflies are flood resistant. Journal of Insect Conservation 17. DOI: https://doi.org/10.1007/s10841-013-9591-7

Keyghobadi, N. 2007: The genetic implications of habitat fragmentation for animals. Canadian Journal of Forest Research 85-10. DOI: https://doi.org/10.1139/Z07-095

Kolbezen, M. 1985: Hidrografske značilnosti poplav na Ljubljanskem barju. Geografski zbornik 24.

Komac, B. 2022: Veliki gozdni požari v Sloveniji. Geografski vestnik 94-2. DOI: https://doi.org/10.3986/GV94202

Komac, B., Natek, K., Zorn, M. 2008: Geografski vidiki poplav v Sloveniji. Ljubljana. DOI: https://doi.org/10.3986/9789612545451

Komac, B., Zorn, M., Pavšek, M. 2010: Naravne nesreče – družbeni problem? Od razumevanja do upravljanja. Naravne nesreče 1. Ljubljana.

Konvička, M., Nedved, O., Fric, Z. 2002: Early-spring floods decrease the survival of hibernating larvae of a wetland-inhabiting population of Neptis Rivularis (Lepidoptera: Nymphalidae). Acta Zoologica Academiae Scientiarum Hungaricae 48-2.

Košiček, B. 2022: Načrt sanacije gozdov, poškodovanih v požaru Goriški Kras, od 15. julija do 1. avgusta 2022. Predlog načrta, Zavod za gozdove Slovenije. Ljubljana.

Lyet, A, Cheylan, M., Prodon, R., Besnard, A. 2009: Prescribed fire and conservation of a threatened mountain grassland specialist: a capture recapture study on the Orsini's viper in the French Alps. Animal Conservation 12-3. DOI: https://doi.org/10.1111/j.1469-1795.2009.00245.x

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

Moranz, R. A., Fuhlendorf, S.D., Engle, D. M. 2014: Making sense of a prairie butterfly paradox: The effects of grazing, time since fire, and sampling period on Regal fritillary abundance. Biological Conservation 173. DOI: https://doi.org/10.1016/j.biocon.2014.03.003

Nicholls, C. N., Pullin, A. S. 2003: The effects of flooding on survivorship in overwintering larvae of the large copper butterfly *Lycaena dispar batavus* (Lepidoptera: Lycaenidae), and its possible implications for restoration management. European Journal of Entomology 100-1. DOI: https://doi.org/10.14411/eje.2003.014

Nowicki, P., Marczyk, J., Kajzer-Bonk, J. 2015: Metapopulations of endangered *Maculinea* butterflies are resilient to large-scale fire. Ecohydrology 8-3. DOI: https://doi.org/10.1002/eco.1484

Nowicki, P., Deoniziak, K., Dziekanska, I., Kostro-Ambroziak, A., Plazio, E., Rutkowski, R., Sielezniew. M. 2018: What keeps 'living dead' alive: demography of a small and isolated population of *Maculinea* (= *Phengaris*) *alcon*. Journal of Insect Conservation 23. DOI: https://doi.org/10.1007/s10841-018-0078-4

Parise, M. 2015: Karst Geo-Hazards: Causal factors and management issues. Acta Carsologica 44-3. DOI: https://doi.org/10.3986/ac.v44i3.1891

Pečenko, A. 2005: Požari v Naravi. Požarna Ogroženost Naravnega Okolja. Plakat, Agencija RS za okolje – Urad za meteorologijo. Ljubljana.

Perko, D., Ciglič, R. 2020: Slovenia's Landscapes. The Geography of Slovenia. World Regional Geography Book Series. Cham. DOI: https://doi.org/https://doi.org/10.1007/978-3-030-14066-3_14

Plum, N. M., Filser, J. 2005: Floods and drought: Response of earthworms and potworms (Oligochaeta: Lumbricidae, Enchytraeidae) to hydrological extremes in wet grassland. Pedobiologia 49-5. DOI: https://doi.org/10.1016/j.pedobi.2005.05.004

Prebevšek, M. 1998: Gozd srednjedebelnik kot sonaravna tvorba, njegov razvoj in perspektive v sproščenem gojenju gozdov. Magistrsko delo, Univerza v Ljubljani. Ljubljana.

Pryke, J. S., Samways. M. J. 2012: Importance of using many taxa and having adequate controls for monitoring impacts of fire for arthropod conservation. Journal of Insect Conservation 16. DOI: https://doi.org/10.1007/s10841-011-9404-9

Rakar, B. 2016: Populacijska struktura in varstvo barjanskega okarčka (*Coenonympha oedippus*) v dolini reke Dragonje. Diplomsko delo, Univerza v Ljubljani. Ljubljana.

Ravbar, N. 2010: Naravne nesreče na Krasu. Od razumevanja do upravljanja, Naravne nesreče 1. Ljubljana.
Ricouart, F., Cereghino, R., Gers, C., Winterton, P., Legal, L. 2013: Influence of fire prevention management strategies on the diversity of butterfly fauna in the eastern Pyrenees. Journal of Insect Conservation 17-1. DOI: https://doi.org/10.1007/s10841-012-9489-9
Robel, R. J., Hughes, J. P., Hull, S. D., Kemp, K. E., Klute, D. S. 1998: Spring burning: resulting avian abundance and nesting in Kansas CRP. Journal of Range Management 51-2. DOI: https://doi.org/10.2307/4003197
Sielezniew, M., Pałka, K., Michalczuk, W., Bystrowski, C., Hołowiński, M., Czerwiński, M. 2010: False Ringlet *Coenonympha oedippus* (FABRICIUS, 1787) (Lepidoptera: Nymphalidae) in Poland: State of knowledge and conservation prospects. Oedippus 26.
Sušnik A., Gregorič, G. 2017: Kmetijska suša v 21. stoletju v Sloveniji. Ranljivost Slovenije zaradi suše. 28. Mišičev vodarski dan. Maribor.
Swengel, A. B. 1996: Effects of fire and hay management on abundance of prairie butterflies. Biological Conservation 76-1. DOI: https://doi.org/10.1016/0006-3207(95)00085-2
Swengel, A. B. 2001: A literature review of insect responses to fire, compared to other conservation managements of open habitat. Biodiversity and Conservation 10-7. DOI: https://doi.org/10.1023/A:1016683807033
Swengel, A. B., Swengel, S. R. 2007: Benefit of permanent non-fire refugia for Lepidoptera conservation in fire-managed sites. Journal of Insect Conservation 11. DOI: https://doi.org/10.1007/s10841-006-9042-9
Šašić, M. 2010: False Ringlet *Coenonympha oedippus* (Fabricius, 1787) (Lepidoptera: Nymphalidae) in Croatia: Current status, population dynamics and conservation management. Oedippus 26.
Turlure, C., Radchuk, V., Baguette, M., Meijrink, M., van den Burg, A., Wallis De Vries, M., van Duinen. G. J. 2013: Plant quality and local adaptation undermine relocation in a bog specialist butterfly. Ecology and Evolution 3-2. DOI: https://doi.org/10.1002/ece3.427
Van Swaay, C., Cuttelod, A., Collins, S., Maes, D., Munguira, M. L., Šašić, M., Settele, M., Verovnik, R., Verstrael, T., Warren, M., Wiemers, M., Wynhoff, I. 2010: European red list of butterflies. Luxembourg.
Veble, D., Brečko Grubar, V. 2016: Pogostost in obseg požarov v naravi na Krasu in slovenski Istri. Geografski vestnik 88-1. DOI: https://doi.org/10.3986/GV88101
Vereš, K. 2022: Ocena stanja populacije barjanskega okarčka *Coenonympha oedippus* (Lepidoptera: Nymphalidae) po požaru na Cerju. Magistrsko delo, Univerza na Primorskem. Koper.
Verovnik, R., Čelik, T., Grobelnik, V., Šalamun, A., Sečen, T., Govedič, M. 2009: Vzpostavitev monitoringa izbranih ciljnih vrst metuljev (Lepidoptera). Zaključno Poročilo – III. Mejnik. Končno poročilo, Univerza v Ljubljani. Ljubljana.
Verovnik, R., Zakšek V., Čelik T., Govedič M., Rebeušek F., Zakšek B., Grobelnik V., Šalamun A. 2011: Vzpostavitev in izvajanje monitoringa izbranih ciljnih vrst metuljev v letih 2010 in 2011. Končno poročilo, Univerza v Ljubljani. Ljubljana.
Verovnik, R., Zakšek, V., Govedič, M., Zakšek, B., Kogovšek, N., Grobelnik, V., Šalamun, A. 2015: Vzpostavitev in izvajanje monitoringa izbranih ciljnih vrst metuljev v letih 2014 in 2015. Končno poročilo, Univerza v Ljubljani. Ljubljana.
Zajc, T. 2010: Odnos med posedki in poplavami na Ljubljanskem barju v luči klimatskih sprememb. Diplomsko delo, Univerza v Ljubljani. Ljubljana.
Zoratti, B. 1995: Gozdni požar na Goriškem Krasu. Ujma 9.
Zorn, M., Komac, B. 2009: The importance of landsliding in a Flysch Geomorphic System: The example of the Goriška Brda Hills (W Slovenia). Zeitschrift Fur Geomorphologie 53-2. DOI: https://doi.org/10.1127/0372-8854/2009/0053S3-0057
Zakšek, B., Verovnik, R., Zakšek, V., Kogovšek, N., Govedič, M. 2019: Monitoring izbranih ciljnih vrst metuljev v metu 2019. Končno poročilo, Center za kartografijo favne in flore. Miklavž na Dravskem polju.
Zakšek, V., Verovnik, R. 2020: Barjanski okarček (*Coenonympha oedippus*) na območju Natura 2000 Slovenska Istra (SI3000212). Končno poročilo, Univerza v Ljubljani. Ljubljana.
Zupan, S., Bužan, E., Brečko Grubar, V., Jugovic, J. 2020: Importance of traditional landscapes in Slovenia for conservation of endangered butterfly. Open Geosciences 12-1. DOI: https://doi.org/10.1515/geo-2020-0179
Zupan, S., Jugovic, J., Čelik, T., Buzan, E. 2021: Population genetic structure of the highly endangered butterfly *Coenonympha oedippus* (Nymphalidae: Satyrinae) at its southern edge of distribution. Genetica 149-1. DOI: https://doi.org/10.1007/s10709-020-00108-0

Acta geographica Slovenica, 63-1, 2023, 73–87

ENCOURAGING RESEARCH AND DEVELOPMENT COLLABORATION AMIDST GEOGRAPHICAL CHALLENGES IN LESS DEVELOPED REGIONS OF THE EUROPEAN UNION: A SYSTEMATIC LITERATURE REVIEW

Eristian Wibisono

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Pécs, capital of Southern Transdanubia, Hungary, is one of the European Capital of Culture cities and UNESCO Global Learning City. A region characterized by less developed industry, research and development, and innovation.

DOI: https://doi.org/10.3986/AGS.10934
UDC: 910(4-773)

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Encouraging research and development collaboration amidst geographical challenges in less developed regions of the European Union: A systematic literature review

ABSTRACT: This study explores the growing literature on research and development (R&D) collaboration in the context of less developed regions (LDRs) in the European Union (EU) and examines the opportunities for LDRs to successfully collaborate with developed regions. A systematic review of the literature shows that studies on R&D collaboration in LDRs are at the forefront of regional innovation research in the EU and that opportunities to explore this research topic are still wide open. A critical review and synthesis of the selected articles shows that LDRs have equal opportunities to collaborate and build successful relationships with developed regions by paying attention to at least five motivational drivers and critical factors to enhance the success of their R&D collaborations.

KEY WORDS: R&D collaboration, geographical challenges, less developed regions, European Union, systematic literature review, motivational drivers, critical factors

Spodbujanje sodelovanja na področju raziskav in razvoja v manj razvitih regijah Evropske unije, ki se spopadajo z geografskimi izzivi: sistematični pregled literature

POVZETEK: Avtor v članku proučuje rastočo literaturo o sodelovanju na področju raziskav in razvoja v manj razvitih regijah Evropske unije ter možnosti njihovega uspešnega sodelovanja z razvitimi regijami. Na podlagi sistematičnega pregleda literature ugotavlja, da so raziskave o tovrstnem sodelovanju v ospredju proučevanja regionalnih inovacij v Evropski uniji in da je prostora za nadaljnje raziskave na tem področju še veliko. Kritični pregled in sinteza izsledkov izbranih člankov kažeta, da imajo vse manj razvite regije enake možnosti za sodelovanje in vzpostavljanje uspešnih odnosov z razvitimi regijami, če upoštevajo vsaj pet motivacijskih gonil in ključnih dejavnikov, ki lahko izboljšajo uspešnost njihovega sodelovanja na področju raziskav in razvoja.

KLJUČNE BESEDE: sodelovanje na področju raziskav in razvoja, geografski izzivi, manj razvite regije, Evropska unija, sistematični pregled literature, motivacijska gonila, ključni dejavniki

The article was submitted for publication on 5th of July, 2022.
Uredništvo je prejelo prispevek 5. julija 2022.

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1 Introduction

Compared to more developed regions, less developed regions (LDRs) face more challenges in scaling up their innovation, especially when it comes to their geographical location, e.g. due to their peripheral location (Grillitsch and Nilsson 2015; Amoroso, Coad and Grassano 2018) or sparsely populated areas (Dubois, Kristensen and Teräs 2017; Sörvik et al. 2019). To increase the intensity of knowledge spillovers and research and development (R&D) investments from more advanced neighbors (Caragliu and Nijkamp 2016; Lavoratori, Mariotti and Piscitello 2020), collaboration is one of the key drivers of innovation in LDRs (Tödtling, Lehner and Kaufmann 2009; Capello and Cerisola 2021). Unfortunately, even though the European Union (EU) has launched flagship programs based on research and innovation to reduce the development gap in Europe, such as the EU Framework Program (Cecere and Corrocher 2015; Proskuryakova, Meissner and Rudnik 2017; Ulnicane 2022) or the Smart Specialization place-based innovation policy strategy (McCann and Ortega-Argilés 2014; Hassink and Gong 2019), many studies show gaps in collaboration patterns between regions. This is because the selection of collaboration partners based on similarity or proximity between partners is still an influential factor for project applicants (Schwartz et al. 2012; Capone and Lazzeretti 2018).

The related literature continues to grow, although it is still segmented by field and expertise. Studies by Filippopoulos and Fotopoulos (2022) and Neuländtner (2020), which examine constraints to innovation collaboration due to geographic barriers in disadvantaged regions of Europe, suggest that creating and increasing the intensity of collaborative networks can increase opportunities for collaboration and innovation. Lalrindiki and O'Gorman (2021) highlight the important role of non-spatial proximity in substituting for the effects of spatial proximity. Badillo and Moreno (2018) highlight the importance of the capacity to absorb external knowledge and experience in collaborations between non-contiguous regions. Barzotto et al. (2019) highlight that specific motivations for collaboration are essential to distinguish LDRs from other types of regions. The results of this study suggest that even with significant geographic constraints, LDRs can successfully collaborate with more developed regions if they have the relevant motivation and the keys to success that support the motivation. However, understanding different cases in different regions, despite the same regional context, is quite challenging. Therefore, a systematic understanding and representation is needed to make these conditions easy to understand so that these problems can be overcome.

This study aims to fill the gap in the literature that has yet to explore the development and present the systematic results of studies related to the geographical challenges of R&D collaboration in the LDRs of the EU. The study also addresses relevant research questions related to how LDRs can develop R&D collaboration amidst the geographical challenges they face, the most pertinent motivations that can drive collaboration, and the critical factors that can support these motivations to increase the chances and success of collaboration. A systematic literature review approach was used to investigate all these questions.

The remaining part of the paper is organized as follows. The second section outlines the methodological procedures used to systematically conduct the literature review. The third section outlines the research findings based on the selected articles, which consist of a systematic distribution, critical reviews, and presents the motivations and critical points for improving R&D collaboration in LDRs. The fourth section concludes the study.

2 Material and methods

This study builds on the methodological approach recently conducted by Wibisono (2022) and Razpotnik Visković and Logar (2022), who conducted a systematic literature review and applied a three-step protocol in conducting the study, including 1) an initial scoping search; 2) searching, finding, and retrieving articles; and 3) conducting a systematic review.

The *first protocol* began with an initial scoping process based on the research objectives or questions. The initial scoping process referred to the PICOC concept (Roehrs et al. 2017; Mengist, Soromessa and Legese 2020). The population (P) of this study focused on LDRs in EU member states. The intervention (I) was conducted on articles relevant to the research question, highlighting the critical findings of the studies. The comparative factor (C) is represented by the synthesis of articles addressing the issue of R&D collaboration in LDRs and what factors can foster R&D collaboration in LDRs. The outcome of this study (O) is expected to provide insights on how to address the geographical challenges related to R&D collaboration in the EU context (C).

The *second protocol* searches and retrieves literature from the Web of Science database. The keywords used in the database search were '*geograph*; collaborati*; network*; region*; innovati*; europ**'. An asterisk next to each keyword indicates that the exact spelling of the word was included in the search, e.g., geography, geographical; collaboration, collaborative; network, network; region, region, regional; innovation, innovative; Europe, European. Several other restrictions were also applied (as inclusion factors), including topic limitations, language (English), document type (article), publication year (2015–2022), and Web of Science category/field (economics, geography, management, business, urban and regional planning). In terms of keywords and their relation to the research objectives, I did not use the terms 'challenge' in relation to 'geography or 'less developed' in relation to 'region' in the search process. The aim was to find as much literature as possible on R&D collaboration in the EU region. In addition to the broad meaning of the term 'challenge', 'less developed' is not yet a standardized term to describe specific regions in the EU. Other terms such as 'peripheral regions', 'sparsely populated areas' and 'lagging regions' are often used in the literature on the same research topic.

The initial scoping process with these details resulted in 34 potentially relevant articles. The screening process was then continued by matching the attributes of the articles (especially the titles and abstracts) with the research questions/objectives. When reading the titles and abstracts, besides referring to the research objectives, to find the most eligible or highly relevant articles, attention was also paid to the content of articles related to 'geographical challenges' and 'less developed regions'. Of the 34 articles, 23 had a broad focus and were not explicitly related to the research objectives (despite having one or more

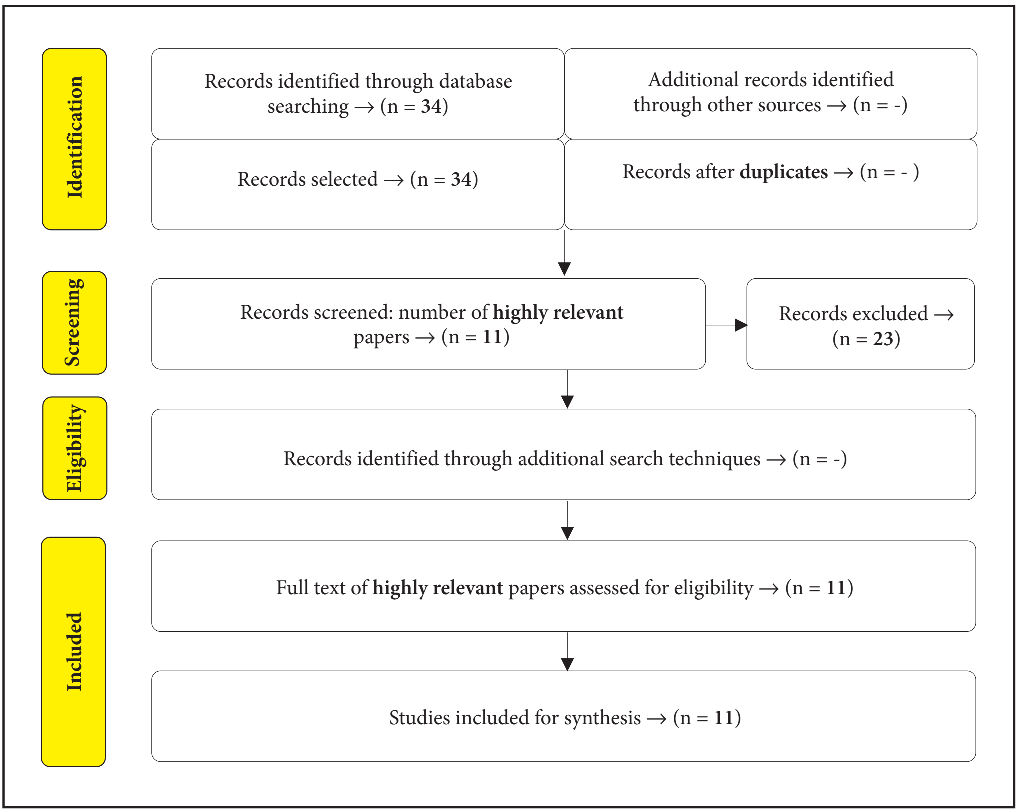

Figure 1: PRISMA diagram.

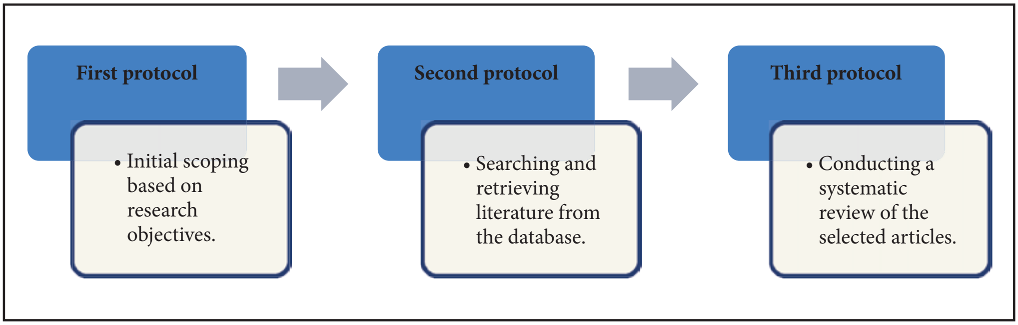

Figure 2: The research protocol.

combinations of the search terms). The articles generally addressed, for example, the relationship between innovation and economic growth or regional governance, university-industry collaboration (UIC), the evolution of regional innovation, critical resources of regional innovation, and comparative studies of Europe with other regions or countries (Asia and Africa). After excluding these irrelevant articles, only the remaining 11 eligible articles were considered for inclusion and synthesis in this study.

The PRISMA diagram (de Barcelos Silva et al. 2020; Page et al. 2021; Bejjani, Göcke and Menter 2023) in Figure 1 summarizes the article search and selection process.

The *third protocol* consists of a systematic review of the eleven selected articles. This set of articles will first be analyzed descriptively to see the characteristics, patterns, distribution of the articles, the specific focus of each article, including the journal that published it, the quality of the journal, and the scientific field or subject category of the journal. The next step was to analyze the content of the eleven selected articles according to the research objectives. This stage is the essential part of the study, which presents the critical findings of the selected articles and synthesizes them in such a way as to achieve the research objectives.

The three research protocols are presented in Figure 2.

3 Systematic literature review

3.1 Systematic distribution of selected articles

This subsection shows the systematic distribution of the selected articles. The articles are grouped by year of publication, journal and publisher, and journal topic category. Table 1 shows that from 2017 onwards, despite the initial scope limitation for 2015-2022, studies specifically addressing R&D collaboration as part of regional innovation have been published in leading journals. In 2017, two authors wrote on this topic. In 2018, studies related to this research objective were published in four articles, the most compared to previous years. In 2019, two articles were published. In the following three years, one article was published each year.

Table 1: List of selected literature.

No.	Year of Publication	No. of Articles	Authors
1	2017	2	Berge (2017), Marek et al. (2017)
2	2018	4	Amoroso, Coad and Grassano (2018), Badillo and Moreno (2018), De Noni, Orsi and Belussi (2018), Lata, von Proff and Brenner (2018)
3	2019	2	Barzotto et al. (2019), Miguelez (2019)
4	2020	1	Neuländtner and Scherngell (2020)
5	2021	1	Lalrindiki and O'Gorman (2021)
6	2022	1	Filippopoulos and Fotopoulos (2022)

Table 2 shows the distribution of articles by journal and publisher and the quality or quartile (Scimago Journal Rank) of the journal. Three articles were published in Annals of Regional Science – Springer Verlag, followed by Research Policy – Elsevier B.V. with two articles, and the remaining six were published in different journals. From this distribution, the selected articles were published in journals of high quality or the top quartile.

Of the eleven articles selected, seven (64%) were published in top-quartile (Q1) journals. This indicates that research on R&D collaboration is at the forefront of regional innovation studies. However, there are still many opportunities for research on this topic. While other research on innovation has increased and found that collaboration is crucial for innovation, research specifically addressing R&D collaboration and its interaction with factors such as spatial and non-spatial proximity and knowledge networks still needs to be improved, especially in the context of the LDRs of the EU. Such studies, published in leading journals, provide ample opportunities for future researchers to further explore how R&D collaboration can foster regional innovation in LDRs of the EU.

Looking at Figure 3, the articles are distributed across several subject categories of the journal, namely: Social Sciences (37%), Technology and Innovation Management (27%), Economics, Econometrics and Finance (18%), and Geography, Planning and Development (18%). This chart may help guide future research in finding studies relevant to R&D collaboration in the context of LDRs of the EU.

Table 2: Sources of publications.

No.	Publication Source & Publisher	No. of Articles	Quartile (SJR 2022)
1	Annals of Regional Science – Springer Verlag	3	Q2 – Social Sciences
2	Economics of Innovation and New Technology – Routledge	1	Q1 – Economics, Econometrics and Finance
3	Papers in Regional Science – Wiley-Blackwell	1	Q1 – Geography, Planning and Development
4	Regional Studies – Routledge	1	Q1 – Social Sciences
5	Research Policy – Elsevier B.V.	2	Q1 – Management of Technology and Innovation
6	Technovation – Elsevier Ltd.	1	Q1 – Management of Technology and Innovation
7	Cambridge Journal of Regions, Economy and Society – Oxford University Press	1	Q1 – Geography, Planning and Development
8	Triple Helix – Brill Academic Publishers	1	Q2 – Economics, Econometrics and Finance

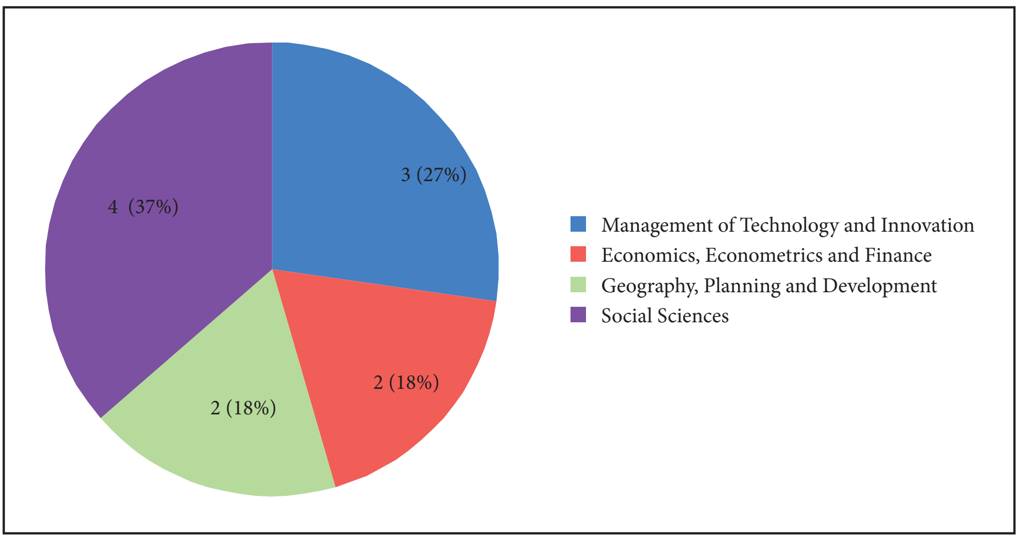

Figure 3: Journal subject categories.

3.2 Critical findings of selected articles

This subsection critically reviews the main content of the selected articles. The articles are divided into two groups (Figure 4). It should be noted that the second group of articles does not explicitly consider the type of region (in this case, LDR) as the first group of articles does. However, as the geographical challenges in the second group of articles are also discussed in the context of R&D collaboration for innovation at the regional level, it can be assumed that LDRs also face similar challenges.

Filippopoulos and Fotopoulos (2022) addressed the issue of differences in innovation performance between developed and LDRs in 183 NUTS (Nomenclature of Territorial Units for Statistics) 2 regions in the EU. The study applied the Fuzzy-set Qualitative Comparative Analysis (FsQCA) method to address methodological gaps in innovation studies that are difficult to address using econometric approaches. The critical findings of this study show that LDRs are characterized by public R&D-driven innovation mechanisms and actively participate in collaborative R&D networks with more developed regions. However, LDRs are also characterized by innovation at a more superficial technological level, which is one of the reasons why these regions have low patent production. Not to mention that they also lack knowledge spillovers from neighboring regions due to unfavorable geographical conditions.

In line with this, Barzotto et al. (2019) show that collaboration between LDRs and developed regions, while motivated by technological upgrading, is not essentially driven by technological proximity. This condition causes more developed regions to benefit less from technology upgrading when they collaborate with LDR, which becomes a challenge for LDR to attract them into collaboration. In the context of smart specialization, Barzotto et al. (2019) emphasize that technological proximity should not be the primary goal of collaboration for LDRs, but rather other strategic or public policy goals, such as collaboration in the entrepreneurial discovery process (EDP), which allows LDRs to involve stakeholders or other partners from more developed regions.

In the context of research networks in the EU Framework Program, Amoroso, Coad and Grassano (2018) point to the spatial clustering of knowledge networks, which creates an imbalance between developed regions and LDRs. The geographical barriers and limited capacity of R&D resources in LDRs contribute to low technology absorption in the region. Meanwhile, collaboration is easier for developed regions because they are more flexible in choosing collaboration partners with a background of proximity or similar innovation characteristics. Even after considering all geographic and non-geographic proximity factors, geographic distance remains an essential consideration for collaboration in developed regions. Not surprisingly, the intensity of collaboration in LDRs is low.

To foster innovation in LDRs, De Noni, Orsi and Belussi (2018) highlight the importance of strengthening organizational and institutional capacities to generate collaborative networks. Analyzing a seven-year dataset of 205 EU regions shows that collaborative R&D networks in LDRs can be fostered by continuously

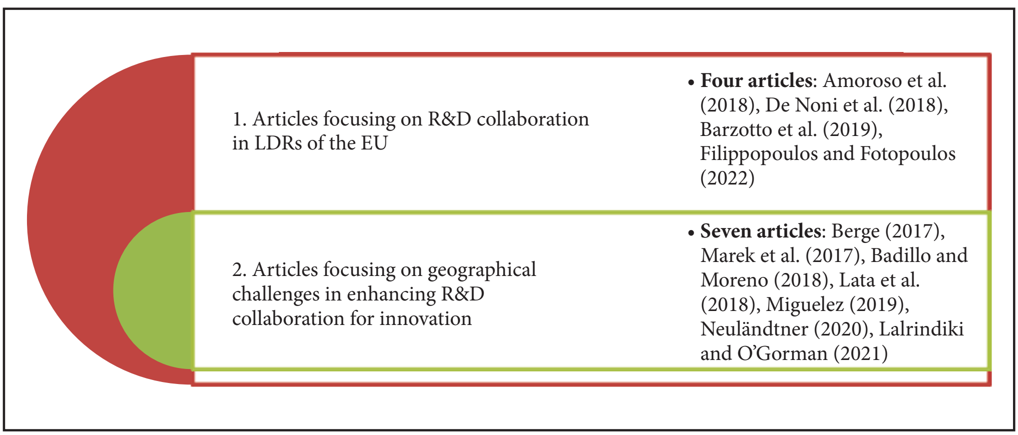

Figure 4: Grouping of articles by study focus.

creating and strengthening links between LDRs and other regions with broader knowledge by improving their organizational and institutional capacity. In absorbing external knowledge, LDRs should involve key innovation actors as one of the stakeholders, such as inventors or senior researchers. The combination of these factors has the potential to create a solid internal knowledge network that can attract developed regions to collaborate with LDRs.

Regarding geographic constraints, Lalrindiki and O'Gorman (2021) examined the interaction and interdependence of non-geographic factors in the collaboration of triple helix actors in non-contiguous European regions. They recommended an interregional innovation system (iRIS) framework that integrates various non-geographic proximity factors to foster collaboration. The interdependence of non-geographic proximity, such as cognitive proximity and social proximity, tends to increase the effectiveness of iRIS through a process of openness to learning and knowledge sharing based on mutual trust, understanding, respect, and intensive communication between partners. Meanwhile, organizational proximity can enhance collaboration by improving organizations' management quality and leadership spirit. It has much to do with the planning, structuring, and distributing of tasks in collaborative projects.

On the same issue, Badillo and Moreno (2018) proved the positive significance of domestic-international collaborative alliances of Spanish firms. Innovation collaborations with high-tech global firms in the United States (US), India, and China significantly impact the technological change of Spanish domestic firms. The most significant impact is due to innovation collaborations with the US. Meanwhile, the results of collaborations with India and China, although less significant than those with the US, are still more impactful than collaborations with domestic firms or other EU members. In these collaborations, domestic firms are highly motivated to absorb external knowledge and technology effectively and efficiently from partner firms. The results of this study highlight the importance of enhancing the absorptive capacity of local partners to achieve optimal impact from innovation collaborations, especially if they have to cross geographically distant boundaries.

With respect to smaller firms, such as small and medium-sized enterprises (SMEs), Marek et al. (2017) investigated the interaction of spatial and proximity factors in German National Collaboration Program projects from 2006 to 2012 that heavily involved the private sector. The unique finding of this study is that the impact of geographic and organizational proximity on collaboration forms an inverted U-curve or has a negative direction at saturation or a certain threshold. Organizational proximity cannot simply replace geographic proximity, but the two are interdependent. Similarly, cognitive proximity cannot directly replace geographic proximity, but the link between them can potentially strengthen collaboration. Organizational proximity and cognitive proximity in interregional collaboration in Germany require a high level of knowledge absorption by collaborating firms, which is one of the keys to the success of this program.

Geographic distance is still a serious problem in patent collaboration in Europe. Lata, von Proff and Brenner (2018) point this out in their study and compare it with the US. While in the US distance between locations can weaken collaboration, in Europe this geographic distance is more related to language and national borders. In this respect, R&D collaboration in Europe is still possible for short to medium distances, such as a maximum of 300 km. Beyond this distance, collaboration opportunities are further reduced, especially when language and national borders are already dominant constraints. In Europe, cognitive proximity is more conducive to collaboration as R&D and innovation policies grow from mature knowledge (Tödtling and Trippl 2005; Ranga and Etzkowitz 2013). The challenge, however, is how cognitive proximity can counteract the negative effects of geographic proximity.

Miguelez (2019) explores collaboration and social proximity among inventors from different regions who share the commonality of having previously worked in the same field and location. The study uses microdata of biotechnology inventors from the European Patent Office (EPO) from 1978 to 2005. Assuming that these social relationships are long-lasting, the results of the conditional fixed effects logit model estimation suggest that such relationships can accelerate the formation of collaborative relationships in their current spatial context and give rise to joint patents. The positive effect of past co-location factors is even more significant when the spatial distance between regions becomes larger (e.g., at the NUTS 2 regional level) or when knowledge workers have crossed national borders. Indeed, there will be higher transaction costs when there are cultural and organizational differences in extra-regional or international collaborations to make these collaborations happen. However, the social relationships that have developed between them in the past are expected to overcome these barriers.

Berge (2017) investigated the impact of R&D collaboration networks in overcoming geographical barriers in five major EU countries (Germany, France, Spain, Italy, and the United Kingdom). The main idea of the study is that network connectivity can compensate for increased geographical distance in R&D collaboration. Using gravity and Poisson regression modeling of 17,292 regionally paired chemical science co-publication data (as a measure of network proximity between regions) from 132 NUTS 2 regions in 2001–2005, the results of his study show that network proximity can increase as geographical distance increases, both in the sense of physical space and through the influence of national borders. This finding suggests that interregional collaboration remains possible over large distances by creating network connectivity or increasing network proximity between potential collaboration partners.

Neuländtner (2020) combines the two dimensions of geographic and technological proximity and collaborative networks in a unified model. A dataset of 505 EU metropolitan and non-metropolitan regions that have received EU Framework Program projects was grouped by Key Enabling Technologies (KETs) into six interregional R&D networks. By analyzing a negative binomial spatial interaction modeling approach, the results show that geographical barriers of distance and borders are still a significant challenge in building collaborative networks and that the negative effect of national borders on collaboration by the KET group in the EU is profound, even though the EU Framework Program is designed to minimize such risks (Koschatzky and Stahlecker 2010; Pandza, Wilkins and Alfoldi 2011; Arnold 2012; Varga and Sebestyén 2017). With respect to technology-motivated collaborations, the negative effects of geographic distance tend to drive nanotechnology collaborations, while the negative effects of national geographic boundaries tend to drive R&D collaborations in microelectronics and advanced materials technologies. On the other hand, network effects across regions enable collaboration in all technology groups regardless of geographical barriers. Regions with high network embeddedness are more likely to form collaborations, especially if they have sufficient network centrality. This study contributes to R&D policy advice for motivating regional technological capacity building. The data configuration in this study shows that if geographical factors can cluster regional collaboration by specific technology groups, network effects open up collaboration for all regions across all technology categories. Therefore, regional innovation policies should be encouraged to overcome geographical barriers by creating new knowledge networks. The creation of local knowledge networks can be fostered by cooperation between local R&D institutions and those with experience in extra-regional or international cooperation.

3.3 Motivational drivers and critical factors for successful R&D collaboration in LDRs of the EU

This subsection is designed to answer the main research question of this study, i.e., how R&D collaboration can be realized in LDRs of the EU, given their geographical challenges, and what motivations and critical factors can support these motivations and enhance the success of LDR collaboration. Like other regions, LDRs have the necessary capital to develop their regions, although innovation is not necessarily a top development priority. To activate regional resources for innovation, LDRs are first encouraged to have internal knowledge networks supported by adequate organizational and institutional capacities (De Noni, Orsi and Belussi 2018). As a first step, LDRs need to build linkages with other more developed regions that are appropriate to their resources. Furthermore, LDRs are expected to have the capacity to absorb diverse external knowledge and experience of more developed regions in managing innovation organizations and institutions as the main capital to create internal knowledge networks (Capello and Lenzi 2018; Trippl, Zukauskaite and Healy 2019; Marques and Morgan 2021; Wibisono 2022). The involvement of critical actors in innovation should also be encouraged to create interregional linkages (Gertler and Levitte 2005; Yoon and Park 2017).

According to Barzotto et al. (2019), the main motivation for innovation collaboration in LDRs should not be technologically driven only, as is the case for collaboration between more developed regions. LDRs are still at a more basic technological stage, which may be less attractive for more advanced regions. Therefore, the motivations for LDR collaboration could be more strategic or for policy-making purposes. For example, regional domain specialization through the Entrepreneurial Discovery Process (EDP) is identified in the policy context of the Smart Specialization Strategy (S3). Collaboration in the context of smart specialization enables inter-organizational and inter-regional cooperation to improve the success of its implementation (Di Cataldo, Monastiriotis, and Rodríguez-Pose et al. 2020; Foray, Eichler and Keller 2021; Ghinoi et al. 2021).

However, it is important to consider that collaboration must also be mutually beneficial (Silva et al. 2021). Providing incentives to developed regions that may not be related to knowledge or innovation can encourage them to consider collaborating with LDRs (Foray 2014; Uyarra 2019; Meyer, Gerlitz and Klein 2022). This description leads us to the *first motivation* for R&D collaboration in LDRs, which is driven by strategic or policy objectives. The critical factor is creating a mutually beneficial relationship between the collaboration partners.

Technological similarity and cognitive proximity offer many advantages for collaboration, especially for those with geographical proximity (Lazzeretti, Capone and Cinti 2010; Bathelt and Henn 2014). As explained in the study by Marek et al. (2017), regional collaboration projects in Germany benefit from the geographical proximity of regions, coupled with their technological level and absorptive capacity. These factors are essential for planning the project schemes to be developed. In the case of LDR, this experience can be instructive. Given that, according to Lata, von Proff and Brenner (2018), collaboration is still possible at short and medium distances (up to 300 km), LDRs that fit this category have a great opportunity to realize collaboration. Cognitive proximity can be fostered by increasing absorptive capacity when the initial connection is established (Badillo and Moreno 2018; De Noni, Orsi and Belussi 2018). If technology is a strong motivation for collaboration in LDRs, they should strongly consider absorptive capacity to attract more advanced neighboring regions to collaborate (Hellsmark et al. 2016; Meissner 2019; Tang et al. 2020). This description suggests a *second motivation* for R&D collaboration in LDRs that is driven by cognitive or technological proximity, and the critical factor is increased regional absorptive capacity.

For geographically distant regions, organizational and institutional proximity further compensates for the barriers of geographic distance. Establishing initial links, strengthening organizations and institutions, and learning from the experiences of more advanced regions are essential processes in collaboration (Gertler and Levitte 2005; Ranga 2018; Lalrindiki and O'Gorman 2021). These processes create mutual trust and understanding between collaborative partners. For organizational and institutional proximity to be a factor that can offset the negative effects of geographic distance, leaders of organizations in the region must have good leadership and management skills, as these skills will be very influential in planning, implementing, and developing the collaboration. The mutual trust and understanding created in the process will lead to openness and ease of communication. This description shows the *third motivation* for R&D collaboration in the LDR, which is driven by organizational and institutional proximity, and an important factor is leadership and management skills.

The study by Neuländtner and Scherngell (2020) is one of the few empirical studies that combines several proximity factors and network effects in one analytical framework, which are analyzed separately in other studies (e.g., Cantner and Graf 2006; Allen, James and Gamlen 2007; Fritsch and Kauffeld-Monz 2010; Marrocu, Paci and Usai 2013). According to the results of these studies, cooperation in LDRs is likely to be

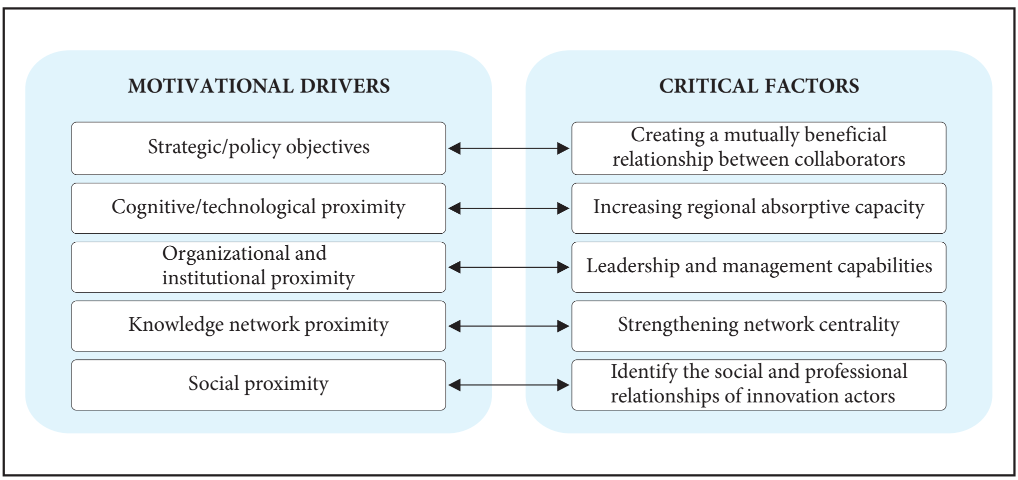

Figure 5: Motivational drivers and critical factors for R&D collaboration in the LDRs of the EU.

successful when interregional networks are formed and various network effects occur, supported by a combination of proximity factors. Under these conditions, network centrality becomes crucial, as it will attract other regions to collaborate with LDRs. As Berge (2017) argues, network proximity is inversely proportional to geographic distance, implying that geographic barriers can be overcome by increasing network connectivity. The network proximity effect ultimately removes geographic distance when network proximity is optimal (Chen and Lin 2014; Janssen, Bogers and Wanzenböck 2020; Pires et al. 2020; Komlósi et al. 2022). This description suggests a *fourth motivation* for R&D collaboration in LDRs, driven by knowledge network proximity, and an important factor is to strengthen network centrality.

The mobility of knowledge workers is important because the social interactions and relationships formed in the process will benefit the region in the future, even over long geographical distances. Long-term social interactions are also thought to create proximity and foster collaboration (Agrawal, Cockburn and McHale 2006; Torre 2008; Breschi and Lissoni 2009; Lavie, Kang and Rosenkopf 2011). Using a dataset spanning three decades, Miguelez (2019) provides evidence that innovation actors who have worked in the same field and location in the past have social ties, potentially opening up opportunities for future collaboration. Certain less developed regions are likely to have at least some of these innovation actors. The challenge for the region is to find and identify them and explore opportunities for collaboration through this social proximity. As suggested by Lalrindiki and O'Gorman (2021), social proximity is related to cognitive proximity, which assumes that social relationships can open up opportunities for knowledge exchanges. This description suggests a *fifth motivation* for R&D collaboration in LDRs driven by social proximity, and a critical factor is the identification of past social interactions and relationships of innovation actors.

Five motivational drivers and critical factors for R&D collaboration in the LDRs of the EU are presented in Figure 5.

4 Conclusion

This study aims to fill the literature gap on R&D collaboration for innovation in the context of a less developed region of the EU characterized by geographical challenges. The exploration and investigation of relevant literature through the systematic literature review protocol shows that this topic is developing and is at the forefront of the EU innovation studies. On the other hand, the limited research on this topic opens opportunities for future research to explore further. The critical review of the selected articles reveals two crucial emphases. *First*, if LDRs are to establish successful collaborative relationships with developed regions, three things need to be prioritized, namely, openness to external knowledge that can be used to enhance regional innovation, the ability to absorb knowledge and experience from partner regions, and the ability to identify critical actors to engage in collaboration for innovation. *Second*, five motivational drivers need to be reinforced by five critical factors to improve the success of LDR collaboration with developed regions, namely, collaboration motivated by strategic and public policy objectives needs to be supported by mutually beneficial relationships between partners, collaboration motivated by cognitive proximity needs to be strengthened by knowledge absorption capabilities and capacity, collaboration motivated by institutional proximity needs to be supported by leadership and organizational management capabilities, collaboration motivated by knowledge network proximity requires strengthening the centrality of knowledge networks, and collaboration motivated by social proximity can be focused on past relationships between innovation actors.

This study is expected to have practical and academic implications for the implementation of innovation policy through R&D collaboration between LDRs and developed regions, by considering the challenges and factors supporting its success and encouraging future studies focusing on innovation development in LDRs of the EU. Given the limited current literature explicitly addressing related issues in the databases searched, it is inevitable that the results of this study cannot be generalized to broader issues of R&D collaboration. The study also recognizes its limitations in robustly justifying and comprehensively presenting the interrelation between geographically challenged and less developed regions. Therefore, categorizing or differentiating between less developed and other types of regions, such as peripheral, sparsely populated, lagging, and underdeveloped, may suggest different interpretations of the study results. Finally, the points presented in this study regarding motivational drivers and critical factors are still propositions, and therefore further research needs to be conducted to validate them empirically.

ACKNOWLEDGMENTS: The author gratefully acknowledge the support provided by POLISS (https://poliss.eu), a project funded by the European Union H2020 Research and Innovation Program, Grant Agreement No. 860887. The views and opinions expressed in this paper are those of the authors and do not necessarily reflect those of the European Union. Neither the European Union nor the grantor is responsible for them. The author would also like to thank Dr. Balázs Lengyel, Professor Tamás Sebestyén, the editorial team, and two anonymous reviewers for their constructive criticism and suggestions.

5 References

Agrawal, A., Cockburn, I., McHale, J. 2006: Gone but not forgotten: knowledge flows, labor mobility, and enduring social relationships. Journal of Economic Geography 6-5. DOI: https://doi.org/10.1093/jeg/lbl016

Allen, J., James, A. D., Gamlen, P. 2007: Formal versus informal knowledge networks in R&D: a case study using social network analysis. R&d Management 37-3. DOI: https://doi.org/10.1111/j.1467-9310.2007.00468.x

Amoroso, S., Coad, A., Grassano, N. 2018: European R&D networks: a snapshot from the 7th EU Framework Programme. Economics of Innovation and New Technology 27-5,6. DOI: https://doi.org/10.1080/10438599.2017.1374037

Arnold, E. 2012: Understanding long-term impacts of R&D funding: The EU framework programme. Research evaluation 21-5. DOI: https://doi.org/10.1093/reseval/rvs025

Badillo, E. R., Moreno, R. 2018: Does absorptive capacity determine collaboration returns to innovation? A geographical dimension. The Annals of Regional Science 60-3. DOI: https://doi.org/10.1007/s00168-015-0696-7

Barzotto, M., Corradini, C., Fai, F. M., Labory, S., Tomlinson, P.R. 2019: Enhancing innovative capabilities in lagging regions: An extra-regional collaborative approach to RIS3. Cambridge Journal of Regions, Economy and Society 12-2. DOI: https://doi.org/10.1093/cjres/rsz003

Bathelt, H., Henn, S. 2014: The geographies of knowledge transfers over distance: toward a typology. Environment and Planning A: Economy and Space 46-6. DOI: https://doi.org/10.1068/a46115

Bejjani, M., Göcke, L., Menter, M. 2023: Digital entrepreneurial ecosystems: A systematic literature review. Technological Forecasting and Social Change 189. DOI: https://doi.org/10.1016/j.techfore.2023.122372

Berge, L. R. 2017: Network proximity in the geography of research collaboration. Papers in Regional Science 96-4. DOI: https://doi.org/10.1111/pirs.12218

Breschi, S., Lissoni, F. 2009: Mobility of skilled workers and co-invention networks: an anatomy of localized knowledge flows. Journal of economic geography 9-4. DOI: https://doi.org/10.1093/jeg/lbp008

Cantner, U., Graf, H. 2006: The network of innovators in Jena: An application of social network analysis. Research policy 35-4. DOI: https://doi.org/10.1016/j.respol.2006.01.002

Capello, R., Cerisola, S. 2021: Catching-up and regional disparities: a resource-allocation approach. European Planning Studies 29-1. DOI: https://doi.org/10.1080/09654313.2020.1823323

Capello, R., Lenzi, C. 2018: Regional innovation evolution and economic performance. Regional Studies 53-1. DOI: https://doi.org/10.1080/00343404.2018.1502421

Capone, F., Lazzeretti, L. 2018: The different roles of proximity in multiple informal network relationships: Evidence from the cluster of high technology applied to cultural goods in Tuscany. Industry and Innovation 25-9. DOI: https://doi.org/10.1080/13662716.2018.1442713

Caragliu, A., Nijkamp, P. 2016: Space and knowledge spillovers in European regions: the impact of different forms of proximity on spatial knowledge diffusion. Journal of Economic Geography 16-3. DOI: https://doi.org/10.1093/jeg/lbv042

Cecere, G., Corrocher, N. 2015: The intensity of interregional cooperation in information and communication technology projects: An empirical analysis of the Framework Programme. Regional Studies 49-2. DOI: https://doi.org/10.1080/00343404.2012.759651

Chen, L. C., Lin, Z. X. 2014: Examining the role of geographical proximity in a cluster's transformation process: the case of Taiwan's machine tool industry. European Planning Studies 22-1. DOI: https://doi.org/10.1080/09654313.2012.722973

de Barcelos Silva, A., Gomes, M. M., da Costa, C. A., da Rosa Righi, R., Barbosa, J.L.V., Pessin et al. 2020: Intelligent personal assistants: A systematic literature review. Expert Systems with Applications 147-1. DOI: https://doi.org/10.1016/j.eswa.2020.113193

De Noni, I., Orsi, L., Belussi, F. 2018: The role of collaborative networks in supporting the innovation performances of lagging-behind European regions. Research Policy 47-1. DOI: https://doi.org/10.1016/j.respol.2017.09.006

Di Cataldo, M., Monastiriotis, V., Rodríguez-Pose, A. 2020: How 'smart'are Smart Specialisation strategies? Journal of Common Market Studies 60-5. DOI: https://doi.org/10.1111/jcms.13156

Dubois, A., Kristensen, I., Teräs, J. 2017: Outsmarting geography: implementing territorial innovation strategies in sparsely populated regions. European Planning Studies 25-2. DOI: https://doi.org/10.1080/09654313.2017.1320355

Filippopoulos, N., Fotopoulos, G. 2022: Innovation in economically developed and lagging European regions: A configurational analysis. Research Policy 51-2. DOI: https://doi.org/10.1016/j.respol.2021.104424

Foray, D., 2014. Smart specialisation: Opportunities and challenges for regional innovation policy. London. DOI: https://doi.org/10.4324/9781315773063

Foray, D., Eichler, M., Keller, M. 2021: Smart specialization strategies – insights gained from a unique European policy experiment on innovation and industrial policy design. Review of Evolutionary Political Economy 2-1. DOI: https://doi.org/10.1007/s43253-020-00026-z

Fritsch, M., Kauffeld-Monz, M. 2010: The impact of network structure on knowledge transfer: an application of social network analysis in the context of regional innovation networks. The Annals of Regional Science 44-1. DOI: https://doi.org/10.1007/s00168-008-0245-8

Gertler, M. S., Levitte, Y. M. 2005: Local nodes in global networks: the geography of knowledge flows in biotechnology innovation. Industry and innovation 12-4. DOI: https://doi.org/10.1080/13662710500361981

Ghinoi, S., Steiner, B., Makkonen, T., Hassink, R. 2021: Smart Specialisation strategies on the periphery: a data-triangulation approach to governance issues and practices. Regional Studies 55-3. DOI: https://doi.org/10.1080/00343404.2020.1791321

Grillitsch, M., Nilsson, M. 2015: Innovation in peripheral regions: Do collaborations compensate for a lack of local knowledge spillovers? The Annals of Regional Science 54-1. DOI: https://doi.org/10.1007/s00168-014-0655-8

Hassink, R., Gong, H. 2019: Six critical questions about smart specialization. European Planning Studies 27-10. DOI: https://doi.org/10.1080/09654313.2019.1650898

Hellsmark, H., Mossberg, J., Söderholm, P., Frishammar, J. 2016: Innovation system strengths and weaknesses in progressing sustainable technology: The case of Swedish biorefinery development. Journal of Cleaner Production 131. DOI: https://doi.org/10.1016/j.jclepro.2016.04.109

Janssen, M. J., Bogers, M., Wanzenböck, I. 2020: Do systemic innovation intermediaries broaden horizons? *A proximity perspective on R&D partnership formation*. Industry and Innovation 27-6. DOI: https://doi.org/10.1080/13662716.2019.1618701

Komlósi, É., Sebestyén, T., Tóth-Pajor, Á., Bedő, Z. 2022: Do specific entrepreneurial ecosystems favor high-level networking while others not? Lessons from the Hungarian IT sector. Technological Forecasting and Social Change 175. DOI: https://doi.org/10.1016/j.techfore.2021.121349

Koschatzky, K. Stahlecker, T. 2010: A new challenge for regional policy-making in Europe? Chances and risks of the merger between cohesion and innovation policy. European Planning Studies 18-1. DOI: https://doi.org/10.1080/09654310903343492

Lalrindiki, M., O'Gorman, B. 2021: The role of proximity in developing an inter-regional innovation system. Triple Helix 8-3. DOI: https://doi.org/10.1163/21971927-bja10024

Lata, R., von Proff, S., Brenner, T. 2018: The influence of distance types on co-patenting and co-publishing in the USA and Europe over time. The Annals of Regional Science 61-1. DOI: https://doi.org/10.1007/s00168-017-0857-y

Lavie, D., Kang, J., Rosenkopf, L. 2011: Balance within and across domains: The performance implications of exploration and exploitation in alliances. Organization Science 22-6. DOI: https://doi.org/10.1287/orsc.1100.0596

Lavoratori, K., Mariotti, S., Piscitello, L. 2020: Location and Intra-firm co-location of MNEs' activities: Does geographical proximity always matter? Regional Studies 54-10. DOI: https://doi.org/10.1080/00343404.2020.1732901

Lazzeretti, L., Capone, F., Cinti, T. 2010: The regional development platform and »related variety«: Some evidence from art and food in Tuscany. European Planning Studies 18-1. DOI: https://doi.org/10.1080/09654310903343518

Marek, P., Titze, M., Fuhrmeister, C., Blum, U. 2017: R&D collaborations and the role of proximity. Regional Studies 51-12. DOI: https://doi.org/10.1080/00343404.2016.1242718

Marques, P., Morgan, K. 2021. Innovation without regional development? The complex interplay of innovation, institutions, and development. Economic Geography 97-5. DOI: https://doi.org/10.1080/00130095.2021.1972801

Marrocu, E., Paci, R., Usai, S. 2013: Proximity, networking and knowledge production in Europe: What lessons for innovation policy? Technological Forecasting and Social Change 80-8. DOI: https://doi.org/10.1016/j.techfore.2013.03.004

McCann, P., Ortega-Argilés, R. 2014: Smart specialisation in European regions: Issues of strategy, institutions and implementation. European Journal of Innovation Management 17-4. DOI: https://doi.org/10.1108/EJIM-05-2014-0052

Meissner, D. 2019: Public-private partnership models for science, technology, and innovation cooperation. Journal of the Knowledge Economy 10-4. DOI: https://doi.org/10.1007/s13132-015-0310-3

Mengist, W., Soromessa, T., Legese, G. 2020: Method for conducting systematic literature review and meta-analysis for environmental science research. MethodsX 7-2. DOI: https://doi.org/10.1016/j.mex.2019.100777

Meyer, C., Gerlitz, L., Klein, M. 2022: Creativity as a Key Constituent for Smart Specialization Strategies (S3), What Is in It for Peripheral Regions? Co-creating Sustainable and Resilient Tourism with Cultural and Creative Industries. Sustainability 14-5. DOI: https://doi.org/10.3390/su14063469

Miguelez, E. 2019: Collaborative patents and the mobility of knowledge workers. Technovation 86-87. DOI: https://doi.org/10.1016/j.technovation.2019.01.001

Neuländtner, M. 2020: An Empirical Agent-Based Model for Regional Knowledge Creation in Europe. ISPRS International Journal of Geo-Information 9-8. DOI: https://doi.org/10.3390/ijgi9080477

Neuländtner, M., Scherngell, T. 2020: Geographical or relational: What drives technology-specific R&D collaboration networks? The Annals of Regional Science 65-3. DOI: https://doi.org/10.1007/s00168-020-01002-5

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L. et al. 2021: The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Systematic reviews 10-1. DOI: https://doi.org/10.1016/j.rec.2021.07.010

Pandza, K., Wilkins, T.A., Alfoldi, E.A. 2011: Collaborative diversity in a nanotechnology innovation system: Evidence from the EU Framework Programme. Technovation 31-9. DOI: https://doi.org/10.1016/j.technovation.2011.05.003

Pires, S. M., Polido, A., Teles, F., Silva, P., Rodrigues, C. 2020: Territorial innovation models in less developed regions in Europe: the quest for a new research agenda? European planning studies 28-8. DOI: https://doi.org/10.1080/09654313.2019.1697211

Proskuryakova, L., Meissner, D., Rudnik, P. 2017: The use of technology platforms as a policy tool to address research challenges and technology transfer. The Journal of Technology Transfer 42-1. DOI: https://doi.org/10.1007/s10961-015-9421-z

Ranga, M. 2018: Smart specialization as a strategy to develop early-stage regional innovation systems. European Planning Studies 26-11. DOI: https://doi.org/10.1080/09654313.2018.1530149

Ranga, M., Etzkowitz, H. 2013: Triple Helix systems: an analytical framework for innovation policy and practice in the Knowledge Society. Industry and higher education 27-4. DOI: https://doi.org/10.5367/ihe.2013.0165

Razpotnik Visković, N. Logar, E. 2022: Certification, labelling and branding in tourism research: systematic review. Acta geographica Slovenica 62-2. DOI: https://doi.org/10.3986/AGS.10858

Roehrs, A., Da Costa, C. A., da Rosa Righi, R., De Oliveira, K. S. F. 2017: Personal health records: a systematic literature review. Journal of medical Internet research 19-1. DOI: https://doi.org/10.2196/jmir.5876

Schwartz, M., Peglow, F., Fritsch, M., Günther, J. 2012: What drives innovation output from subsidized R&D cooperation? – Project-level evidence from Germany. Technovation 32-6. DOI: https://doi.org/10.1016/j.technovation.2012.03.004

Silva, C., Ribeiro, P., Pinto, E. B., Monteiro, P. 2021: Maturity model for collaborative R&D university-industry sustainable partnerships. Procedia Computer Science 181-5. DOI: https://doi.org/10.1016/j.procs.2021.01.234

Sörvik, J., Teräs, J., Dubois, A., Pertoldi, M. 2019: Smart specialisation in sparsely populated areas: Challenges, opportunities and new openings. Regional Studies 53-7. DOI: https://doi.org/10.1080/00343404.2018.1530752
Tang, Y., Chen, Y., Wang, K., Xu, H., Yi, X. 2020: An analysis on the spatial effect of absorptive capacity on regional innovation ability based on empirical research in China. Sustainability 12-7. DOI: https://doi.org/10.3390/su12073021
Tödtling, F., Lehner, P., Kaufmann, A. 2009: Do different types of innovation rely on specific kinds of knowledge interactions? Technovation 29-1. DOI: https://doi.org/10.1016/j.technovation.2008.05.002
Tödtling, F., Trippl, M. 2005: One size fits all?: Towards a differentiated regional innovation policy approach. Research policy 34-8. DOI: https://doi.org/10.1016/j.respol.2005.01.018
Torre, A. 2008: On the role played by temporary geographical proximity in knowledge transmission. Regional studies 42-6. DOI: https://doi.org/10.1080/00343400801922814
Trippl, M., Zukauskaite, E., Healy, A. 2019: Shaping smart specialization: The role of place-specific factors in advanced, intermediate and less-developed European regions. Regional Studies 54-10. DOI: https://doi.org/10.1080/00343404.2019.1582763
Ulnicane, I. 2022: Artificial Intelligence in the European Union: Policy, ethics and regulation. The Routledge handbook of European integrations. London. https://doi.org/10.4324/9780429262081-19
Uyarra, E. 2019: Smart Specialization as Place-based Policy: Lessons Learnt? Regional Insights 1-6. DOI: https://doi.org/10.1080/13673882.2018.00001022
Varga, A., Sebestyén, T. 2017: Does EU Framework Program participation affect regional innovation? The differentiating role of economic development. International Regional Science 40-4. DOI: https://doi.org/10.1177/0160017616642821
Wibisono, E. 2022: Smart Specialisation in less-developed regions of the European Union: A Systematic Literature Review. REGION 9-2. DOI: https://doi.org/10.18335/region.v9i2.388
Yoon, J., Park, H.W. 2017: Triple helix dynamics of South Korea's innovation system: a network analysis of inter-regional technological collaborations. Quality & Quantity 51-3. DOI: https://doi.org/10.1007/s11135-016-0346-x

Acta geographica Slovenica, 63-1, 2023, 89–109

PREDICTING THE POTENTIAL ECOLOGICAL NICHE DISTRIBUTION OF SLOVENIAN FORESTS UNDER CLIMATE CHANGE USING MAXENT MODELLING

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The *Hacquetio-Fagetum* forests in the southeastern part of the Mirna Valley.

DOI: https://doi.org/10.3986/AGS.11561
UDC: 630*111(497.4)"2080/2100"
581.9:630*0:551.583(497.4)"2080/2100"

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Predicting the potential ecological niche distribution of Slovenian forests under climate change using MaxEnt modelling

ABSTRACT: The aim of the article is to assess the potential impacts of climate change on Slovenian forests in the period 2080–2100 based on two climate scenarios: SSP1-2.6 (optimistic) and SSP5-8.5 (pessimistic) using the MaxEnt software. Slovenian forests are divided at the ecological community level into thirteen forest vegetation types. Analyses of changes in ecological niche areas, distances of vectors between centroids of present areas and future ecological niches, and general spatial changes are carried out. In addition, changes in the altitudinal zones of forest vegetation types were investigated. The results indicate significant changes for Thermophilous beech forests and Thermophilous hop-hornbeam, sessile oak, downy oak, Scots pine and black pine forests. The potential changes in the altitudinal zones of forest vegetation types indicate a clear trend of forest vegetation types moving to higher altitudinal zones.

KEY WORDS**:** phytogeography, ecological niche modelling, shared socio-economic pathways (SSP), forest vegetation types, Slovenia

Ocena možnih vplivov podnebnih sprememb na prostorsko razporeditev ekoloških niš slovenskih gozdov z uporabo metode maksimalne entropije

POVZETEK: Namen raziskave je bil oceniti možne vplive podnebnih sprememb na slovenske gozdove v obdobju 2080–2100 glede na dva podnebna scenarija: SSP1-2.6 (optimistični) in SSP5-8.5 (pesimistični) z metodo maksimalne entropije. Gozdni rastiščni tipi so razdeljeni na trinajst gozdnih vegetacijskih tipov. Opravljeni sta analizi prostorskih sprememb ekoloških niš in razdalj vektorjev med centroidi sedanjih območij in napovedanih ekoloških niš ter sinteza skupnih možnih prostorskih sprememb gozdnih vegetacijskih tipov. Raziskane so tudi možne spremembe sestave vegetacijskih pasov. Rezultati kažejo na možnost znatnih sprememb ekoloških niš. Največje skupne prostorske spremembe so bile ocenjene za termofilna bukovja in termofilna črnogabrovja, hrastovja, rdečeborovja in črnoborovja. Rezultati analize možnih sprememb vegetacijskih pasov kažejo trend pomikanja v višje nadmorske višine.

KLJUČNE BESEDE: fitogeografija, modeliranje ekoloških niš, smeri skupnega družbenogospodarskega razvoja (SSP), gozdni rastiščni tipi, Slovenija

The article was submitted for publication on February 13th, 2023.
Uredništvo je prejelo prispevek 13. februarja 2023.

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1 Introduction

This study uses MaxEnt, one of the ecological niche modelling methods, to assess the potential impacts of climate change on Slovenian forests. Ecological niche modelling has become an important branch of phytogeography as the question of the potential impacts of climate change on species distribution becomes increasingly important. Planet Earth is facing changes in its climate system due to massive anthropogenic greenhouse gas emissions (Masson-Delmotte et al. 2021). The impacts of climate change may significantly alter or damage ecosystems, biodiversity and various plant and wildlife habitats, including the stability of society (Baisero et al. 2020; Brodie et al. 2020; Pörtner et al. 2022).

Martinez Del Castillo et al. (2022) predicted growth declines of European beech forests by 2090 for the CMIP6 climate scenarios SSP1-2.6 and SSP5-8.5. They predicted the most significant productivity losses towards the southern distribution limit of *Fagus sylvatica*. A reduction in areas suitable as habitat for most tree species, with higher elevation areas is expected in Greece in SSP1-2.6 and SSP5-8.5 experiencing greater potential habitat shrinkage (Fyllas et al. 2022). Buras and Menzel (2019) projected a decline in tree species richness in Mediterranean and Central European lowlands based on the CMIP5 climate scenarios RCP4.5 and RCP8.5, while Scandinavian and Central European high mountain forests are expected to experience an increase in diversity over the period 2061–2090. Another European study by Dyderski et al. (2018) shows different response patterns of tree species to projected climate change in RCP2.6 and RCP4.5 scenarios, although the species studied would face a significant decrease in suitable habitat area.

With about 61.5% of the country's land area, Slovenia is the country with the third largest forest area in relation to the total area in the EU-28, according to Eurostat. The diverse ecological conditions have enabled the development of a relatively high forest species richness on a small area (Kutnar, Kobler and Bergant 2009). Kutnar, Kobler and Bergant (2009) showed that global warming could have a significant impact on the redistribution of Slovenian forest vegetation types (FVTs).

A later study by Kutnar and Kobler (2011) predicted a decline in beech forests and an increase of thermophilous forests by 2100 for both optimistic and pessimistic climate scenarios. It was also predicted that a large proportion of coniferous forests would be transformed to deciduous forests. According to Kutnar and Kobler (2014), the abundance of three of the most important tree species in Slovenian forests – *Picea abies*, *Fagus sylvatica* and *Abies Alb*a – is likely to decrease significantly by the end of the 21st century. In the pessimistic scenario, the population of these tree species could decline by 97%, 82% and 97%, respectively. They predicted the spread of thermohilous, drought-tolerant species and vegetation types (e.g. *Ostrya carpinifolia*, *Fraxinus ornus*, *Quercus pubescens*), the largest potential increase was predicted for *Robinia pseudoacacia*.

The aim of this study is to assess the potential impacts in the period 2080–2100 based on the two CMIP 6 climate scenarios: SSP1-2.6 (optimistic) and SSP5-8.5 (pessimistic). The optimistic scenario predicts an increase in global average temperature of 2.0 °C (with a 5–95% range of 1.3–2.8 °C) in the period 2081–2100 compared to the period 1850–1900. In contrast, the pessimistic scenario, characterised by high GHG emissions and limited mitigation action, predicts a stronger increase in global average temperature of 4.8 °C (with a 5–95% range of 3.6-6.5 °C) during the same period compared to the period 1850–1900 (Lee et al. 2021).

2 Methods

2.1 Data

The 78 most important Slovenian forest communities were grouped into 13 FVTs at the ecological community level based on their common preferences for site conditions following the approach from Kutnar, Kobler and Bergant (2009) and Kutnar and Kobler (2011) (Table 1).

The FVT sampling data were taken from the Slovenian Forest Vegetation Map at a scale of 1:100,000 (Košir et al. 1974; Košir et al. 2003; Košir et al. 2007). The map covers the entire territory of Slovenia. Part of the FVT08 (Table 1) located on the Karst plateau and in the coastal region) was manually added to the FVT10, as we were guided by the latest forestry vegetation data from 2021 (Bončina et al. 2021), which were not available in GIS. For the presence data, 200 points were created randomly for each FVT, except for FVT09, FVT11 and FVT13. For these FVTs, 130 points were created randomly, as their area is relatively small compared to the grid cell size of the environmental data (500 m).

Table 1: The 13 Slovenian forest vegetation types.

Forest vegetation type	Representative forest communities
Acidophilous beech forests (FVT01)	*Blechno–Fagetum, Castaneo–Fagetum, Hieracio rotundati–Fagetum, Luzulo–Fagetum*
Acidophilous Scots pine forests (FVT02)	*Vaccinio myrtilli–Pinetum, Galio rotundifolii–Pinetum*
Lower mountainous beech forests on neutral or calcareous soils (FVT03)	*Hacquetio–Fagetum* var. geogr. *Geranium nodosum, Hacquetio–Fagetum* var. geogr. *Anemone trifolia, Hacquetio–Fagetum* var. geogr. *Ruscus hypoglossum, Hedero–Fagetum*
Mountainous beech forests on neutral or calcareous soils (FVT04)	*Arunco–Fagetum, Lamio orvalae–Fagetum* var. geogr. *Dentaria pentaphyllos, Lamio orvalae–Fagetum* var. geogr. *Dentaria polyphyllos, Aceri–Fraxinetum* s. lat.
High mountainous beech forests on neutral or calcareous soils in the Alpine region (FVT05)	*Homogyno sylvestris–Fagetum, Ranunculo platanifolii–Fagetum* var. geogr. *Hepatica nobilis, Anemono trifoliae–Fagetum* var. geogr. *Luzula nivea, Anemono trifoliae–Fagetum* var. geogr. *Helleborus niger, Lamio orvalae–Fagetum* var. geogr. *Sesleria autumnalis*
High Mountainous beech forests on neutral or calcareous soils in the Dinaric region (FVT06)	*Omphalodo–Fagetum* var. geogr. *Calamintha grandiflora, Stellario montanae–Fagetum, Ranunculo platanifolii–Fagetum* var. geogr. *Calamintha grandiflora, Polysticho lonchitis–Fagetum, Isopyro–Fagetum, Cardamini savensi–Fagetum*
Thermophilous beech forests (FVT07)	*Ostryo–Fagetum, Seslerio autumnalis–Fagetum, Ornithogalo pyrenaici–Fagetum*
Colline oak–hornbeam forests (FVT08)	*Ornithogalo pyrenaici–Carpinetum, Abio albae–Carpinetum betuli, Helleboro nigri–Carpinetum betuli, Epimedio–Carpinetum, Pruno padi–Carpinetum betuli*
Lowland willow, alder, and pedunculate oak forests (FVT09)	*Alnetum glutinosae* s. lat., *Alnetum incanae, Querco roboris–Carpinetum, Pseudostellario–Quercetum, P.–Carpinetum, Salicetea purpureae*
Thermophilous hop–hornbeam, sessile oak, downy oak, Scots pine, and black pine forests (FVT10)	*Aristolochio luteae–Quercetum pubescentis, Ostryo carpinifoliae–Fraxinetum orni, Cytisantho–Ostryetum, Genisto januensis–Pinetum, Lathyro–Quercetum petraeae, Fraxino orni–Pinetum nigrae, Querco–Ostryetum carpinifoliae, Seslerio autumnalis–Ostryetum*
Silver fir forests (FVT11)	*Bazzanio–Abietetum, Galio rotundifolii–Abietetum, Neckero–Abietetum*
Norway spruce forests (FVT12)	*Adenostylo glabrae–Piceetum, Luzulo sylvaticae–Piceetum, Asplenio–Piceetum, Rhytidiadelpho lorei–Piceetum, Mastigobryo–Piceetum, Laburno alpini–Piceetum, Sphagno-Piceetum, Hacquetio–Piceetum*
Dwarf mountain pine scrubs (FVT13)	*Hyperico grisebachii–Pinetum mugo, Rhodothamno–Pinetum mugo, Rhodothamno–Laricetum*

Table 2: Description of bioclimatic variables (adapted from O'Donnell and Ignizio 2012).

Variable	BIO1	BIO2	BIO3	BIO4	BIO5
Description	Annual mean temperature	Mean diurnal range	Isothermality	Temperature seasonality	Max temperature of warmest month
Variable	BIO6	BIO7	BIO8	BIO9	BIO10
Description	Min temperature of coldest month	Temperature annual range	Mean temperature of wettest quarter	Mean temperature of driest quarter	Mean temperature of warmest quarter
Variable	BIO11	BIO12	BIO13	BIO14	BIO15
Description	Mean temperature of coldest quarter	Annual precipitation	Precipitation of wettest month	Precipitation of driest month	Precipitation seasonality
Variable	BIO15	BIO16	BIO17	BIO18	
Description	Precipitation of wettest quarter	Precipitation of driest quarter	Precipitation of warmest quarter	Precipitation of coldest quarter	

Twenty-one layers of environmental predictors were used in this study. Based on several examples (Portilla Cabrera and Selvaraj 2020; Du et al. 2021; Saha, Rahman and Alam 2021; Zeng et al. 2021), we used 18 bioclimatic variables (Table 2) and an additional 3 layers: the approximation of soil pH, the Euclidean distance of water bodies and the topographic wetness index (TWI). The last environmental predictor was calculated using SAGA software (TWI (one step)) (Conrad et al. 2015). The bioclimatic data were obtained from the WorldClim portal (Fick and Hijmans 2017). The layer to approximate the soil pH was calculated with GIS using the Slovenian soil map from 2007 provided by the Slovenian Ministry of Agriculture, Forestry and Fisheries, and theoretical assumptions about the response of soil types (Repe 2010). GIS was used to approximate the last two layers using DEM and a layer of linear Slovenian water bodies provided by the Slovenian environment agency (2006) and the Agency for real estate cadastre (2013).

All covariates were used with a spatial resolution of 500 m and extended to the entire study area, which is the Republic of Slovenia. The bioclimatic reference variables for present-day conditions represented the period 1970–2000. The bioclimatic data obtained had a spatial resolution of 2.5 arc minutes and were downscaled using a combination of methods described by other authors (Ninyerola, Pons and Roure 2000; Ninyerola, Pons and Roure 2007; Poggio, Simonetti and Gimona 2018). The downscaling process in this study is described by Gregorčič, Rozman and Repe (2022).

The future bioclimatic data represent the projected climatic conditions in the period 2080–2100. Two climate scenarios (SSP1-2.6, SSP5-8.5) and three Earth System Models (CNRM-ESM2-1, BCC-CSM2- MR, and MIROC6) were used. The final future bioclimatic variables were produced by averaging the results of all three ESMs.

The bias files for each FVT were created using the buffered minimum convex polygon (MCP) method from SDM Toolbox and integrated into ArcGIS Pro (Brown 2014).

2.2 Modelling

The modelling was done using MaxEnt software, which has several advantages. The method requires species occurrence data, it can handle both continuous and categorical covariates, the output is continuous and allows fine distinction between suitability of different areas (Phillips, Anderson and Schapire 2006). However, there are also some disadvantages: the method is prone to overfitting (Radosavljevic and Anderson 2014). The most important measure of model quality is AUC (area under the curve) values. AUC is a measure of two-dimensional space under the receiver operating characteristic (ROC) curve. Nevertheless, some authors advise against using AUC values for various statistical reasons (Lobo, Jiménez-Valverde and Real 2008; Hanczar et al. 2010). Inference from presence-only data also requires strong assumptions that are often violated (Yackulic et al. 2013).

The modelling was based on 4 theoretical (A) and 3 methodological (B) assumptions (Guisan, Thuiller and Zimmermann 2017):

A1 – The relationship between species and environmental needs is considered to be in equilibrium.
A2 – It is assumed that all environmental predictors required to capture the desired niche of the modelled FVT are available at the resolution relevant to the modelled FVT.
A3 – It is assumed that the likely future environment is accessible to the species to the same extent as it is today.
A4 – The entire realised niche is captured in the model.
B1 – The statistical modelling methods used are appropriate for the data being modelled.
B2 – There are no errors in the independent variables.
B3 – The data on the occurrence of FVT are unbiased.

Prior to final modelling, a pre-selection of variables was made, testing collinearity between bioclimatic covariates to avoid multicollinearity in the model. An approximation of soil pH from the digital soil map was used to model the potential ecological niche of each FVT. The distance between the water body level and the ITV level was only used for modelling the ecological niche of FVT09. The selection of bioclimatic covariates for a given FVT was based firstly on a collinearity test and secondly on the significance of the covariates for the respective FVT. A total of 10,000 random sample points were created in the study area. The bioclimatic covariates were included in the sample and the Pearson coefficient matrix was calculated. If two covariates had a correlation greater than 0.8 or less than –0.8, one was excluded from the final model. To exclude the independent variable that was less important for the modelling results, we ran 13 test-MaxEnt

Table 3: The final selection of independent variables per FVT.

	BIO1	BIO2	BIO3	BIO4	BIO5	BIO6	BIO7	BIO8	BIO9	BIO10	BIO11
FVT01	×	✓	×	×	×	✓	✓	✓	✓	✓	×
FVT02	✓	×	✓	✓	×	×	✓	✓	✓	×	×
FVT03	×	×	✓	✓	✓	✓	✓	✓	✓	×	×
FVT04	×	×	✓	×	×	✓	✓	✓	✓	✓	×
FVT05	×	✓	×	✓	✓	✓	✓	✓	✓	×	×
FVT06	×	×	✓	×	×	✓	✓	✓	✓	✓	×
FVT07	×	×	✓	✓	✓	×	✓	✓	✓	×	×
FVT08	×	×	✓	✓	✓	✓	✓	✓	✓	×	×
FVT09	×	×	✓	×	×	✓	✓	✓	✓	✓	×
FVT10	×	×	✓	✓	×	×	✓	✓	✓	×	✓
FVT11	×	×	×	✓	×	✓	×	✓	✓	×	✓
FVT12	×	✓	×	×	×	✓	✓	✓	✓	✓	×
FVT13	×	✓	×	×	×	✓	✓	✓	✓	✓	×

	BIO12	BIO13	BIO14	BIO15	BIO16	BIO17	BIO18	BIO19	soil pH approximation	TWI	distance to hydrological network.
FVT01	✓	×	×	✓	×	×	×	×	✓	×	×
FVT02	✓	×	×	✓	×	×	×	×	✓	×	×
FVT03	×	×	×	✓	×	×	✓	✓	✓	×	×
FVT04	×	×	×	✓	×	×	×	✓	✓	×	×
FVT05	×	×	×	✓	×	×	✓	✓	✓	×	×
FVT06	×	×	×	✓	×	✓	×	×	✓	×	×
FVT07	×	×	×	✓	×	×	✓	✓	✓	×	×
FVT08	×	×	×	✓	×	×	✓	✓	✓	×	×
FVT09	×	×	×	✓	×	×	✓	✓	✓	✓	✓
FVT10	×	×	×	✓	×	×	✓	✓	✓	×	×
FVT11	×	×	×	✓	×	×	✓	✓	✓	×	×
FVT12	✓	×	×	✓	×	×	×	×	✓	×	×
FVT13	×	×	×	✓	×	×	✓	✓	✓	×	×

models for each FVT with 20 or 22 covariates for the period 1970–2000 and bias files. 20% of the FVT sample points were used for data validation using a cross-validation test, and the regularisation multiplier had a default value of 1.0. Based on the results of the Jackknife test, the one with the least significance among two highly correlated independent variables was excluded from the final selection (Table 3). Sometimes the Jackknife results showed a negative value for a particular covariate, which meant that this covariate was detrimental to the final results (Phillips 2017). In these cases, we excluded the covariate from the final selection. This was necessary for FVT04 – BIO2, FVT07 – BIO6 and FVT11 – BIO2, BIO7 (Table 3).

The final potential ecological niche modelling of FVT was conducted with the same settings as in the test phase and new selection of independent variables. In addition, a regularisation multiplier value of 0.8 was used for FVT01 and FVT02 because the probability distribution for 1970–2000 was too wide when using a regularisation multiplayer value of 1.0.

Separate spatial results were merged into one layer using the GIS software. Each raster cell in the study area maintained the highest probability value from all 13 ecological niche distribution layers. Each ecological niche distribution layer was subtracted from the merged layer. In the final step, raster cells with a value of 0.0 were classified as the result of the ecological niche distribution modelling of the specific FVT. To evaluate the results, the area and centroid differences between the present FVTs and the modelled ecological niches were calculated. This enables a holistic assessment of the results (Guisan, Thuiller and Zimmermann 2017).

3 Results

3.1 Performance Statistics

The performance of the models was statistically analysed by assessing the area under the curve (AUC) values. The AUC test value of each modelling procedure was higher than 0.7. The FVT03, FVT01 and FVT07 scored 0.71, 0.77 and 0.78, respectively. The FVT04, FVT11, FVT10, FVT08, FVT05 and FVT06 scored 0.84, 0.84, 0.86, 0.86, and 0.87 respectively. The FVT02, FVT12, FVT13 and FVT09 scored 0.90, 0.92, 0.92, and 0.94 respectively, indicating excellent results (Araújo et al. 2005). Table 4 summarizes the response curves for all covariates for each selected FVT.

3.2 Changes in the ecological niche areas based on the selected SSP scenarios

Currently, *Fagus sylvatica* forests dominate in Slovenia, covering 72.83% of the total national forest area (Bončina et al. 2021). Within the structure of *Fagus sylvatica* forests, FVT01 is the most widespread, while FVT07 make up the smallest proportion. The FVT09 have the smallest share of Slovenia's total national forest area with only 1.52%.

In the optimistic scenario, the results show that the areas of FVT06, FVT13, FVT12 and FVT11 would decrease by 92.81%, 87.19%, 84.42% and 41.30%, respectively. All areas of *Fagus sylvatica* FVTs decreased, except for the FVT07. Thus, the combined area of *Fagus sylvatica* would decrease to 38.81% of the total forest area. Based on current knowledge of successional processes FVT08 could partially replace FVT03, which is consistent with our results. FVT02, FVT07, FVT08 and FVT10 would expand their ecological niches by 67.37%, 126.06%, 201.12% and 327.59%, respectively. Based on these dynamics, FVT10 makes up the largest share of the national forest area.

In the pessimistic scenario, all FVTs would experience a decrease in area, except for FVT07 and FVT10. They expanded by 282.54% and 804.25% respectively. In this scenario, no areas would be suitable for FVT12. Almost 100% decrease would be experienced by FVT01, FVT04, FVT05, FVT03, FVT13 and FVT06, which also experience 97.23%, 98.26%, 98.34%, 99.13%, 99.38% and 99.97% respectively. Although FVT08 could experience expansion in the SSP1-2.6 scenario, the results show that their area would decrease by 78.25% in the SSP5-8.5 scenario. The same pattern is seen for FVT09, although they would experience the smallest area decrease of all FVTs (8.03%). When analysing absolute numbers, FVT10 and FVT07 would occupy the largest share of the total forest area (6,951.64 km^2 or 65.26% and 3,089.88 km^2 or 29.01%, respectively). All other FVT area sizes would be negligible.

Table 4: *Summary of the response curves of selected covariates for each FVT* (The primary and secondary optima are referred to as (1) and (2), respectively. If there are two equally important optima, both are labelled (1). In the line for the approximation to the soil pH, (a) stands for automorphic soils with predominantly eutrophic properties and (b) for automorphic soils with predominantly dystric properties.).

	FVT01	FVT02	FVT03	FVT04	FVT05	FVT06	FVT07
BIO1 (°C)		9					
BIO2 (°C)	7				16,5$^{(1)}$, 6$^{(2)}$		
BIO3 (%)		34	34–37	42		41–44	8$^{(1)}$, 48$^{(2)}$
BIO4 (°C)		560–570		630			
BIO5 (°C)			25		18		21.5–23
BIO6 (°C)	–5.1		–4.5	–6	–8	≤ –9	
BIO7 (°C)	20–29	29	28–29.5	33	23	24.5	26
BIO8 (°C)	15.8	19$^{(1)}$, 7$^{(2)}$	17.5$^{(1)}$, 6$^{(2)}$	15.5$^{(1)}$, 5$^{(2)}$	13$^{(1)}$, 3$^{(2)}$	5$^{(1)}$, 13.5$^{(2)}$	15
BIO9 (°C)	–1.9$^{(1)}$, 13$^{(2)}$	–0.5	–1	–2$^{(1)}$, 9.5–12.5$^{(2)}$	–4$^{(1)}$, 12$^{(2)}$	9.5$^{(1)}$, –3$^{(2)}$	13$^{(1)}$, –3$^{(2)}$
BIO10 (°C)	18.5			14.5–16.5		11.5–13.5	
BIO12 (mm)	800$^{(1)}$, 1050$^{(2)}$	950$^{(1)}$, 1300$^{(2)}$					
BIO15 (%)	37	22.5$^{(1)}$, 34$^{(2)}$	20–27.5	22.5–32	23–24	16.5–18.5$^{(1)}$, 31.5$^{(2)}$	17$^{(1)}$, 32$^{(2)}$
BIO17 (mm)						480	
BIO18 (mm)			295–370		465		550–640$^{(1)}$, 320$^{(2)}$
BIO19 (mm)			195	460$^{(1)}$, 155$^{(2)}$	490$^{(1)}$, 220$^{(2)}$		390–460$^{(1)}$, 155$^{(2)}$
soil pH approx.	(b)	(b)	(a)	(a)	(a)	(a)	(a)

	FVT08	FVT09	FVT10	FVT11	FVT12	FVT13
BIO1 (°C)						
BIO2 (°C)					4–6	2–4$^{(1)}$, > 15$^{(2)}$
BIO3 (%)	36	32	40			
BIO4 (°C)	710		620–650	690		
BIO5 (°C)	27$^{(1)}$, 25.5$^{(2)}$					
BIO6 (°C)	–4	–4		–6	–8	–10
BIO7 (°C)	30–31	31	25		21–23	< 26$^{(1)}$, > 28$^{(2)}$
BIO8 (°C)	8$^{(1)}$, 18.5$^{(2)}$	19	9.5	15.5–16	4$^{(1)}$, 12–12.5$^{(2)}$	1–3$^{(1)}$, 12$^{(2)}$
BIO9 (°C)	0	0	15	–2.5	–4$^{(1)}$, 8.5$^{(1)}$	–5
BIO10 (°C)		19.5			12	8.2
BIO11 (°C)			3	–2.5		
BIO12 (mm)					1700–1850	
BIO15 (%)	38$^{(1)}$, 19.5$^{(2)}$	29.5	18.5	33–35$^{(1)}$, 18.5$^{(2)}$	19.5$^{(1)}$, 36$^{(2)}$	23.5
BIO17 (mm)						
BIO18 (mm)	270–355	260$^{(1)}$, 665$^{(2)}$	245–280	420		580
BIO19 (mm)	95$^{(1)}$, 180$^{(2)}$	100$^{(1)}$, 500$^{(2)}$	250	130$^{(1)}$, 320$^{(2)}$		400
soil pH approx.	(b)$^{(1)}$, (a)$^{(2)}$	(b)$^{(1)}$, (a)$^{(2)}$,	(a)	(b)	(a)$^{(1)}$, (b)$^{(1)}$	(a)
TWI		11				
dist. from hydro. network (m)		0				

Table 5: Changes in the ecological niche areas based on the selected SSP scenarios.

	Today		SSP1-2.6			SSP5-8.5		
	km^2	%	km^2	%	% change	km^2	%	% change
FVT01	1,933.4	18.2	978.9	9.2	–9.0	53.6	0.5	–17.6
FVT02	217.4	2.0	363.9	3.4	1.4	152.9	1.4	–0.6
FVT03	1,888.3	17.7	436.0	4.1	–13.6	16.5	0.2	–17.6
FVT04	615.1	5.8	491.4	4.6	–1.2	10.7	0.1	–5.7
FVT05	947.2	8.9	314.2	3.0	–5.9	15.8	0.1	–8.7
FVT06	1,566.4	14.7	112.6	1.1	–13.6	0.5	0.0	–14.7
FVT07	807.7	7.6	1,801.7	16.9	9.3	3,089.9	29.0	21.4
FVT08	703.0	6.6	2,117.0	19.9	13.3	152.9	1.4	–5.2
FVT09	161.4	1.5	298.4	2.8	1.3	148.4	1.4	–0.1
FVT10	768.8	7.2	3,287.2	30.9	23.6	6,951.6	65.3	58.0
FVT11	680.2	6.4	399.3	3.8	–2.6	58.8	0.6	–5.8
FVT12	200.8	1.9	31.3	0.3	–1.6	/	/	–1.9
FVT13	162.8	1.5	20.9	0.2	–1.3	1.0	0.0	–1.5
Sum	10,652.6	100.0	10,652.6	100.0	0.0	10,652.6	100.0	0.0

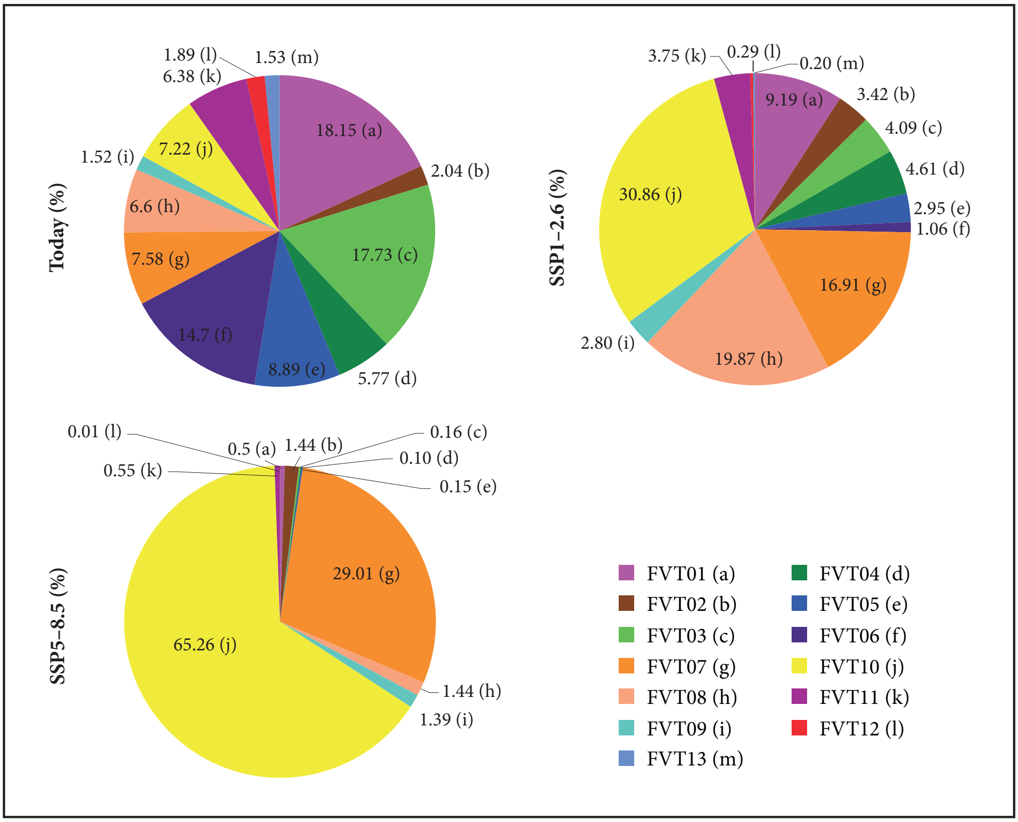


Figure 1: Shares of the ecological niche area changes based on the selected SSP scenarios.

3.3 Vectors between centroids of forest vegetation types for the selected SSP scenarios

In the optimistic scenario, Thermophilous beech forests (FVT07), Lowland willow, alder and pedunculate oak forests in the lowlands (FVT09) and High mountainous beech forests on neutral or calcareous soils in the Dinaric region (FVT06) experienced the greatest spatial changes in centroids (81.10 km, 58.64 km, 47.89 km) in eastern (77.89°), western (272.61°) and northern (2.95°) directions, respectively. Norway spruce forests (FVT12) experienced the least spatial changes in centroids (6.35 km) in east (90.34°) direction. All results are listed in Table 5.

In the pessimistic scenario, Lowland willow, alder and pedunculate oak forests (FVT09), Thermophilous beech forests (FVT07) and High mountain beech forests on neutral or calcareous soils in the Dinaric region (FVT06) would experience the largest spatial changes of centroids (89.35 km, 82.24 km, 72.56 km) in western (262.15°), eastern (77.52°) and northwestern (296.55°) directions, respectively. Dwarf mountain pine scrub (FVT13) would experience the least spatial change in centroids (21.60 km) in the west (286.59°) direction (Figure 2).

Table 6: Lengths and directions of vectors between centroids of forest vegetation types for the selected SSP scenarios.

	SSP1-2.6		SSP5-8.5	
	(km)	Azimuth (°)	(km)	Azimuth (°)
FVT01	12.33	north (348.35)	27.57	north-west (303.05)
FVT02	13.02	north-east (62.22)	31.12	north-east (60.47)
FVT03	32.11	west (265.69)	61.25	north-west (303.44)
FVT04	34.85	west (291.77)	50.5	north-west (304.14)
FVT05	20.94	west (277.49)	27.63	west (276.82)
FVT06	47.89	north (2.95)	72.56	north-west (296.55)
FVT07	81.1	east (77.98)	82.24	east (77.52)
FVT08	15.21	west (285.04)	55.47	north (356.21)
FVT09	58.64	west (272.612)	89.35	west (262.15)
FVT10	21.14	east (69.99)	38.78	north-east (60.41)
FVT11	46.55	west (261.13)	42.64	west (270.24)
FVT12	6.35	east (90.34)	/	/
FVT13	13.64	west (273.77)	21.6	west (286.59)

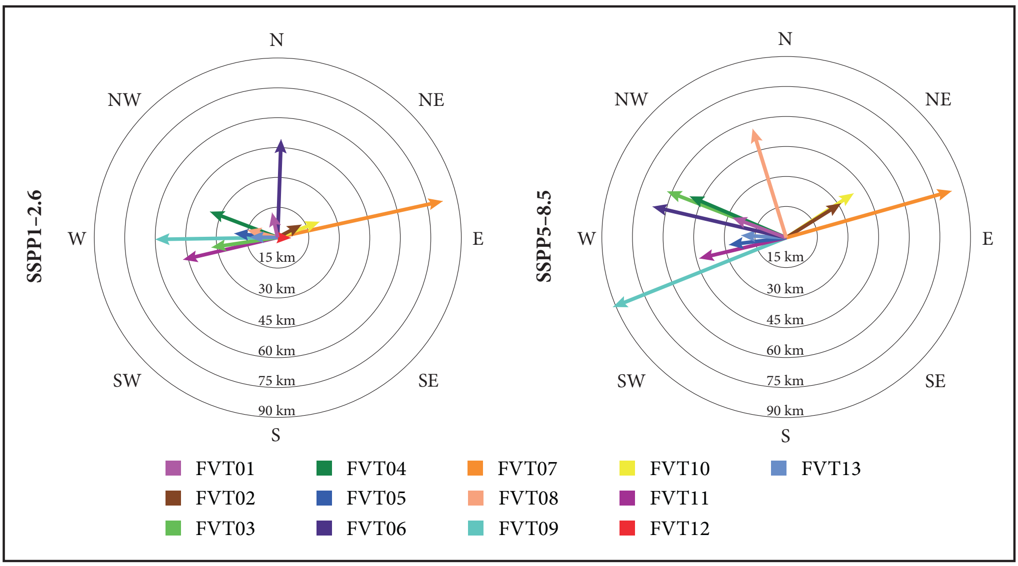


Figure 2: Graphical representation of vectors between centroids of forest vegetation types for the selected SSP scenarios.

3.4 Synthesis of the ecological niche changes for the selected SSP scenarios

Combining the results of changes in ecological niche areas and vectors between centroids, we obtained the final synthesis results for the potential impacts of climate change on Slovenian forests in the period 2080–2100 based on the selected SSP scenarios (Table 6, Figure 3). In the optimistic scenario, the ecological niche of Thermophilous beech forests (FVT07) would experience the greatest spatial change. High mountain beech forests on neutral or calcareous soils in the Dinaric region (FVT06) and Thermophilous hornbeam, sessile oak, downy oak, Scots pine and black pine forests (FVT10) would experience the second and third largest spatial changes, respectively. The least spatial changes would occur in the ecological niches of Norway spruce forests (FVT12), Acidophilous Scots pine forests (FVT02) and Dwarf mountain pine scrubs (FVT13).

Under the pessimistic scenario, the ecological niche of Thermophilous hop hornbeam, sessile oak, downy oak, Scots pine and black pine forests (FVT10) would experience the greatest spatial changes. Thermophilous beech forests (FVT07) and Beech forests in the lower uplands on neutral or calcareous soils (FVT03) would experience the second and third largest spatial changes, respectively. The least spatial changes would occur in the ecological niches of Norway spruce forests (FVT12), Lowland willow, alder and pedunculate oak forests (FVT09) and Acidophilous Scots pine forests (FVT02).

Table 7: Synthesis of the ecological niche changes for the selected SSP scenarios.

	SSP1-2.6				SP5-8.5			
	Area change factor	Vector change factor	Spatial change	Order	Area change factor	Vector change factor	Spatial change	Order
FVT01	0.38	0.15	0.057	8	0.30	0.31	0.09	5
FVT02	0.06	0.16	0.010	12	0.01	0.35	0.004	11
FVT03	0.58	0.40	0.232	4	0.30	0.69	0.21	3
FVT04	0.05	0.43	0.022	10	0.10	0.57	0.06	6
FVT05	0.25	0.26	0.065	6	0.15	0.31	0.05	9
FVT06	0.58	0.59	0.342	2	0.25	0.81	0.21	4
FVT07	0.39	1.00	0.390	1	0.37	0.92	0.34	2
FVT08	0.56	0.19	0.106	5	0.09	0.62	0.06	7
FVT09	0.05	0.72	0.036	9	0.002	1.00	0.002	12
FVT10	1.00	0.26	0.260	3	1.00	0.43	0.43	1
FVT11	0.11	0.57	0.063	7	0.10	0.48	0.05	8
FVT12	0.07	0.08	0.006	13	0.00	0.00	0.00	13
FVT13	0.06	0.17	0.010	11	0.03	0.24	0.01	10

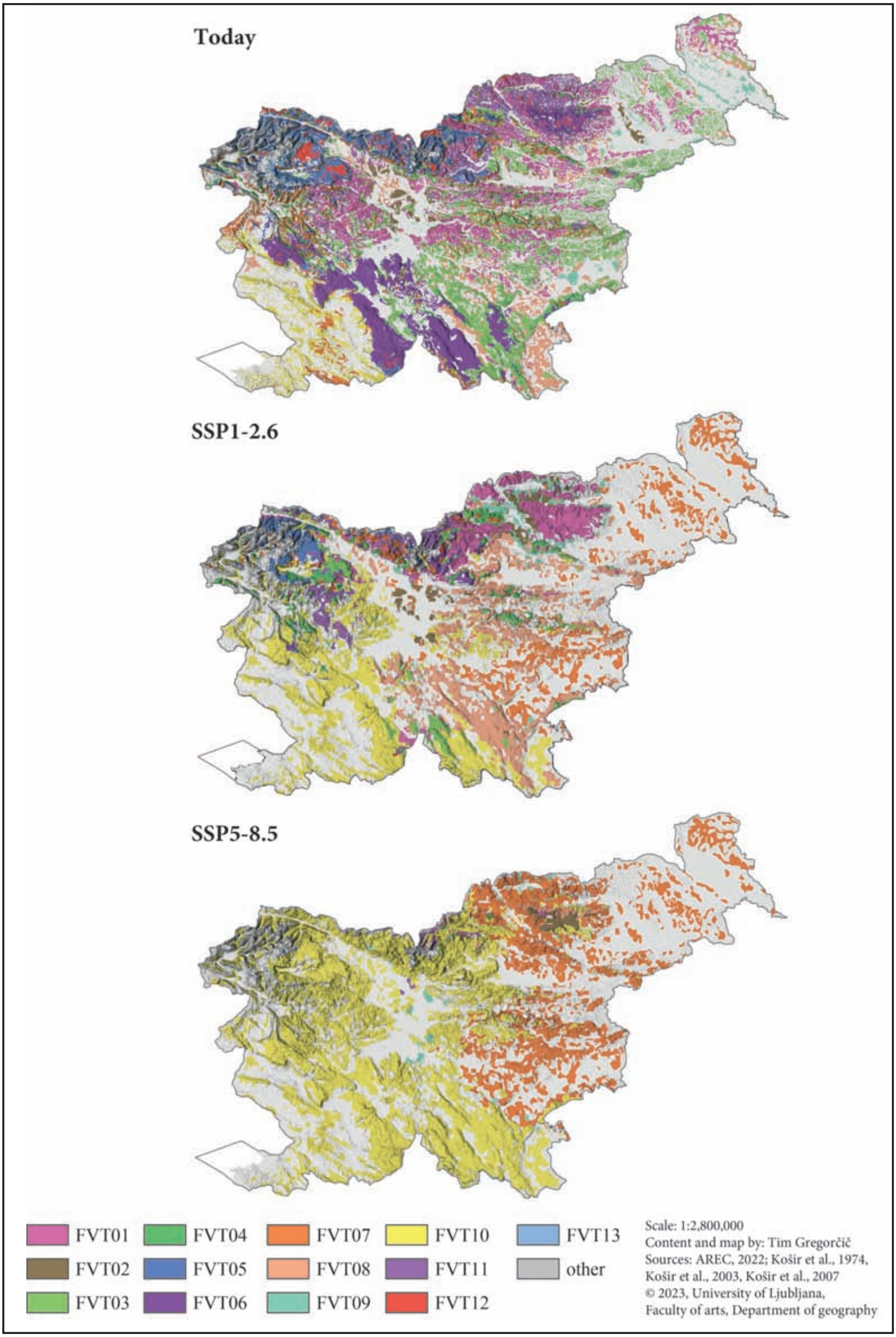
3.5 Changes in the altitudinal zones of the forest vegetation types

The analysis of the results indicates significant potential changes in the structure of the 7 altitudinal zones of the forest vegetation types occurring in Slovenia (Wraber 2008, cited in Ogrin and Plut 2012).

Today, most of the area of Acidophilous beech forests (FVT01) (50.59%) thrives in the lowlands. Most of the area suitable for Acidophilous beech forests (FVT01) (54.80% and 83.39%) would shift to the montane belt in SSP1-2.6 and SSP5-8.5, respectively. This FVT could also reach the lower alpine belt, where it does not occur today (Figures 4 and 5).

Most of today's Acidophilous Scots pine forests (FVT02) are found in the lowlands (89.67%). They can also grow at higher altitudes, with the highest representation in the montane belt. In scenario SSP1-2.6, the largest proportion of suitable area would be found in the lower montane belt (50.66%). In scenario SSP5-8.5, the largest proportion of suitable area would be found in the upper montane belt (97.00%). The pessimistic scenario also indicates potential areas in the lower alpine belt where it does not occur today.

Figure 3: Potential spatial ecological niche changes of Slovenian FVTs for selected SSP scenarios. ➤ p. 100


Today
SSP1-2.6
SSP5-8.5
FVT01
FVT02
FVT03
FVT04
FVT05
FVT06
FVT07
FVT08
FVT09
FVT10
FVT11
FVT12
FVT13
other
Scale: 1:2,800,000
Content and map by: Tim Gregorčič
Sources: AREC, 2022; Košir et al., 1974, Košir et al., 2003, Košir et al., 2007
© 2023, University of Ljubljana, Faculty of arts, Department of geography

Lower mountain beech forests on neutral or calcareous soils (FVT03) is another type that is most widespread in the lowlands today (61.39%), but also reaches the montane belt with a relatively small area share (2.98%). In scenario SSP1-2.6, the largest proportion of suitable areas is in the montane belt (76.16%) and in the lower Alpine belt in scenario SSP5-8.5 (50.78%).

The largest proportion of today's Mountain beech forests on neutral or calcareous soils (FVT04) thrives in the lower montane belt (55.18%). In the optimistic and pessimistic climate scenarios, the most suitable areas would shift to the montane belt (58.11% and 61.84%, respectively). Mountain beech forests on neutral or calcareous soils (FVT04) could also disappear from the lowlands in the SSP5-8.5 scenario.

Most of today's high Mountain beech forests on neutral or calcareous soils in the Alpine region (FVT05) thrive in the montane belt (82.17%), although they are found in all altitudinal zones except the alpine and lower nival belt. The largest proportion of suitable areas would decrease in the optimistic scenario but would remain in the montane belt (73.66%) and could also spread into the alpine belt. In the pessimistic scenario, the largest proportion of suitable areas would shift to the lower alpine belt (62.91%).

Like the High mountain beech forests on neutral or calcareous soils in the Alpine region (FVT05), the High mountain beech forests on neutral or calcareous soils in the Dinaric region (FVT06) are mainly present in the montane belt (59.79%) and can be found at all altitudes, except for the alpine and lower nival belt. The largest proportion of suitable area would not only remain in the montane belt (87.80%) but would also increase as the area in the lowland and lower montane zones is reduced in the SSP1-2.6 scenario. In the SSP5-8.5 scenario, most of the suitable area for High mountain beech forests on neutral or calcareous soils in the Dinaric region (FVT06) would be in the upper montane belt (50.01%), while the other half would be in the lower alpine belt.

Thermophilous beech forests (FVT07) are most widespread in the lower montane belt and may occur into the upper montane belt. Suitable areas for this FVT would spread into the lower Alpine belt in the optimistic and pessimistic climate scenarios, while most areas would be found in the montane belt (86.09% and 73.46%, respectively).

The present Colline oak-hornbeam forests (FVT08) thrive in the first 3 altitudinal zones, with 94.06% occurring in the lowlands. In the SSP1-2.6 scenario, most suitable areas would remain in the lowlands (47.52%), although the proportion in the lower montane belt would be almost the same (46.61%). In the SSP5-8.5 scenario, suitable areas for Colline Oak-Hornbeam Forests (FVT08) would be found in the higher altitude zones, including the lower Alpine belt, with the majority in the montane belt (79.56%).

Like the Colline oak-hornbeam forests (FVT08), most of the present Lowland willow, alder and pedunculate oak forests (FVT09) grow in the first 3 altitudinal zones, with 99.35% in the lowlands. In the optimistic scenario, the areas suitable for these FVTs would remain in the same altitudinal zones, but most would grow in the lower montane belt (55.69%). In the pessimistic scenario, most suitable areas would remain in the lowlands (64.88%), but would increase in the higher latitudes, including the lower Alpine belt. As Lowland willow, alder and pedunculate oak forests (FVT09) depend on a high-water table, the spread of suitable areas at higher altitudes is questionable.

Thermophilous hop hornbeam, sessile oak, downy oak, Scots pine and black pine forests (FVT10) are most widespread in the lowlands (48.50%) and can be found at higher altitudes, including the lower Alpine belt. In scenarios SSP1-2.6 and SSP5-8.5, most suitable areas were located in the lower montane belt (42.98% and 41.32%, respectively). Under the pessimistic scenario, suitable areas would also be found in the alpine belt (Figure 4).

Most of today's Silver fir forests (FVT11) grow in the lower montane belt (51.40%) and are found as far as the lower Alpine belt. In the optimistic climate scenario, the areas suitable for FVT would remain in the same altitudinal zones, with the majority in the montane belt (63.00%). In the pessimistic scenario, the majority of the suitable areas would remain in the montane belt (56.24%) and increase in the alpine belt.

Spruce forests (FVT12) mainly thrive in the lower montane belt (87.65%). In the optimistic scenario, the largest proportion of suitable areas would be in the lower alpine belt, while the results for the pessimistic scenario indicate no suitable areas.

Dwarf mountain pine scrub (FVT13) is most widespread in the montane belt (41.35%) and can be found in all elevation zones except lowland. In the optimistic scenario, most suitable areas would be in the alpine belt (40.21%), while in the SSP5-8.5 scenario, the lower alpine belt would be most suitable (50.00%) and would only occur in the upper montane and lower alpine belts.

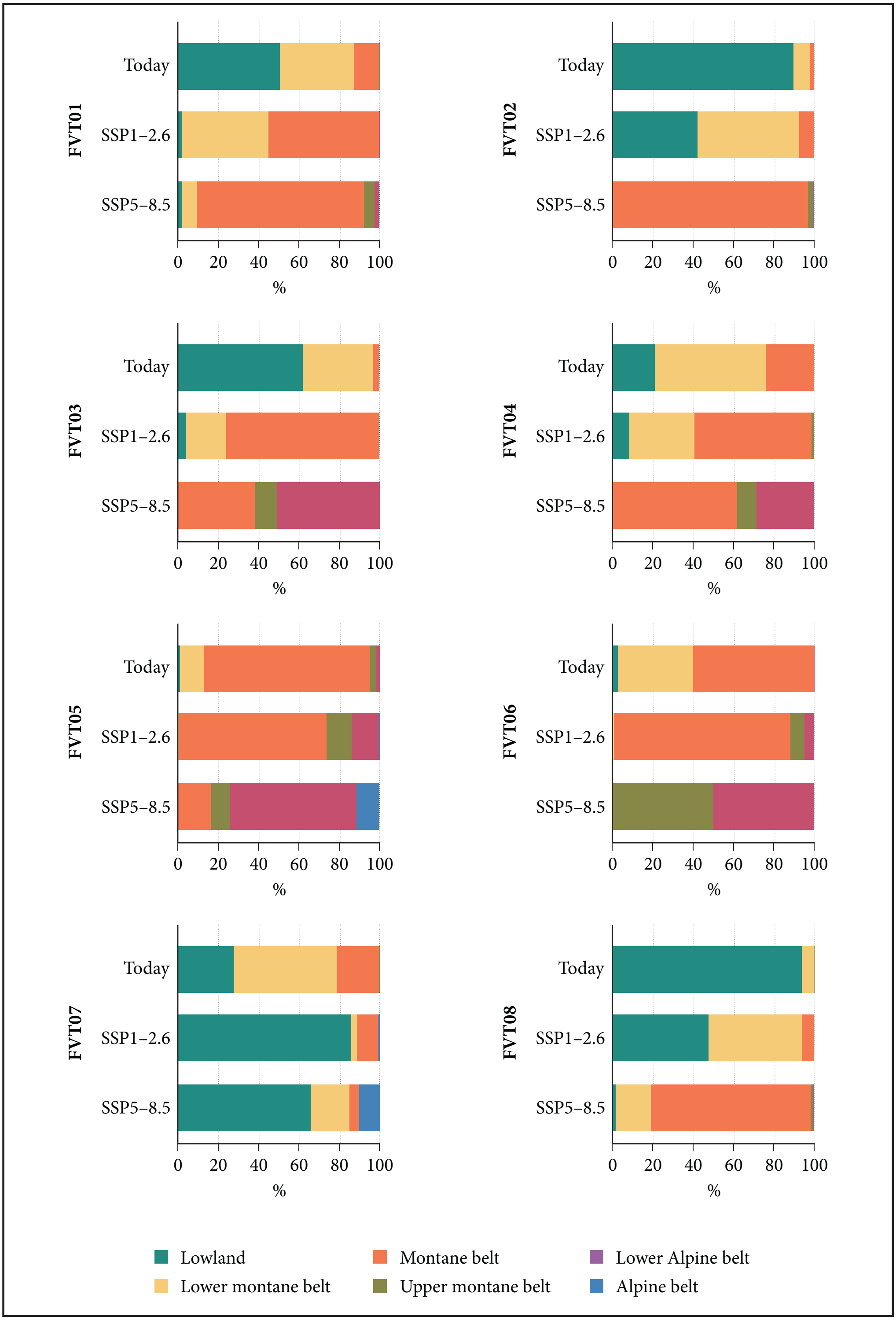

FVT01
FVT02
FVT03
FVT04
FVT05
FVT06
FVT07
FVT08
Today
SSP1–2.6
SSP5–8.5
0
20
40
60
80
100
%
Lowland
Lower montane belt
Montane belt
Upper montane belt
Lower Alpine belt
Alpine belt

Figure 4: Potential altitudinal ecological niche changes of the first eight Slovenian FVTs for the selected SSP scenarios.

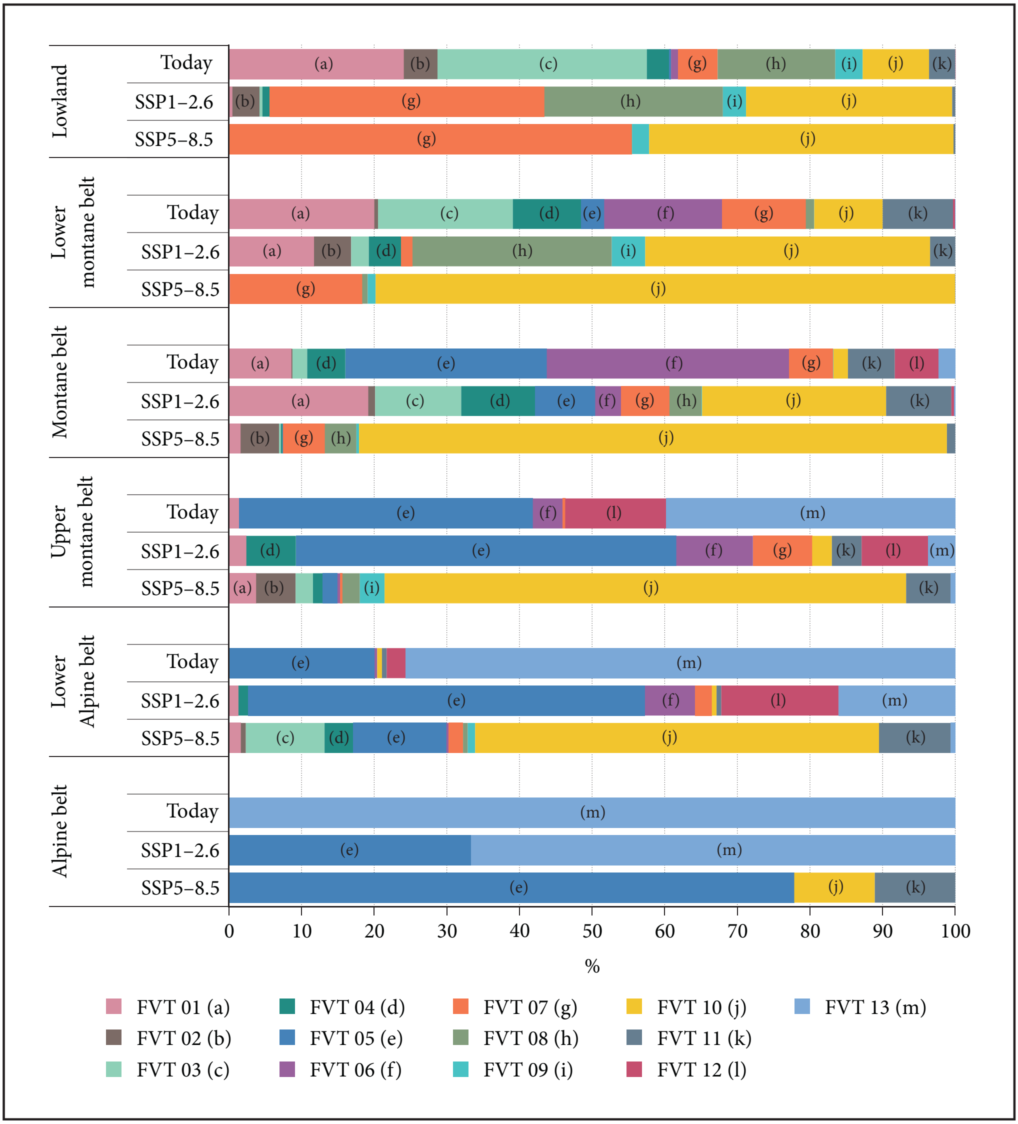


Figure 5: Potential structural changes of Slovenian altitudinal zones for the selected SSP scenarios.

4 Discussion

In SSP1-2.6, modelling results indicate that suitable areas for FVT02, FTV07, FVT08 and FVT10 would expand, while suitable areas of other FVTs would decrease. In SloveniaFVT02 are characterised as secondary FVTs. With the rise in temperature, intensification of droughts and their more frequent occurrence, the decline of suitable areas for FVT02 is more realistic. The expansion of FVT08 could be a consequence of the temperature increase at the time of winter temperature inversions. Currently, most FVT08 areas are located in the thermal belt, which is warmer than the bottoms of the valleys and basins during temperature inversions. In SSP5-8.5, only the thermophilous FVTs would expand. As the suitable areas of FVT06 and FVT13 are expected to be extremely small (0.51 km^2 and 1.02 km^2, respectively), it is possible that these areas remained due to possible methodological shortcomings (data quality, etc.) and would not exist in the SSP5-8.5 scenario, if realised. Based on these results, there could be a gradual decrease in suitable areas for FVT11. However, on a smaller spatial scale, they also thrive under warmer site conditions, such as in the low karst plain of Bela krajina. In shady gorges with appropriate humidity, they could therefore become even more competitive.

This was the first study to use MaxEnt modelling software and scenarios from SSP to assess the potential impacts of climate change on Slovenian forests. Our results show that even if the optimistic scenario occurs, site conditions may change drastically, potentially affecting the future distribution of Slovenian forest vegetation types.

The results generally confirm the direction of possible changes in the findings of Kutnar, Kobler and Bergant (2009). However, the methodology of their study was different, using different climate scenarios, independent variables, future time periods and modelling methods. Therefore, the comparability between these two studies is limited and will not be discussed in detail. Broadly, projected trends for *Fagus sylvatica* FVTs indicate a decline in suitable area, including for Thermophilous beech forests (FVT07), which is partly consistent with our results. However, in agreement with our results, the study also predicted an increase in area share for Colline oak–hornbeam forests (FVT08) and Thermophilous hop–hornbeam, sessile oak, downy oak, Scots pine and black pine forests (FVT10).

Kutnar and Kobler (2011; 2014) had similar comparability problems but they focused on predicting changes that would occur by the end of the 21st century. Therefore, a comparison of their results with our study is still useful. Nevertheless, we refrain from a quantitative comparison, as this would be inappropriate due to the impossibility of making quantitative comparisons between the climate scenarios of both studies. In summary, our results are largely consistent with theirs. Their 2011 paper also found an increase in suitable area for thermophilous FVTs and a decrease for other FVTs. However, the comparison raises questions about the mechanisms driving the spread of thermophilous FVTs and their ecological relationships. Moreover, our projections are rather conservative with respect to the possible disappearance of FVTs in the pessimistic scenario. These observations highlight the importance of further research into the mechanisms and dynamics of FVTs in a changing climate, and the need to be cautious when making projections about their future distribution.

There are some other studies that have analysed the potential impacts of climate change on forests in Europe using MaxEnt. Although they are only partially comparable with our results due to different target time periods, climate scenarios (RCPs), study areas, study area scales and ecological levels, some common general directions of change can be observed. Decolonisation of *Picea abies* (part of FVT12 in this study) at lower altitudes in Slovenia and spread of *Quercus petraea* were predicted by Mauri et al. (2022) for the moderate climate scenario (RCP4.5). The results of Dyderski et al. (2018) suggest that conifer species are more threatened by climate change intensification, which is consistent with our results. A case study in Greece by Fyllas et al. (2022) showed that Thermophilous *Quercus ilex* would be among the species with the lowest habitat loss under the pessimistic climate scenario (RCP8.5). High unsuitability for *Fagus sylvatica* with a 93% decline in habitat suitability was predicted.

When interpreting the changes in the altitudinal zones of the FVTs, one must be aware of their arbitrarily set altitudinal limits. This was necessary because of the analysis of the scale of the whole country. In reality, the elevation zones depend more on the ecological conditions of specific sites and less on the latitude zones themselves. Therefore, the same latitudinal zones may have different latitudinal boundaries across the country; however, this could not be taken into account (Kutnar et al. 2012). In summary, regarding the changes in latitude, the intensification of climate change shows a clear trend towards shifting FVTs to higher altitudes, which is related to the shift of current temperature conditions to higher altitudes.

Our results generally support similar research by Kutnar and Kobler (2011), who suggest that a rise in temperature and changing rainfall patterns due to climate change have the potential to cause a shift of FVTs from lower to higher elevations. However, we cannot directly and quantitatively compare our results with those of Kutnar and Kobler, as they used an intermediate scenario in their study to assess elevation, which was not the case in our study. This trend has already been recognised in several other studies that did not relate to our study area or species (Zhang et al. 2018; Zhao, Zhang and Xu 2020; Soilhi et al. 2022). The shift of FVT05, FVT10 and FVT11 in the Alpine belt is an indicator of one of the methodological shortcomings. According to the soil map of Slovenia, only lithosols are found in this altitudinal zone. From the perspective of pedogenesis, this is a young and poorly developed soil type (Repe 2010). Therefore, the above-mentioned FVTs cannot thrive in this soil type, even though the bioclimatic conditions might make this possible in the coming decades. FVT12 include both primary and secondary FVTs. Thus, although they consist of boreal species, they are mainly found in the lower montane belt. Without human influence, these FVTs are likely to occur today only in frost depressions and at the upper timberline (Bončina et al. 2021), and there would most likely be no suitable areas for these FVTs in SSP1-2.6.

One of the main drawbacks of this study and other ecological niche modelling studies in general is that large-scale weather events and other natural hazards in forests are not taken into account, although they can have a strong impact on forest ecosystems (Vido and Nalevanková 2021). With the intensification and/or increasing frequency of extreme weather events as one of the consequences of global warming (Taccoen et al. 2019; Masson-Delmotte et al. 2021), their increasing influence on forest adaptation to climate change is also expected. Unfortunately, this factor cannot be quantified spatially.

However, many tree species have flexibility and adaptive abilities to adapt to the changing environment. These abilities are not yet fully understood by science (Lindner et al. 2010). Slovenian forests have already been exposed to a number of disturbance factors in recent years, such as bark beetle infestations, storms and ice storms, which may be related to climate change. As a result, the structure and composition of these forests have changed significantly. In the last 15 years, both Norway spruce (*Picea abies*) and silver fir (*Abies alba*) have declined, while the European beech (*Fagus sylvatica*) has increased, primarily due to the decline of the other two aforementioned species (Kutnar, Kermavnar and Pintar 2021).

The results and the methodology used in this study point to several future study topics and extensions. Further methods for modelling ecological niches should be tested and compared with the results of the MaxEnt software. Another approach to assess the potential impact of climate change on Slovenian forests is the analysis of palynological samples from warmer periods of Earth's history. Although we assumed that the upper forest boundary would not change due to the specifics of the methodology, we know that the boundary would most likely shift to higher elevations, which could be investigated using ecological niche modelling. With the rapid spread of several non-native invasive plant species in Slovenia (e.g. *Robinia pseudoacacia*, *Ailanthus altissima*, *Acer negundo*, etc.), the question arises as to how these species might affect forest structure in the future, especially since we already know that they can successfully spread to forest fire pits (Stančič and Repe 2018). Another study confirmed that *Robinia pseudoacacia*, as the dominant invasive species in Slovenian forests, has already significantly changed the composition of Slovenian forest ecosystems (Kutnar and Kobler 2013). Furthermore, the study suggests that the spread of *Robinia pseudoacacia* is likely to continue due to the intensification of climate change. However, it should be noted that modelling the ecological niche of invasive species can be problematic, as it violates the assumption that species are in equilibrium or pseudo-equilibrium with the environment, as Guisan, Thuiller and Zimmermann (2017) point out.

5 Conclusion

This study addresses the potential impact of climate change on Slovenian forests within the context of the SSP1-2.6 and SSP5-8.5 climate scenarios, employing the MaxEnt methodology. The modelling process has yielded statistically accurate results, which generally align with the expected trajectory of climate change effects on Slovenian forests, drawing from current understanding of the ecological requirements of Slovenian FVTs and previous investigations in this domain. Under both scenarios, an expansion of thermophilous FVTs is projected, accompanied by a significant decline in *Fagus sylvatica* FVTs. However, it is important to note that the results obtained are not scientifically provable in practice. While we have made efforts to incorporate all relevant independent variables into the modelling process, the complexity of natural systems renders it impossible to consider all factors that influence FVT development comprehensively. Therefore, caution must be exercised when interpreting the data. It is crucial for the reader to recognise that the outcomes do not constitute deterministic predictions. Instead, the results present potential areas that could exhibit suitability for selected FVTs during the specified time period, based on the current ecological characteristics of their habitats. We generally confirmed the expected trajectory of potential climate change impacts on Slovenian forests, based on current knowledge of the ecological needs of Slovenian FVTs.

6 References

Araújo, M. B., Pearson, R. G., Thuiller, W., Erhard, M. 2005: Validation of species–climate impact models under climate change. Global Change Biology 11-9. DOI: https://doi.org/10.1111/j.1365-2486.2005.01000.x

Baisero, D., Visconti, P., Pacifici, M., Cimatti, M., Rondinini, C. 2020: Projected global loss of mammal habitat due to land-use and climate change. One Earth 2-6. DOI: https://doi.org/10.1016/j.oneear.2020.05.015

Bončina, A., Rozman, A., Dakskobler, I., Klopčič, M., Babij, V., Pojanec, A. 2021: Gozdni rastiščni tipi Slovenije. Vegetacijske, sestojne in upravljavske značilnosti. Ljubljana.

Brodie, G., Holland, E., N'Yeurt, A. D. R., Soapi, K., Hills, J. 2020: Seagrasses and seagrass habitats in Pacific small island developing states: Potential loss of benefits via human disturbance and climate change. Marine Pollution Bulletin 160. DOI: https://doi.org/10.1016/j.marpolbul.2020.111573

Brown, J. L. 2014: SDMtoolbox: A python-based GIS toolkit for landscape genetic, biogeographic and species distribution model analyses. Methods in Ecology and Evolution 5-7. DOI: https://doi.org/10.1111/2041-210X.12200

Buras, A., Menzel, A. 2019: Projecting tree species composition changes of European forests for 2061–2090 Under RCP 4.5 and RCP 8.5 scenarios. Frontiers in Plant Science 9. DOI: https://doi.org/10.3389/fpls.2018.01986

Conrad, O., Bechtel, B., Bock, M., Dietrich, H., Fischer, E., Gerlitz, L., Wehberg, J. et al. 2015: System for automated geoscientific analyses (SAGA) v. 2.1.4. Geoscientific Model Development 8-7. DOI: https://doi.org/10.5194/gmd-8-1991-2015

Du, Z., He, Y., Wang, H., Wang, C., Duan, Y. 2021: Potential geographical distribution and habitat shift of the genus *Ammopiptanthus* in China under current and future climate change based on the MaxEnt model. Journal of Arid Environments 184. DOI: https://doi.org/10.1016/j.jaridenv.2020.104328

Dyderski, M. K., Paź, S., Frelich, L. E., Jagodziński, A. M. 2018: How much does climate change threaten European forest tree species distributions? Global Change Biology 24-3. DOI: https://doi.org/10.1111/gcb.13925

Fick, S. E., Hijmans, R. J. 2017: WorldClim 2: New 1-km spatial resolution climate surfaces for global land areas. International Journal of Climatology 37-12. DOI: https://doi.org/10.1002/joc.5086

Fyllas, N. M., Koufaki, T., Sazeides, C. I., Spyroglou, G., Theodorou, K. 2022: Potential impacts of climate change on the habitat suitability of the dominant tree species in Greece. Plants 11-12. DOI: https://doi.org/10.3390/plants11121616

Gregorčič, T., Rozman, A., Repe, B. 2022: Uporaba metode maksimalne entropije pri proučevanju potencialnega vpliva podnebnih sprememb na slovenske gozdove. Dela 57. DOI: https://doi.org/10.4312/dela.57.57-88

Guisan, A., Thuiller, W., Zimmermann, N. E. 2017: Habitat suitability and distribution models: With applications in R. Cambridge. DOI: https://doi.org/10.1017/9781139028271

Hanczar, B., Hua, J., Sima, C., Weinstein, J., Bittner, M., Dougherty, E. R. 2010: Small-sample precision of ROC-related estimates. Bioinformatics 26-6. DOI: https://doi.org/10.1093/bioinformatics/btq037

Košir, Ž., Zorn Pogorelc, M., Kalan, J., Marinček, L., Smole, I., Čampa, L., Šolar, M. et al. 1974: Gozdnovegetacijska karta Slovenije 1 : 100.000. Ljubljana.

Košir, Ž., Zorn Pogorelc, M., Kalan, J., Marinček, L., Smole, I., Čampa, L., Šolar, M. et al. 2003: Gozdnovegetacijska karta Slovenije (digitalna verzija). Ljubljana.

Košir, Ž., Zorn Pogorelc, M., Kalan, J., Marinček, L., Smole, I., Čampa, L., Šolar, M. et al. 2007: Gozdnovegetacijska karta Slovenije (digitalna verzija). Ljubljana.

Kutnar, L., Kermavnar, J., Pintar, A. M. 2021: Climate change and disturbances will shape future temperate forests in the transition zone between Central and SE Europe. Annals of Forest Research 64-2. DOI: https://doi.org/10.15287/afr.2021.2111

Kutnar, L., Kobler, A. 2011: Prediction of forest vegetation shift due to different climate-change scenarios in Slovenia. Šumarski List 135-3,4.

Kutnar, L., Kobler, A. 2012: Possible impacts of global warming on forest tree species composition in Slovenia. Sustainable Land Management and Climate Changes. Proceedings of the Internatioanl Conference on »Land Conservation« – LANDCON 1209. Belgrade. Internet: http://data.sfb.rs/sftp/landcon1209/Landcon1209_Abstracts.pdf (13. 6. 2023).

Kutnar, L., Kobler, A., 2014. Possible impacts of global warming on forest tree species composition on Slovenia. Challenges: Sustainable Land Management – Climate Change. Reiskirchen.
Kutnar, L., Kobler, A. 2013: Sedanje stanje razširjenosti robinije (*Robinia pseudoacacia L.*) v Sloveniji in napovedi za prihodnost. Acta Silvae et Ligni 102.
Kutnar, L., Kobler, A., Bergant, K. 2009: Vpliv podnebnih sprememb na pričakovano prostorsko prerazporeditev tipov gozdne vegetacije. Zbornik gozdarstva in lesarstva 89.
Kutnar, L., Veselič, Ž., Dakskobler, I., Robič, D. 2012: Tipologija gozdnih rastišč Slovenije na podlagi ekoloških in vegetacijskih razmer za potrebe usmerjanja razvoja gozdov. Gozdarski vestnik 70-4.
Lee, J. Y., Marotzke, J., Bala, G., Cao, L., Corti, S., Dunne, J. P., Engelbrecht, F. et al. 2021: Future global climate: Scenario-based projections and near-term information. Climate Change 2021: The Physical Science Basis. Cambridge, New York.
Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., Garcia-Gonzalo, J. et al. 2010: Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. Forest Ecology and Management 259-4. DOI: https://doi.org/10.1016/j.foreco.2009.09.023
Lobo, J. M., Jiménez-Valverde, A., Real, R. 2008: AUC: A misleading measure of the performance of predictive distribution models. Global Ecology and Biogeography 17-2. DOI: https://doi.org/10.1111/j.1466-8238.2007.00358.x
Martinez Del Castillo, E., Zang, C. S., Buras, A., Hacket-Pain, A., Esper, J., Serrano-Notivoli, R., Hartl, C. et al. 2022: Climate-change-driven growth decline of European beech forests. Communications Biology 5. DOI: https://doi.org/10.1038/s42003-022-03107-3
Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., Caud, N. et al. 2021: Climate change 2021: The physical science basis. Cambridge, New York.
Mauri, A., Girardello, M., Strona, G., Beck, P. S. A., Forzieri, G., Caudullo, G., Manca, F., Cescatti, A. 2022: EU-Trees4F, a dataset on the future distribution of European tree species. Scientific Data 9. DOI: https://doi.org/10.1038/s41597-022-01128-5
Ninyerola, M., Pons, X., Roure, J. M. 2000: A methodological approach of climatological modelling of air temperature and precipitation through GIS techniques. International Journal of Climatology 20-14. DOI: https://doi.org/10.1002/1097-0088(20001130)20:14<1823::AID-JOC566>3.0.CO;2-B
Ninyerola, M., Pons, X., Roure, J. M. 2007: Objective air temperature mapping for the Iberian Peninsula using spatial interpolation and GIS. International Journal of Climatology 27-9. DOI: https://doi.org/10.1002/joc.1462
O'Donnell, M. S., Ignizio, D. A. 2012: Bioclimatic predictors for supporting ecological applications in the conterminous United States. USGS Data Series 691. DOI: https://doi.org/10.3133/ds691
Ogrin, D., Plut, D. 2012: Aplikativna fizična geografija Slovenije. 2. izdaja. Ljubljana.
Phillips, S. J. 2017: A brief tutorial on Maxent. Lessons in Conservation 3. Internet: http://www.amnh.org/content/download/141371/2285439/file/LinC3_SpeciesDistModeling_Ex.pdf (24. 10. 2022).
Phillips, S. J., Anderson, R. P., Schapire, R. E. 2006: Maximum entropy modeling of species geographic distributions. Ecological Modelling 190-3,4. DOI: https://doi.org/10.1016/j.ecolmodel.2005.03.026
Poggio, L., Simonetti, E., Gimona, A. 2018: Enhancing the WorldClim data set for national and regional applications. Science of The Total Environment 625. DOI: https://doi.org/10.1016/j.scitotenv.2017.12.258
Portilla Cabrera, C. V., Selvaraj, J. J. 2020: Geographic shifts in the bioclimatic suitability for *Aedes aegypti* under climate change scenarios in Colombia. Heliyon 6-1. DOI: https://doi.org/10.1016/j.heliyon.2019.e03101
Pörtner, H. O., Roberts, D. C., Tignor, M., Poloczanska, E. S., Mintenbeck, K., Alegría, A., Craig, M. et al. 2022: Climate change 2022: Impacts, adaptation, and vulnerability. Cambridge, New York.
Radosavljevic, A., Anderson, R. P. 2014: Making better Maxent models of species distributions: Complexity, overfitting and evaluation. Journal of Biogeography 41-4. DOI: https://doi.org/10.1111/jbi.12227
Repe, B. 2010: Prepoznavanje osnovnih prsti slovenske klasifikacije. Dela 34. DOI: https://doi.org/10.4312/dela.34.143-166
Saha, A., Rahman, S., Alam, S. 2021: Modeling current and future potential distributions of desert locust *Schistocerca gregaria* (Forskål) under climate change scenarios using MaxEnt. Journal of Asia-Pacific Biodiversity 14-3. DOI: https://doi.org/10.1016/j.japb.2021.05.001

Soilhi, Z., Sayari, N., Benalouache, N., Mekki, M. 2022: Predicting current and future distributions of M*entha pulegium* L. in Tunisia under climate change conditions, using the MaxEnt model. Ecological Informatics 68. DOI: https://doi.org/10.1016/j.ecoinf.2021.101533

Stančič, L., Repe, B. 2018: Post-fire succession: Selected examples from the Karst region, southwest Slovenia. Acta geographica Slovenica 58-1. DOI: https://doi.org/10.3986/AGS.1942

Taccoen, A., Piedallu, C., Seynave, I., Perez, V., Gégout-Petit, A., Nageleisen, L.-M., Bontemps, J.-D., Gégout, J.-C. 2019: Background mortality drivers of European tree species: Climate change matters. Proceedings of the Royal Society B: Biological Sciences 286-1900. DOI: https://doi.org/10.1098/rspb.2019.0386

Vido, J., Nalevanková, P. 2021: Impact of natural hazards on forest ecosystems and their surrounding landscape under climate change. Water 13-7. DOI: https://doi.org/10.3390/w13070979

Yackulic, C. B., Chandler, R., Zipkin, E. F., Royle, J. A., Nichols, J. D., Campbell Grant, E. H., Veran, S. 2013: Presence-only modelling using MAXENT: wWhen can we trust the inferences? Methods in Ecology and Evolution 4-3. DOI: https://doi.org/10.1111/2041-210x.12004

Zeng, J., Li, C., Liu, J., Li, Y., Hu, Z., He, M., Zhang, H., Yan, H. 2021: Ecological assessment of current and future *Pogostemon cablin* Benth. potential planting regions in China based on MaxEnt and ArcGIS models. Journal of Applied Research on Medicinal and Aromatic Plants 24. DOI: https://doi.org/10.1016/j.jarmap.2021.100308

Zhang, K., Yao, L., Meng, J., Tao, J. 2018: Maxent modeling for predicting the potential geographical distribution of two peony species under climate change. Science of The Total Environment 634. DOI: https://doi.org/10.1016/j.scitotenv.2018.04.112

Zhao, H., Zhang, H., Xu, C. 2020: Study on *Taiwania cryptomerioides* under climate change: MaxEnt modeling for predicting the potential geographical distribution. Global Ecology and Conservation 24. DOI: https://doi.org/10.1016/j.gecco.2020.e01313

Acta geographica Slovenica, 63-1, 2023, 111–129

EXTENT AND SPATIAL DISTRIBUTION OF KARST IN SLOVENIA

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A doline in the dolomite karst at Dovce, Rakek.

DOI: https://doi.org/10.3986/AGS.11679
UDC: 913:551.435.88(497.4)

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Extent and spatial distribution of karst in Slovenia

ABSTRACT: This study investigates the spatial distribution of karst in Slovenia using advanced GIS technologies and accurate lithology, hydrology, and digital relief data. Previous approaches led to an incomplete understanding of karst distribution, as they focused on carbonate lithologies and surface features. Our integrated two-step identification method, involving GIS layer overlays and manual review of lithology data, resulted in a comprehensive digital spatial database. We found that karst covers 49.7% of Slovenia's total area, with a diverse range of associated lithologies. This research has important implications for managing and protecting karst aquifers, forest planning, agricultural subsidies, and glacial geomorphology studies, and enables further processing and enhancement by the karst research community.

KEY WORDS: geomorphology, karst, GIS technology, lithology, classification of karst

Obseg in prostorska porazdelitev krasa v Sloveniji

POVZETEK: Ta raziskava preučuje prostorsko razporeditev krasa v Sloveniji z uporabo naprednih tehnologij GIS ter natančnih litoloških, hidroloških in digitalnih podatkov o reliefu. Dosedanji pristopi so vodili k nepopolnemu razumevanju razširjenosti krasa, saj so se osredotočali na karbonatno litologijo in značilnosti površja. Naša integrirana dvostopenjska metoda identifikacije, ki vključuje prekrivanje slojev GIS in ročni pregled litoloških podatkov, je privedla do celovite digitalne prostorske baze podatkov. Ugotovili smo, da kras pokriva 49,7 % celotnega ozemlja Slovenije, z raznoliko paleto pripadajočih litologij. Ta raziskava ima pomembne implikacije za upravljanje in varovanje kraških vodonosnikov, načrtovanje gozdov, kmetijske subvencije in ledeniške geomorfološke študije ter omogoča nadaljnjo obdelavo in nadgradnjo s strani krasoslovcev.

KLJUČNE BESEDE: geomorfologija, kras, GIS tehnologija, litologija, klasifikacija krasa

This article was submitted for publication on February 13th, 2023.
Uredništvo je prejelo prispevek 13. februarja 2023.

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1 Introduction

Karst is a unique geomorphic system characterized by subsurface water flows and is classified in the literature as a subcategory of fluvial geomorphic system (Sweeting 1973; Bögli 1980; White 1988; Ford and Williams 2007). This system is primarily governed by chemical denudation, a surface process that involves chemical weathering of bedrock, particularly through congruent dissolution. Dissolution plays a fundamental role in karst formation, and three basic conditions must be met for its development: soluble rock, water, and the establishment of subsurface drainage (Ford and Williams 2007). Dissolution not only occurs at the surface, but also extends deep into the subsurface, resulting in the formation of dissolution-created channels with high effective permeability (White 2002). These channels are formed from intergranular pores and fractures and allow water to percolate predominantly through the subsurface. In karst systems, aggradation zones are minimal in extent and limited to specific areas such as vadose zone caves and river channels. The dominance of chemical denudation and the absence of aggradation contribute to the characteristic stony surface and diverse landforms unique to this combination of geomorphologic processes (Ford and Williams 2007; Stepišnik 2020; De Waele and Gutiérrez 2022).

Karst, a subtype of fluvial geomorphologic systems characterized by a predominance of subsurface water drainage (Bögli 1980; White 1988), is often defined by the presence of specific landforms rather than by its hydrologic characteristics. Karst areas are usually identified by the presence of dolines or similar karst depressions and cave entrances (Sweeting 1973; Ford and Williams 2007; Sauro 2012) and are often delineated by the absence of a surface drainage network (White 2002). However, this method of classification is problematic because surface form depends on a variety of geomorphologic processes beyond chemical denudation. Consequently, some karst areas have landforms that are not characteristic of karst, such as fluviokarst (Komac 2004; Stepišnik 2021), contact karst (Mihevc 1994; Gams 1995; 2001), and glaciokarst (Smart 1986; Žebre and Stepišnik 2015a; 2015b). Furthermore, the absence of a surface river network does not generally apply to all karst areas; fluviokarst and shallow karst are characterized by the presence of permanent or intermittent surface waters and lakes (Gunn 2004; Stepišnik 2017). Despite these differences, all karst geomorphic systems share common characteristics: soluble bedrock, the presence of water that is not impeded by aridity or cryosphere, and at least some development of subsurface drainage in the karst type of aquifer (Ford and Williams 2007).

The Slovenian karst region occupies an important place in the history of karstology, as this science originated here and has been intensively researched ever since. This research focused on determining the spatial extent of carbonate rocks and karst in Slovenia through various methods. These methods can be categorized based on their approach: identification of karst surface features, distribution of cave entrances, absence of surface drainage networks, and extent of carbonate rocks. Researchers have identified a number of karst surface features, such as dolines (Melik 1935; 1963; Šerko 1947), snow kettles (Melik 1935; 1963; Šerko 1947), and other large karst depressions (Gams 1965; Habič 1982; Novak 1993; Komac and Urbanc 2013a; 2013b; 2016; 2017). They have also studied the spatial distribution of cave entrances (Habič 1982; Novak 1993; Komac and Urbanc 2013a; 2013b; 2016; 2017) to determine the extent of karst in Slovenia. In addition to these features, researchers have considered the absence of a surface drainage network (Šerko 1947; Gams 1965; Habič 1982; Novak 1993; Komac and Urbanc 2013a; 2013b; 2016; 2017) and the extent of carbonate rocks (Melik 1935; 1963; Gams 1974; 2003; Habič 1982; Novak 1993; Komac and Urbanc 2013a; 2013b; 2016; 2017) in defining karst areas. Earlier methods focused mainly on deep karst, which is characterized by surface dissection with karst depressions and the absence of a surface drainage network. However, these methods often excluded other karst geomorphic environments where surface transformations occur by other geomorphic processes. These environments include shallow karst, fluviokarst, glaciokarst, and contact karst (Stepišnik 2020).

Karst distribution inventories are essential for a comprehensive understanding, effective management and sustainable development of karst landscapes. Their importance cuts across all disciplines, influencing hydrogeological research, geomorphological studies, biodiversity conservation efforts, engineering projects and environmental impact assessments. Ongoing efforts to document and update karst inventories on either regional (e.g. Gao, Alexander and Tipping 2005; Petrič et al. 2020a; 2020b), national (e.g. Temovski 2012; Asanidze et al. 2019; Sun et al. 2020), or even global level (e.g. Ford and Williams 2007; Chen et al. 2017; Goldscheider et al. 2020) are essential for informed decision-making, promoting responsible land use practises and ensuring the long-term conservation of these unique and valuable landscapes. Studies on karst distribution usually follow a geology-based approach, where areas with potential for karst development are delineated by compiling areas of soluble rocks from geological maps. In this paper, we have adopted a similar geology-based approach.

The aim of the study is to determine the spatial extent and distribution of karst in Slovenia. For this purpose, the lithostratigraphic map of Slovenia at a scale of 1:250,000 is used as a basis, and other relevant data sources are used as supplementary material (e.g. morphology of the doline surface, location of cave entrances, absence of a surface drainage network, morphology of the karst surface, etc.).

2 Previous research on the extent of karst in Slovenia

So far, various studies have been published on the distribution of karst in Slovenia. The authors use different classifications to categorise the carbonate rocks. In most cases, limestone and dolomite are represented by separate categories, while the descriptions of the impure carbonate rocks vary. Some authors refer to these rocks as »impure carbonate rocks«, while others describe them as »clastic carbonate rocks«. Furthermore, in most cases Holocene carbonate gravel has not been added to the summary values for carbonate rocks.

In addition, most authors dealing with the analysis of the distribution of the karst surface were limited to the classification of the surface by lithological type (e.g. limestone, dolomite). Therefore, the extent of carbonate rocks in Slovenia was often mistakenly considered to be synonymous with the distribution of the karst surface distribution in Slovenia. In this paper, we focus our review of previous research on the sources that define karst as a relief type and not only the extent of carbonate rocks.

The first references in the literature defining the extent of karst in Slovenia were provided by Melik (1935). In his research, he describes different karst areas within the ethnic Slovenian boundaries. In his publication, he does not specify the exact extent of the Slovenian karst, but they can be reconstructed on the basis of the attached map. He made a map of the karst areas on the basis of the spatial distribution of dolines and snow kettles, which he most probably identified from topographic maps available at the time. The descriptions of karst areas and the extent of karst in Slovenia were also provided in his following publications (e.g. Melik 1963). According to Melik (1935; 1963), karst covers 28% of the present-day area of Slovenia. In his classification of karst, he used the division of karst according to Cvijić (1893; 1924) into holokarst or perfect karst and merokarst or incomplete karst.

More detailed estimates of the extent of karst in Slovenia were published by Šerko (1947). Based on an analysis of maps at a scale of 1:100,000, he estimated the density of the surface drainage network and the presence of karst landforms such as dolines, snow kettles, uvalas, and poljes. He divided the karst in Slovenia into the Dinaric karst, the Alpine karst and the karst in small isolated areas in the Savinja Alps and in northern and southern Slovenia, based on the location of geomorphological environments to which he attributed common morphogenesis and morphodynamics. He did not quantify the extent of karst in Slovenia, but only depicted it on maps. According to his cartographic data, the extent of karst in Slovenia is 30%.

Gams (1965) defines the extent of karst using an approach similar to that of Šerko (1947) taking into account surface forms, especially karst relief depressions and the density of the surface drainage network. He also points out the shortcomings of his estimates, since it is difficult to assess the extent of karst in dolomitic karst areas and on slopes within the alpine highlands because of the lack of typical karst landforms or karst-specific drainage network patterns. He estimates that the proportion of karst in Slovenia is somewhere between 1/3 and 1/2. Gams (1965) also offers a regional classification of karst in his publication, largely adopted from Šerko (1947), dividing it into the karst of the Julian Alps and Kamnik-Savinja Alps, the karst of the Karawanks, the isolated karst of the pre-Alps and Pannonian area, and the karst of the Dinaric Mountains.

Habič (1969) points out that there are no precise data on the extent of karst in Slovenia, and at the same time refers to the fact that karst covers 1/3 of the territory, which corresponds to Gams (1965). In his publication he gives a hydrographic regionalization in which the karst is divided into Alpine karst, Dinaric karst and Isolated karst on the basis of geological, hydrological and geomorphological features, which was largely adopted from Šerko (1947).

Gams (1972) states that the proportion of karst in Slovenia is about 1/3. He did not specify a method for determining the proportion of karst, but probably referred to earlier publications (Gams 1965; Habič 1969). In this publication he presents a new regionalization of karst, based mainly on Šerko's (1947) division of karst. Gams (1972) concludes that karst in Slovenia is primarily located on carbonate rocks.

Gams (1974), in a comprehensive overview of karst, describes in detail the various karst areas in Slovenia and other parts of the Dinaric Mountains. He states that the proportion of carbonate rocks in Slovenia is 43%. The proportion of karst associated mainly with carbonate rocks is somewhat lower.

Habič (1982), in his interpretation of the extent of karst in Slovenia, considered not only hydrological, morphographic, and geological characteristics, but also the distribution of speleological objects. He estimated that the extent of karst in Slovenia is about 44%. Moreover, he characterised karst on the basis of hydrological and lithological characteristics and not only on the basis of spatial distribution, as in previous literature (Gams 1965; 1972; 1974; Šerko 1947). It is divided into deep karst, partial karst, a combination of deep and partial karst, and karst with developed intergranular conductivity. About 31% of the area of Slovenia is attributed to deep karst on limestones, while the area of the other karst types is about 13%.

The estimated proportion of karst identified by Šušteršič (1991) in the overview map of karst in Slovenia is about 50%. He classified karst on the basis of location and hydrological function in an approach similar to Cvijić (1924), Šerko (1947) and Habič (1982). He divides it into alpine karst, low and high Dinaric karst, and isolated and incomplete pre-alpine karst. In his typification he does not define the poljes as karst areas.

Novak (1993) states that karst covers an area of 9,000 km^2, which is 44.4% of the area of Slovenia. Like his predecessors (Gams 1965; 1972; Habič 1969; 1982; Šerko 1947; Šušteršič 1991), he characterises karst according to its location and states that karst in Slovenia was formed in limestones and dolomites dating from the Triassic to the Oligocene and in Pleistocene conglomerates.

In the Geographical Atlas of Slovenia (Fridl et al. 1998) two general maps of the karst in Slovenia are published at a scale of 1:750,000. On a general map of the karst area, Mihevc (1998) divided the karst into Alpine, Pre-Alpine, High-Dinaric and Low-Dinaric karst and marked many karst landforms, e.g. karst plateaus, plains, poljes, large collapse dolines, caves, blind valleys and others. The estimated karst area in Slovenia is 50.2% on his map (Mihevc 1998). In the same publication, Kranjc (1998) shows two types of karst on a map of karst waters, namely on limestone and dolomite. On both types of karst he marks karst poljes or »flood-prone areas on karst« as he writes on the map. The estimated karst area in Slovenia is 45% on his map.

Gabrovec and Hrvatin (1998; 2016) published a map of genetic relief types, on which they also determined the areas of limestone and dolomite karst relief. According to their 1:750.000 (1998) and 1:1,000,000 (2016) scale map, limestone karst covers 25% of the area in Slovenia and dolomite karst covers 14% of the area. Altogether, the karst covers 39% of Slovenia. The sources do not indicate what data they used to determine the extent of karst relief. The authors describe that in some areas there is an interweaving of different geomorphic systems. Therefore, poljes are not counted as karst genetic relief types, but as an accumulative fluvial-denudational relief. High-mountain regions where the glacial genetic relief type occurs are designated as glacial, regardless of the bedrock.

The most frequently cited figure for the proportion of karst was given by Gams (2003) in a comprehensive regional overview of karst areas in Slovenia. Despite a detailed overview of all karst areas, he quotes an old data for the proportion of karst, where it is estimated at 43%–35% on limestone, and 8% on dolomite (Gams 1974).

Some recent interpretations of the extent of karst were made by Komac and Urbanc (2013b). They summarise the proportion of karst according to Gams (1974). In their GIS-based karst classification, they used the method of Habič (1982), dividing karst areas into two categories based on the spatial distribution of carbonate rocks, the presence of dolines and cave entrances, and the absence of a surface drainage network. Intensively karstified areas cover an estimated 24% of Slovenia, and less intensively karstified areas 21%.

Subsequent studies by Komac and Urbanc (2013b) indicate that the proportion of karst in Slovenia is 45.6%. They determined the proportion based the spatial distribution of carbonate rocks on geological map of Slovenia in scale 1:250,000 (Buser 2010a). Based on the concurrent presence of caves, dolines and surface water streams, they determined that intensively karstified areas make up 31.8% of the Slovenian territory. All other areas on carbonate rocks, accounting for 13.7% of Slovenia, were classified as potentially karstified. They found that limestone is the predominant rock type subject to karstification, but that dolomite is also common in intensively karstified areas. In areas where dolomite is the predominant rock, the degree of karstification is lower as dolomite is less prone to karstification. In their classification of karst, they have excluded areas covered by poljes and areas where karst is overlain by younger sediments. The authors have also published comparable data in some other publications (Komac and Urbanc 2016; 2017).

As part of the World Karst Aquifer Mapping project, the World Karst Aquifer Map (WOKAM; Chen et al. 2017) was created using the Global Lithological Map (GLiM) (Hartmann and Moosdorf 2012) and other relevant data sources (e.g. karst water sources, cave locations, etc.). For WOKAM, the following main mapping units were assessed: carbonate rocks (sedimentary or metamorphic), evaporites, other sedimentary formations, and other metamorphic rocks and igneous rocks. In Slovenia, karst outcrops account for 49.5% of the surface.

3 Materials and methods

The spatial analysis we used to determine the distribution of karst in Slovenia was carried out using two approaches. A vector map of rock types for the entire country was used as a basis. The first approach represented an attempt to fully quantify and objectively determine the karst areas by spatially overlaying the following data: the presence of dolines, cave entrances and the surface river network. The second approach was a manual inspection of the rock type polygon dataset and a manual determination of the presence of karst and the type of karst. For the manual analysis, we relied on the results of the analysis of the first approach for decision-making and reviewed the spatial data considered both spatially (i.e. on the map; Figure 1) and in the associated attribute table. ESRI ArcGISPro 3.0.0 software was used to perform the spatial analyses.

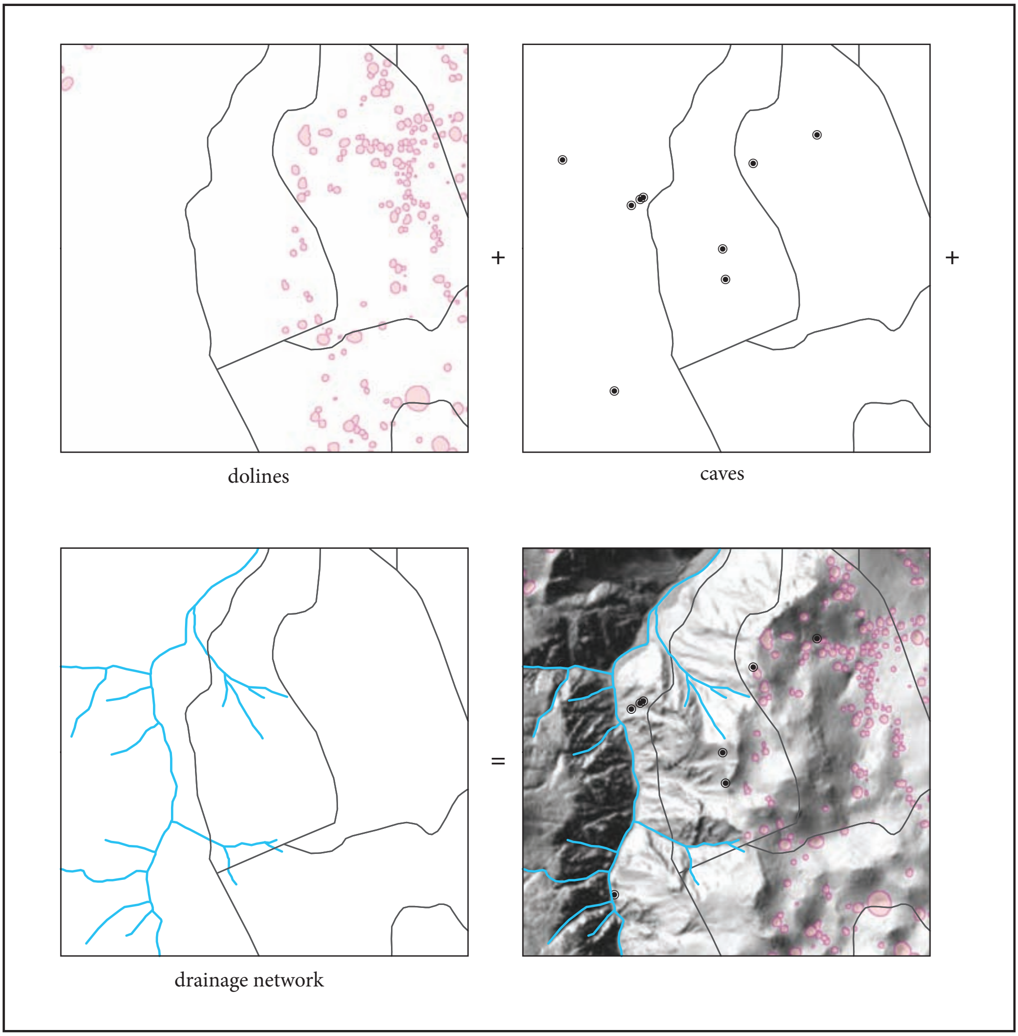


Figure 1: Schematic representation of the steps in the spatial analysis of the lithological units.

3.1 Data sources

As a spatial data source for the surface lithology a vector map of rock types in Slovenia was used (Zemljevid tipov kamnin 2012). This data source was based on the lithostratigraphic map of Slovenia (Litostratigrafska karta Slovenije 2011), which was primarily based on 1:25,000 vectorized geological maps of Slovenia. The data on surface lithology was prepared at a scale of 1:100,000 and is currently the only available and updated lithologic map at this scale that does not contain missing or inconsistent data on the contacts of the individual sheets of the Basic geological map of Slovenia. It is considered more detailed than the 1:250,000 scale geologic map of Slovenia by Buser (2010b), because it is not as generalised and provides data directly from the base geologic maps of Slovenia. The lithological map of Slovenia consists of 12,635 polygon features divided into 25 lithostratigraphic units (Perko, Hrvatin and Ciglič 2015; Hrvatin 2016). All polygons within the layer have a reference to the Basic geological map of Slovenia data: the age and the description of the lithological unit. The database was provided by the authors in a vector format (.shp) and could be analysed in a GIS environment. The data were topologically ordered: all overlapping polygons and all holes in the data set were removed. Such data can then be used for spatial analyses. Using this data source, the occurrence of carbonate rocks in Slovenia was calculated (Gostinčar 2016) and used as a data source for this study. Each polygon contained an attribute defining whether it was classified as carbonate rock (limestone, mixed limestone-dolomite bedrock, dolomite, clastic carbonate rock) or non-carbonate rock.

Dolines are small to medium sized closed depressions and are the most numerous karst feature in Slovenia. The outlines of dolines in Slovenia from Mihevc and Mihevc (2021) were used. A georeferenced catalogue of the dolines is freely available at https://dolines.org/ (polygon, .shp). Dolines were determined using a trained algorithm on the Lidar DEM of Slovenia. The catalogue contains 471,192 dolines in all Slovenian karst areas (Mihevc and Mihevc 2021).

The digital vector layer (point, .shp) of the Cave Register of the Cave Association of Slovenia and the Karst Research Institute ZRC SAZU, as of March 2022, was used to locate the caves. In addition to the coordinates of the cave entrances, the cave register also contains other attributes (e.g. length and depth of the cave, year of discovery, etc.). Cave locations vary in terms of accuracy. The locations of some caves were determined using hand-held GPS, medium-scale maps (e.g. 1:25,000, 1:50,000), while some more recent data are based on lidar data. The data layer we used contained 14,695 caves.

The vector line layer (.shp) of surface waters in Slovenia from the Water Atlas was used as a data source for the surface water network (Slovenian Environment Agency 2022). It is considered the most detailed data source for the surface drainage network in Slovenia; it is based on watercourses marked on topographic maps in 1:5,000 scale, which had been digitised and georeferenced using the national Lidar DEM.

As a source for DEM, we used high-resolution lidar data DEM obtained from the Slovenian national aerial laser scanning conducted in the period between 2011 and 2015 (Triglav Čekada and Bric 2015; Atlas okolja 2022 – http://gis.arso.gov.si/atlasokolja/), which has been widely used for morphographic analyses of the karst surface in recent research, especially in geomorphometric studies of dolines (e.g. Čeru, Šegina and Gosar 2017; Grlj 2021; Mihevc and Mihevc 2021; Ciglič, Čonč and Breg Valjavec 2022). A DEM with a cell resolution of one meter was used. To visualise the high-resolution digital elevation model, the following visualisations from DEM were used to represent the relief: hillshade and sky view factor (Kokalj and Hesse 2017).

3.2 Spatial analysis

To determine whether karst occurs in a particular lithological unit, we added information about the spatial presence of dolines, caves, or a surface drainage network to each polygon of the lithologic map. We used the *Select by Location* function for each of the datasets to determine the polygons of the lithologic layer on which any of the three aforementioned objects are located. Three attributes were assigned to the attribute table of lithologic units: *cave*, *doline*, and *water*, having the following values: »1«: yes (cave / doline / water is present) or »0«: no (cave / doline / water is not present).

The presence of the surface water network could not be fully used as an indicator of the presence or absence of karst. On the karst surface, the surface drainage network is often absent, but in many places, water flows on top of karst – e.g. on fluviokarst, shallow karst, contact karst, etc. Therefore, we were able to calculate the higher probability of occurrence of karst on a single lithologic unit using only the sum of the attribute values for caves and dolines. For all polygons where the value of the attributes *cave* and *doline* is equal to 1, we found that the occurrence of karst is more likely there. In this way, a total of 373 polygons with an area of 1,544 km^2 (7.6% of the total area) were identified as possible karst areas.

Either because of the specificity of individual data layers or because of errors in the data in a large part of the study area, the spatial accuracy of the data used for spatial analysis is insufficient. For example, due to the difference in scale between the lithologic map, which is based on the 1:100,000 scale geologic map, and the other data layers, which are based on more detailed analyses (e.g. lidar), the lithologic map is shown with an offset relative to other layers in at numerous locations (Figure 2 and 5). There were also significant differences between previously identified areas of carbonate rocks in Slovenia (Gostinčar 2016) and polygons representing potentially karstified areas (as indicated in the previous paragraph). Thus, dolines and cave entrances also occur in areas previously determined to be non-carbonate rocks (Gostinčar 2016), e.g. in areas with Quaternary alluvial deposits (e.g. poljes), covered karst, etc. However, we know from previous studies that karst can occur in areas where there is neither specific surface morphology, i.e. dolines, or cave entrances (e.g. Staut 2003; Knez, Mihevc and Slabe 2007; Knez and Slabe 2011).

3.3 Manual inspection

As mentioned above, only 373 polygons (7.6% of the total area of Slovenia) were defined as possible karst areas. These numbers differ strongly in comparison to the karst extent defined in previous studies (as described in chapter 2). Due to the complexity of determining the karst surface, we could therefore not rely only on selected quantitative indicators from selected spatial data, but had to use visual determination of karst occurrence for all polygons of the lithological layer. Therefore, all polygons of the lithological map (12,635 polygons in total) were assessed qualitatively, namely by visual inspection. For the visual inspection of the data, we used the results of the previously calculated spatial data on the potential presence of karst and the data contained in the lithological layer – the age and description of the lithological unit. As a basis for the data of the digital relief model, we used a lidar-derived DEM and shaded relief.

The following types of karst based on lithological properties were determined:

- **karst in limestone**: where limestone is indicated as the only or predominant lithology in the description of the geological map (e.g. nummulitic limestone, limestone with shells, massive limestone);

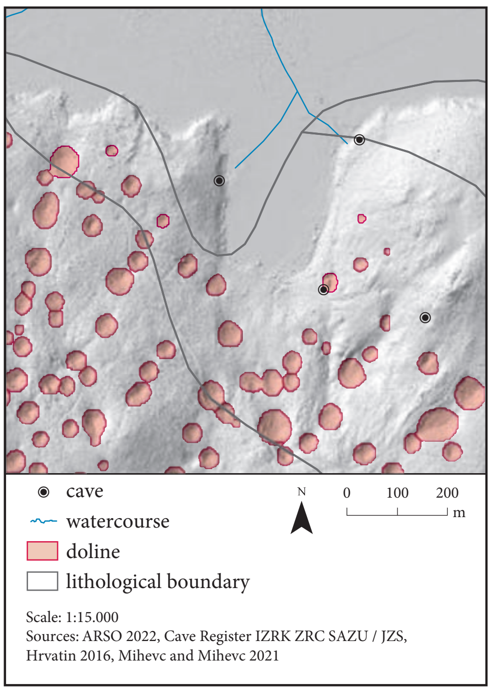


Figure 2: An example of an offset of the lithological map in relation to the other layers on the S margin of Cerknica Polje, resulting in a false spatial overlap of the layers.

- **karst in dolomite**: where dolomite is indicated as the only or predominant lithology in the description of the basic geological map (e.g. dolomite, grey dolomite, sometimes with chert, dolomite with limestone lenses);
- **karst in limestone and dolomite**: the description of the lithostratigraphic units mention both limestone and dolomite without indicating which of the lithologies predominates (e.g. grey limestone and dolomite, white limestone and granular dolomite);
- **karst in clastic carbonate rocks**: lithostratigraphic units of pre-Holocene cemented clastic carbonate rocks (e.g. insets of banded limestone between Lower Carboniferous clastites, Oligocene limestone breccia, limestone breccia);
- **carbonate till-covered karst**: covered karst, where glacial carbonate till is deposited on the surface (e.g. moraine, older consolidated moraine);
- **karst in flysch**: where the predominant lithology is flysch or sedimentary rock characterised by alternating layers of fine grained and coarse grained sedimentary rock (e.g. flysch, breccia deposits, conglomerates and calcareous sandstone in flysch);
- **fine grained sediment-covered karst**: covered karst, where fine grained sediments are deposited over the karst surface (e.g. bauxite clay, alluvium: predominantly clay and sand);
- **carbonate gravel-covered karst**: covered karst, where unconsolidated gravel is deposited (e.g. slope gravel, gravel, partially consolidated slope breccia).

For each polygon, the area was calculated. In conducting the visual inspection, we encountered many cases where there was a dilemma as to whether a particular lithology should be classified as karst or not.

Blind valleys are characteristic contact karst landforms. The inflow part, which usually consists of a fluvial part, usually forms on non-carbonate (non-karstic) lithologies, e.g. shale, sandstone, flysch. At the contact with carbonate rocks, a broader and shallower surface is covered by the non-carbonate alluvium overlying the deeper carbonate rocks. In terms of surface lithology, these areas were mapped as areas of Quaternary alluvium. During visual inspection, such polygons were cut into two parts – the tributary area formed on non-carbonate lithologies was defined as non-karst areas, while the lower parts covering the carbonate rocks were defined as karst (Figure 3).

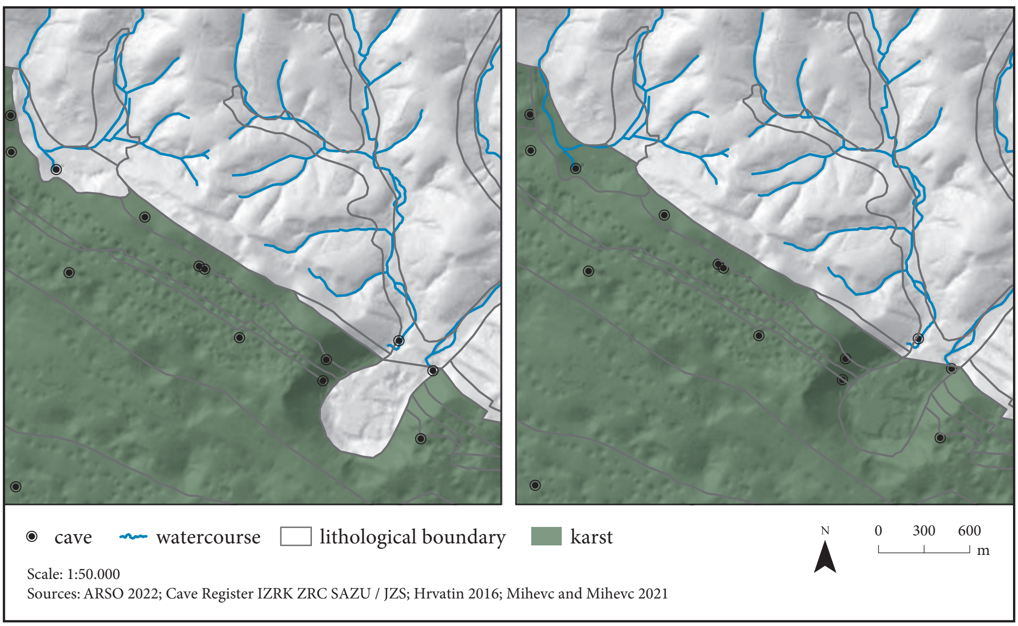


Figure 3: Example of a blind valley where the lithologic polygon has been cut to distinguish between the inflow area (non-karst area) and an outflow area (karst area). Left: polygons before cutting; right: polygons after cutting.

In Slovenia there are numerous areas where covered karst occurs. Some areas of corrosional plateaus in SE Slovenia and most poljes have Quaternary alluvial sediments deposited on the surface and are marked as such in the lithological map. Therefore, in determining the areas of alluvial deposits on the poljes, we used the locations of karst poljes according to Stepišnik (2021). A similar method was used in the area of the Kras Plateau and corrosional karst plateaus in the SE part of Slovenia, where a large part of the surface is covered with Plio-Quaternary sediments, e.g. terra rossa (Figure 4).

Fluviokarst areas are karst areas where the surface is subjected to severe mechanical weathering. Most often, this type of karst is present on dolomite bedrock, which is why dolomite karst is also used as a synonym for fluviokarst in the literature (Gabrovec 1994; 1995; Komac 2003; 2004; 2006; Gostinčar 2016). Fluviokarst environments are also common on impure limestones and in tectonically deformed areas (Roglić 1958; Gostinčar 2016; Stepišnik 2021). Fluviokarst environments are characteristic only of slopes on these rocks, where all precipitation does not drain vertically through the weathered mantle into the karst aquifer, but in some cases also drains superficially. Surface flows reshape the surface through erosion and accumulation processes. For this reason, identifying karst areas in fluvial karst regions is challenging because the surface does not have karst surface morphology but has landforms typical of fluvial areas. The delineation of the extent of this karst type was based on the extent of the lithological units. When karst, especially caves and dolines, were found in the flat areas of a lithological unit, the entire lithological unit was defined as a karst area, even if it contained only fluviokarst landforms.

A similar solution to that used in determining the extent of fluviokarst areas was also used in determining the extent of karst in high mountain environments. Karst slopes in high mountains are modified by the interaction of fluvial, nival, and glacial processes. These slopes generally do not have karst depressions, although they are karst areas with predominant subsurface water drainage. Therefore, when determining the extent of karst in the high mountainous areas, the lithological units were determined as karst if the same units had been identified as karst in other (non-mountainous) areas.

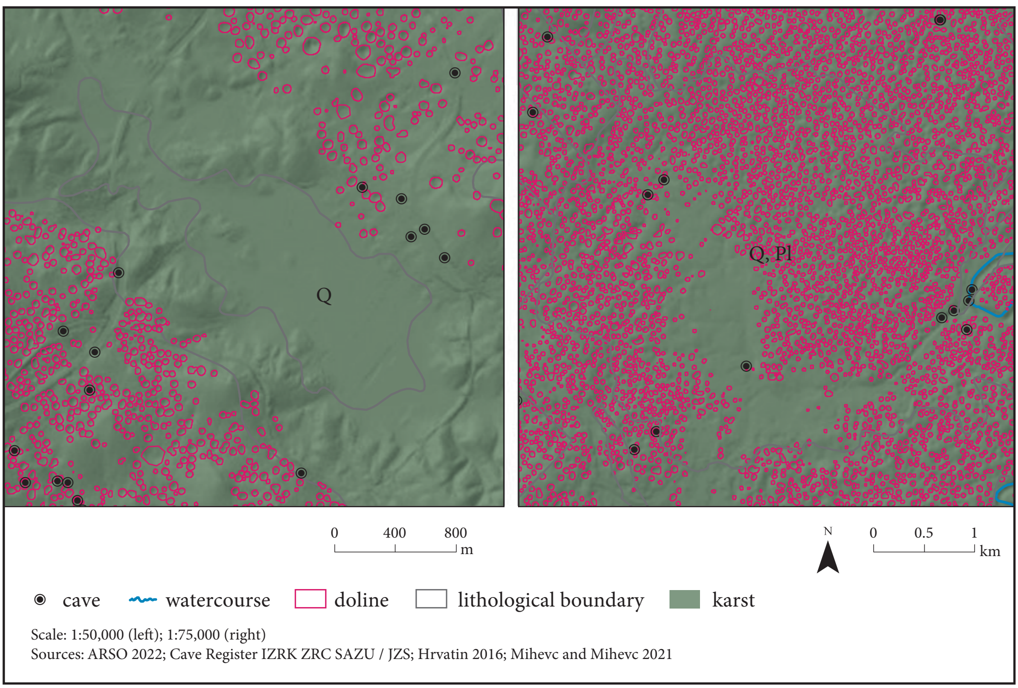


Figure 4: Examples of covered karst. Left: the Rakek–Unec Polje (lithology: Q alluvium – silt, clay, sand), right: doline-dissected karst of White Carniola (*Bela krajina*), covered with brown clay and terra rosa (Q, Pl).

The areas of carbonate conglomerates that make up part of the intermountain basins are also karst areas. In these lithological units, the extent of karst has been defined solely on the basis of surface formations, dolines and caves, and the absence of a surface river network. The lithological units that exhibited these features were defined as karst areas.

4 Results and discussion

A spatial database was created in the form of a polygon shape file (.shp) containing data on the occurrence of karst and the lithological type of karst for each of the 1:100,000 scale lithological polygons in Slovenia. With the help of a spatial database, we can calculate and map the distribution of karst in Slovenia very accurately.

So far, data layers on karst distribution in Slovenia were either created at a small scale and used only as overview maps (e.g. 1:750,000 and smaller), or the maps were produced before the creation of basic 1:100,000 scale geological maps for the territory of Slovenia (created in 1968–1998), they were not created using modern GIS technologies that allow the creation of accurate spatial data, or they were created at a smaller scale than the data layer presented in this article. Our data layer on karst distribution also includes areas with karst poljes, which many authors did not include in their studies, although karst poljes are one of the larger and more characteristic forms of the karst surface.

There are 12,734 polygons in the data layer – due to polygon cutting (as described in the methodology chapter), the number of polygons has increased compared to the initial layer of lithological units (Zemljevid tipov kamnin 2012). The polygons are divided into eight different karst types based on the lithology: karst in limestone, karst in limestone and dolomite, karst in dolomite, karst in clastic carbonate rocks, carbonate-gravel-covered karst, fine grained sediment-covered karst, carbonate till-covered karst, and karst in flysch.

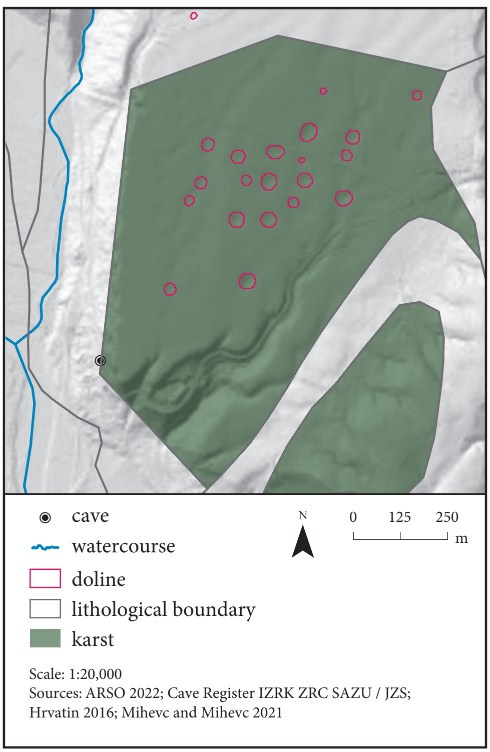


Figure 5: Conglomerate karst with typical circular depressions, indicating the presence of karst.

In identifying karst areas, only surface lithology and morphology were considered. Non-exposed outcrops of karstified rocks, such as karstified strata beneath surface, non-karstified surface strata (flysch megabeds; Placer et al. 2004) or karst in mines (e.g. Šarc et al. 2022), were not considered in our method.

The results of the spatial analysis show that karst occurs on 49.7% of the total area of Slovenia, i.e., about half of the country is karstified (Figure 6). The largest karst area in Slovenia is occupied by karst in limestone (24.6%), followed by karst in dolomite (12.4%) and karst in mixed lithology of limestone and dolomite (1.9%). Karst on relatively pure carbonate rocks occupies a total of 38.9% of the area of Slovenia. Karst in carbonate-clastic rocks has developed on 5.1% of the area. Other karst types in Slovenia, based on the lithology, are carbonate gravel-covered karst (2.5%), fine grained sediment-covered karst (2.0%), carbonate till-covered karst (0.8%) and karst in flysch (0.5%) (Table 1).

Analysis of lithological types shows that 50% of the total karst in Slovenia was formed in limestones, 25% in dolomites, and another 4% in mixed limestone-dolomite lithologies. Karst on carbonate rocks has developed on 78% of the karst areas in Slovenia, and as much as 22% of the total karst has developed in other lithologies (including unconsolidated carbonate sediments, such as gravel or glacial till). These values show the importance of an integrated approach to defining karst in Slovenia, because if we equate the extent of carbonate rocks and karst, we cannot identify more than one fifth of the karst area in Slovenia (Figure 8).

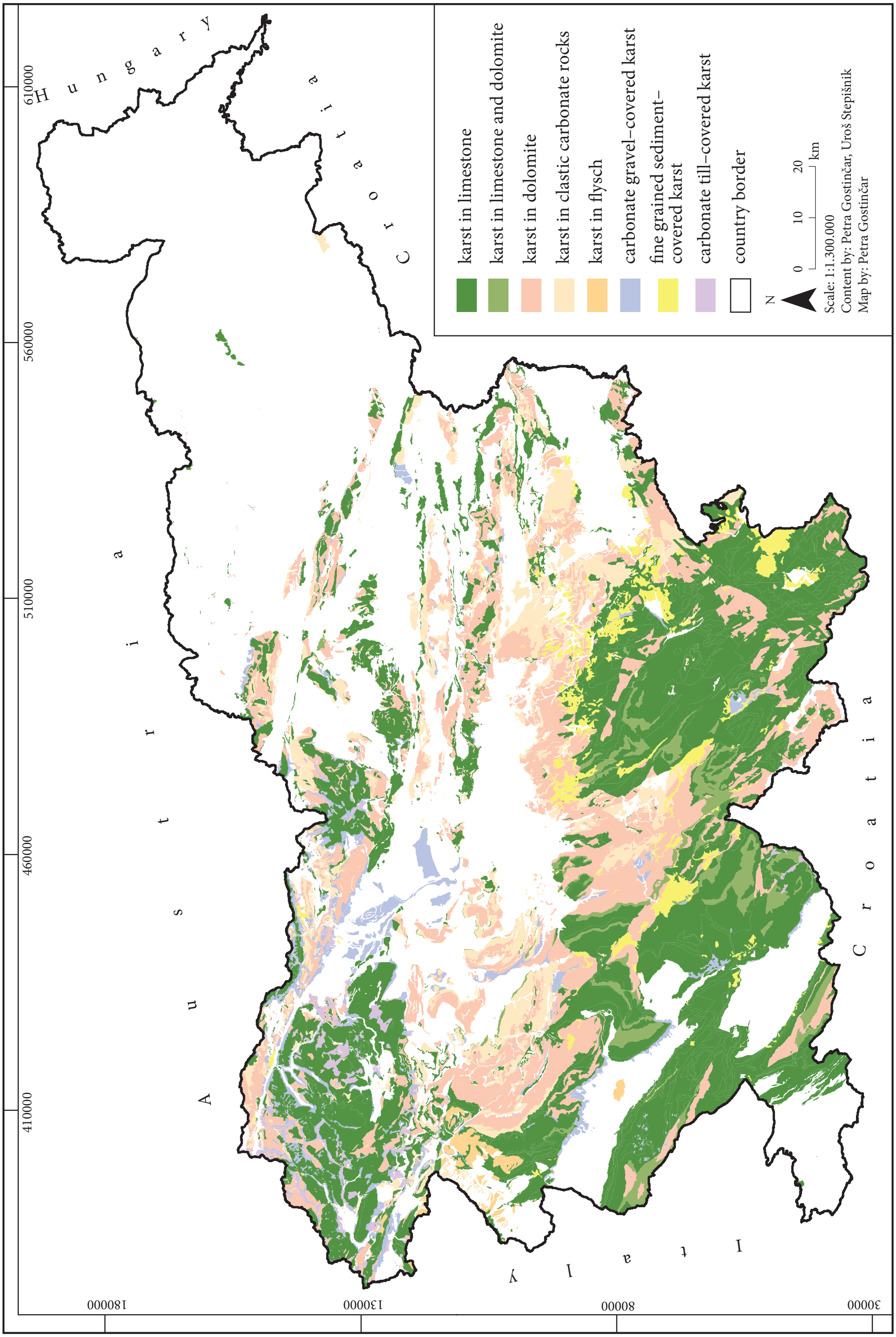
Our approach has allowed us to include a wide range of lithologies where karst occurs, which was not possible with other methods, even though these karst areas and features have been described in the literature. For example, conglomerate karst (Žlebnik 1978; Gabrovšek 2005; Kranjc 2005; Lipar and Ferk 2011; 2022), karst in flysch layers (Mihevc 1992; Staut 2003; Knez and Slabe 2011; Božič 2021), karst in breccias (Knez, Mihevc and Slabe 2007), covered karst (Knez and Slabe 2007; Gams, Otoničar and Slabe 2011).

Karst in limestone occurs in larger compact areas in the Karst Plateau, Podgorje Karst Plateau and Podgrad Lowland, where it is formed in combination with dolomite karst. Limestone karst is also found in the compacted areas of the Javorniki Hills, the Upper Pivka River, and Snežnik Plateau, where it partly alternates with dolomite. The high Dinaric karst plateaus of the Trnovo Forest Plateau (*Trnovski gozd*), Mount Nanos, the Hrušica Plateau, and the Menišija Plateau, as well as the southwestern part of the Gotenica Mountains (*Goteniška gora*), the Big Mountains (*Velika gora*), the Little Mountains (*Mala gora*), the Little Kočevje Mountains (*Kočevska Mala gora*), the Kočevje Rog Plateau (*Kočevski Rog*), the Mount Poljane (*Poljanska gora*), and Dry Carniola (*Suha krajina*). Limestone karst is present in White Carniola (*Bela krajina*), where it mainly alternates with fine grained sediment-covered karst. In the high mountain regions of the Julian Alps and the Kamnik–Savinja Alps, limestone karst mainly alternates with dolomite karst and carbonate till-covered karst. **Karst in dolomite** is the predominant karst type in the Idrija–Cerkno Hills

Table 1: Spatial distribution of karst in Slovenia based on lithology.

Karst type based on lithology	Number of polygons	Area (km^2)	% of surface	
karst in limestone	2023	4993.0	24.6	karst 49.7%
karst in limestone and dolomite	143	385.5	1.9	
karst in dolomite	1464	2504.6	12.4	
karst in clastic carbonate rocks	1336	1033.4	5.1	
carbonate gravel-covered karst	670	501.9	2.5	
fine grained sediment-covered karst	381	414.0	2.0	
carbonate till-covered karst	169	153.6	0.8	
karst in flysch	136	97.2	0.5	
non-karst area	6412	10,189.8	50.3	
SUM	12,734	20,273.0	100	

Figure 6: Spatial distribution of karst in Slovenia in various lithological units. ➤ p. 123
Figure 7: Spatial distribution of karst in Slovenia. ➤ p. 124


karst in limestone
karst in limestone and dolomite
karst in dolomite
karst in clastic carbonate rocks
karst in flysch
carbonate gravel–covered karst
fine grained sediment–covered karst
carbonate till–covered karst
country border
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Scale: 1:1.300.000
Content by: Petra Gostinčar, Uroš Stepišnik
Map by: Petra Gostinčar
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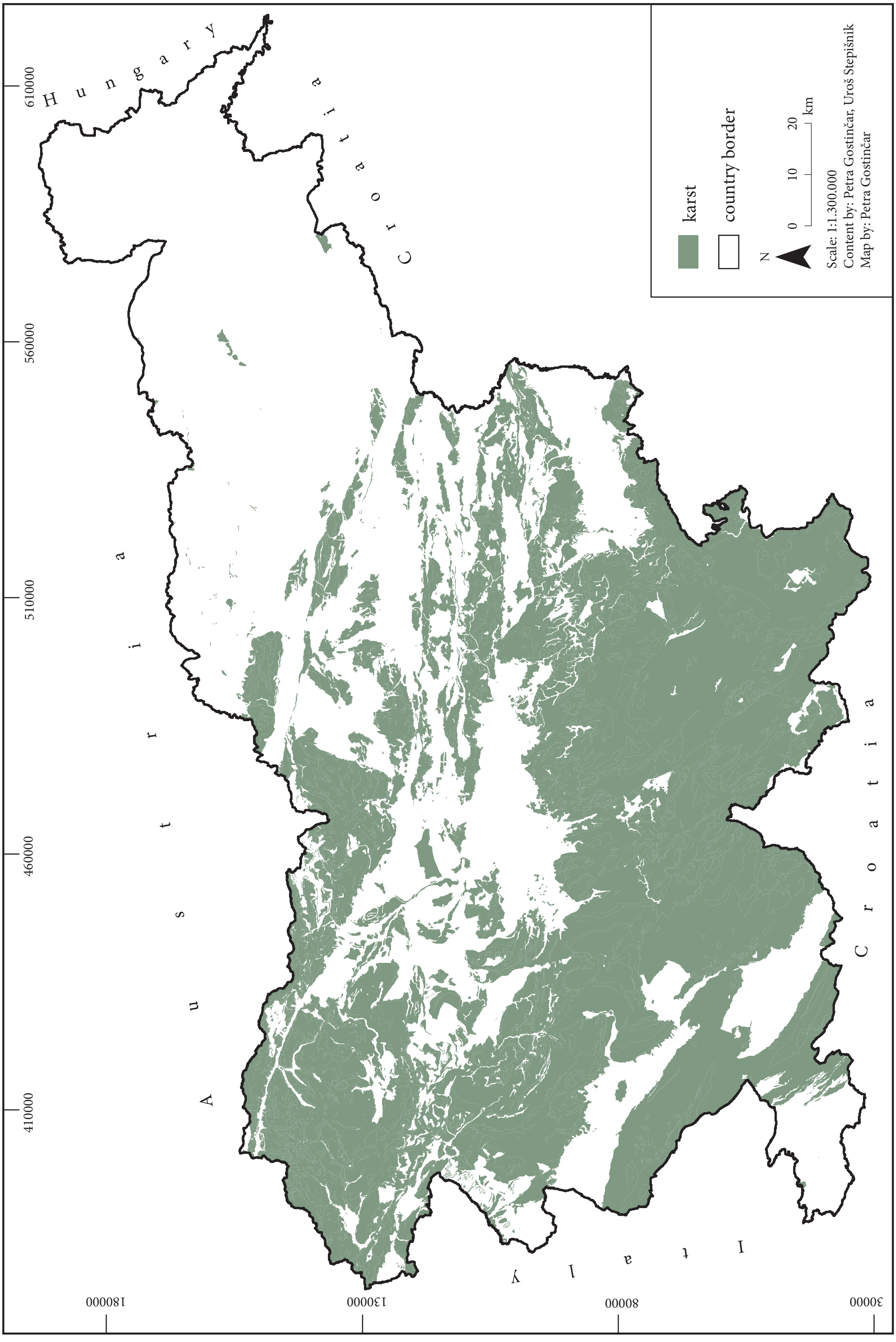
karst
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and on the northern edge of the Trnovo Forest Plateau. It also makes up a large part of the Inner Carniola karst (*Notranjsko podolje*): the Menišija Plateau and Bloke Plateau and, south of Loški Potok, the area surrounding Osilnica and Kostel. Dolomite karst forms the southeastern parts of the Little Kočevje Mountains and the Kočevje Rog Plateau. In the southern part of the Sava Hills, dolomite karst mainly alternates with karst in clastic carbonate rocks, whereas in the central part it mainly alternates with karst in limestones. Areas where **karst in clastic carbonate rocks** is formed are usually highly fragmented. This type of karst is found in the Idrija–Cerkno Hills and the Polhov Gradec Hills, in the Krim Hills, on the Bloke Plateau, and in the Velike Lašče region. Karst on clastic carbonate rocks is the predominant type of karst in the Sava Hills and in the Gorjanci Hills, where it mainly alternates with karst in dolomites. This karst type exists in the Kozje Hills (*Kozjansko*) and in the northeastern part of the Kamnik–Savinja Alps and Kozjak, where it alternates with limestone and dolomite karst. **Carbonate gravel-covered karst** occurs in river basins with higher potential energy, namely in the Julian Alps and the Kamnik–Savinja Alps. Larger compact areas of this karst type are formed in the broad floodplain of the Sava River; namely, the Kranj–Sora Polje, the Dobrave, and the Udin Boršt. **The fine grained sediment-covered karst** type is found at the bottom of the poljes of the Inner Carniola (*Notranjska*) and Lower Carniola (*Dolenjska*) karst – poljes in the catchment area of the Ljubljanica and Krka rivers, where the karst is mainly covered by alluvium. The fine grained sediment-covered karst type occurs in the karst of Lower Carniola and White Carniola, where a variety of clays, mainly from the Plio-Quaternary, are deposited over the karst surface (e.g. bauxite clay). The largest areas of **carbonate till-covered** karst are the Julian Alps and the Kamnik–Savinja Alps, where glacial tills are mainly deposited on high karst plateaus (the Pokljuka Plateau and Jelovica Plateau), where they mostly alternate with karst in limestone. Carbonate till-covered karst is also located at the bottoms of valleys that were influenced by glaciation in past climatic periods. Furthermore, this type of karst is found in the Snežnik Plateau. **Karst in flysch** occurs in western Slovenia – namely Kambreško and in the Vipava Valley (known as Planina breccia). Our method did not detect karst in the flysch megabeds of Slovenian Istria.

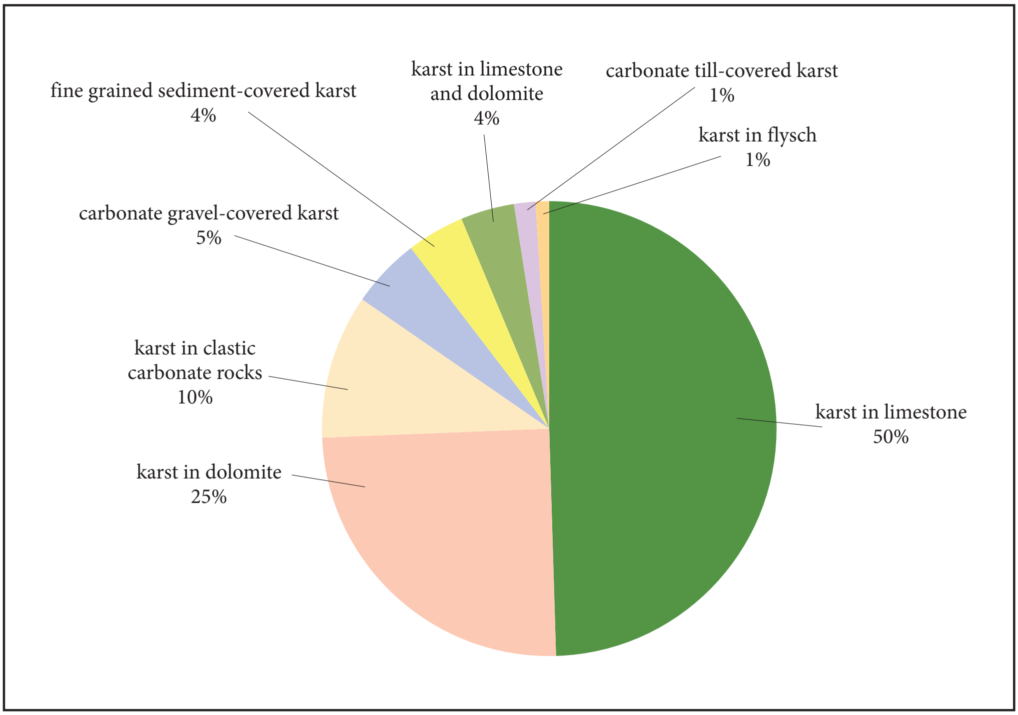

Figure 8: Distribution of different karst lithologies in Slovenia.

5 Conclusions

In the long history of Slovenian karst research, there have been numerous attempts to determine the spatial distribution of karst using various methods. Early approaches relied on characteristic landforms such as karst depressions, poljes, and caves, since few geological data were available. More recent studies have focused on areas of carbonate rocks, where the presence of surface morphology, cave entrances, and the absence of a surface river network are consistent. However, these approaches were only partially successful because they failed to identify all karst areas in Slovenia, considering only »pure« carbonate lithologies and often omitting large areas, usually within karst poljes.

Using advanced GIS technologies and more accurate data layers on lithology, hydrology, and digital relief models, we conducted a two-step identification of karst areas in Slovenia. The first step consisted of overlays of GIS, followed by a manual review of the data layer for lithology. In this way, we were able to determine the spatial distribution of karst in Slovenia and create a comprehensive digital spatial database that contributes to the broader understanding of the Slovenian environment.

Karst covers a significant part of Slovenian territory, and many water sources are located in karst aquifers. The spatial data on karst distribution, when combined with other spatial data such as subsurface water flow, can play an important role in the integrated management of surface and subsurface karst areas. Identification of karst areas has several implications, such as designating karst aquifers for effective management and protection, planning forest management, determining eligibility for agricultural subsidies, and supporting glacial geomorphology research.

The digital format of the data layer produced allows for immediate further processing and enhancement by the karst research community, as well as the creation of digital or web materials and content layers in GIS applications. This study not only provides valuable insight into the extent and diversity of karst in Slovenia, but also provides a solid foundation for future research and management efforts related to this unique and important landscape.

ACKNOWLEDGMENT: This study was carried out in the framework of the programme P1-0011, Regional Geology and the project J1-2479, Past climate change and glaciation at the Alps-Dinarides junction, all funded by the Slovenian Research and Innovation Agency (ARIS).

6 References

Asanidze, L., Lezhava, Z., Tsikarishvili, K., Gaprindashvili, G., Chikhradze, N., Polk, J. 2019: Karst map of Georgia (Caucasus region) scale: 1:1,500,000. Carbonates and Evaporites 34-4. DOI: https://doi.org/10.1007/s13146-019-00525-z

Bögli, A. 1980: Karst hydrology and physical speleology. Berlin, Heidelberg, New York.

Božič, M. 2021: Sedimentologija in geomorfologija eocenske Planinske breče v Vipavski dolini. Bachelor's thesis. University of Ljubljana. Ljubljana.

Buser, S. 2010a: Geološka karta Slovenije 1:250.000. Geološki zavod Slovenije. Ljubljana.

Buser, S. 2010b: Geološka karta Slovenije 1:250.000 (povzeto po OGK 1:100.000 in posodobljeno). Geološki zavod Slovenije. Ljubljana.

Chen, Z., Auler, A. S., Bakalowicz, M., Drew, D., Griger, F., Hartmann, J., Jiang, G., et al. 2017: The World Karst Aquifer Mapping project: Concept, mapping procedure and map of Europe. Hydrogeology Journal 25-3. DOI: https://doi.org/10.1007/s10040-016-1519-3

Ciglič, R., Čonč, Š., Breg Valjavec, M. 2022: The impact of digital elevation model preprocessing and detection methods on karst depression mapping in densely forested Dinaric mountains. Remote Sensing 14-10. DOI: https://doi.org/10.3390/rs14102416

Cvijić, J. 1893: Das Karstphänomen: Versuch einer Morphologischen Monographie. Wien.

Cvijić, J. 1924: Types morphologiques de terrains calcaires. Glasnik Geografskog društva 10-1.

Čeru, T., Šegina, E., Gosar, A. 2017: Geomorphological dating of Pleistocene conglomerates in central Slovenia based on spatial analyses of dolines using LiDAR and ground penetrating radar. Remote Sensing 9-12. DOI: https://doi.org/10.3390/rs9121213

De Waele, J., Gutiérrez, F. 2022: Karst hydrogeology, geomorphology and caves. Hoboken. DOI: https://doi.org/10.1002/9781119605379
Ford, D., Williams, P. D. 2007: Karst hydrogeology and geomorphology. Chichester.
Fridl, J., Kladnik, D., Orožen Adamič, M., Perko, D., Pogačnik, A., Belec, B., Drozg, V. (eds.) 1998: Geografski atlas Slovenije. Ljubljana.
Gabrovec, M. 1994: Relief in raba tal na dolomitnih območjih Slovenije. Ph.D. thesis. University of Ljubljana. Ljubljana.
Gabrovec, M. 1995: Dolomite areas in Slovenia with particular consideration of relief and land use. Geografski zbornik 35-1.
Gabrovec, M., Hrvatin, M. 1998: Površje. Geografski atlas Slovenije. Ljubljana
Gabrovec, M., Hrvatin, M. 2016: Reliefni tipi. Geološki atlas Slovenije. Ljubljana.
Gabrovšek, F. 2005: Caves in conglomerate: Case of Udin Boršt, Slovenia. Acta Carsologica 34-2. DOI: https://doi.org/10.3986/ac.v34i2.274
Gams, I. 1965: Speleological characteristics of the Slovene karst. Naše jame 7-1.
Gams, I. 1972: Geografsko raziskovanje krasa v Sloveniji. Geografski vestnik 44-1.
Gams, I. 1974: Kras: zgodovinski, naravoslovni in geografski oris. Ljubljana.
Gams, I. 1995: Types of the contact karst. Studia carsologica 6-1.
Gams, I. 2001: Notion and forms of contact karst. Acta Carsologica 30-2.
Gams, I. 2003: Kras v Sloveniji v prostoru in času. Ljubljana.
Gams, I., Otoničar, B., Slabe, T. 2011: Development of slope and related subsoil karst: A case study from Bela Krajina, SE Slovenia. Acta Carsologica 40-2. DOI: https://doi.org/10.3986/ac.v40i2.17
Gao, Y., Alexander, E. C., Tipping, R. G. 2005: Karst database development in Minnesota: Design and data assembly. Environmental Geology 47-8. DOI: https://doi.org/10.1007/s00254-005-1240-3
Goldscheider, N., Chen, Z., Auler, A. S., Bakalowicz, M., Broda, S., Drew, D., Hartmann, J., et al. 2020: Global distribution of carbonate rocks and karst water resources. Hydrogeology Journal 28-5. DOI: https://doi.org/10.1007/s10040-020-02139-5
Gostinčar, P. 2016: Geomorphological characteristics of karst on contact between limestone and dolomite in Slovenia. Ph.D. thesis, University of Nova Gorica. Nova Gorica.
Grlj, A. 2021: Omejevanje kraških kotanj z analizo polrezov. Dela 53. DOI: https://doi.org/10.4312/dela.53.5-22
Gunn, J. 2004: Fluviokarst. Encyclopedia of caves and karst science. New York.
Habič, P. 1969: Hidrografska rajonizacija krasa v Sloveniji. Krš Jugoslavije 6-1.
Habič, P. 1982: Pregledna speleološka karta Slovenije. Acta Carsologica 10-1.
Hartmann, J., Moosdorf, N. 2012: The new global lithological map database GLiM: A representation of rock properties at the Earth surface. Geochemistry, Geophysics, Geosystems 13-12. DOI: https://doi.org/10.1029/2012GC004370
Hrvatin, M. 2016: Morfometrične značilnosti površja na različnih kamninah v Sloveniji. Ph.D. thesis, Univerza na Primorskem. Koper.
Knez, M., Mihevc, A., Slabe, T. 2007: Kras v breči Rebrnic v Vipavski dolini. Kraški pojavi, razkriti med gradnjo slovenskih avtocest. Ljubljana.
Knez, M., Slabe, T. (eds.) 2007: Kraški pojavi, razkriti med gradnjo slovenskih avtocest. Ljubljana. DOI: https://doi.org/10.3986/9789612540302
Knez, M., Slabe, T. 2011: Young karst processes in breccia and flysch (Mount Nanos, Slovenia). Congreso de Terrenos Kársticos de Guatemala. Cobán.
Kokalj, Ž., Hesse, R. 2017: Airborne laser scanning raster data visualization: A guide to good practice. Ljubljana. DOI: https://doi.org/10.3986/9789612549848
Komac, B. 2003: Dolomite relief in the Žibrše Hills. Acta geographica Slovenica 43-2. DOI: https://doi.org/10.3986/ags43201
Komac, B. 2004: Dolomitni kras ali fluviokras? Geografski vestnik 76-1.
Komac, B. 2006: Dolec kot značilna oblika dolomitnega površja. Ljubljana.
Komac, M., Urbanc, J. 2013a: Map of the spatial distribution and karstification intensity of surficial karst areas in Slovenia 1:250,000. Geološki zavod Slovenije. Ljubljana.
Komac, M., Urbanc, J. 2013b: Model stopnje zakraselosti za območje Slovenije. Ujma 27-1.
Komac, M., Urbanc, J. 2016: Površinska razširjenost in stopnja zakraselosti. Geološki atlas Slovenije. Ljubljana.

Komac, M., Urbanc, J. 2017: Karta površinske razširjenosti in stopnje zakraselosti kraških območij v Sloveniji 1:250.000. Tolmač. Ljubljana.
Kranjc, A. 1998: Kraške vode. Geografski atlas Slovenije. Ljubljana.
Kranjc, A. 2005: Konglomeratni kras v Sloveniji: zgodovina raziskovanja in poznavanja jam v Udin borštu na Gorenjskem. Acta Carsologica 34-2. DOI: https://doi.org/10.3986/ac.v34i2.275
Lipar, M., Ferk, M. 2011: Eogenetic caves in conglomerate: an example from Udin Boršt, Slovenia. International Journal of Speleology 40-1. DOI: https://doi.org/10.5038/1827-806X.40.1.7
Lipar, M., Ferk, M. 2022: Fluviokarst on Quaternary eogenetic conglomerates; an example from Slovenia. Proceedings of the 18th International Congress of Speleology. Bourget-du-Lac.
Litostratigrafska karta Slovenije. Geološki zavod Slovenije, naročnik ARSO, revizija 2011. Ljubljana.
Melik, A. 1935: Slovenija: geografski opis. Ljubljana.
Melik, A. 1963: Slovenija: geografski opis. Ljubljana.
Mihevc, A. 1992: Gypsum in Tajna jama and in the cave Kubik. Acta Carsologica 21-1.
Mihevc, A. 1994: Morfološke značilnosti Matarskega podolja. Annales: anali za istrske in mediteranske študije. Series historia naturalis 4-4.
Mihevc, A. 1998: Kraško površje. Geografski atlas Slovenije. Ljubljana.
Mihevc, A., Mihevc, R. 2021: Morphological characteristics and distribution of dolines in Slovenia, a study of a lidar-based doline map of Slovenia. Acta Carsologica 50-1. DOI: https://doi.org/10.3986/ac.v50i1.9462
Novak, D. 1993: Hydrogeological research of the Slovenian karst. Naše jame 35-1.
Perko, D., Hrvatin, M., Ciglič, R. 2015: A methodology for natural landscape typification of Slovenia. Acta geographica Slovenica 55-2. DOI: https://doi.org/10.3986/AGS.1938
Petrič, M., Ravbar, N., Gostinčar, P., Krsnik, P., Gacin, M. 2020a: Establishment of a freely accessible GIS database containing the results of groundwater tracing and possibilities of its use. Geologija 63-2. DOI: https://doi.org/10.5474/geologija.2020.017
Petrič, M., Ravbar, N., Gostinčar, P., Krsnik, P., Gacin, M. 2020b: GIS database of groundwater flow characteristics in carbonate aquifers: Tracer test inventory from Slovenian karst. Applied Geography 118. DOI: https://doi.org/10.1016/j.apgeog.2020.102191
Placer, L., Košir, A., Popit, T., Šmuc, A., Juvan, G. 2004: The Buzet Thrust Fault in Istria and overturned carbonate megabeds in the Eocene flysch of the Dragonja Valley (Slovenia). Geologija 47-2. DOI: https://doi.org/10.5474/geologija.2004.015
Roglić, J. 1958: Odnos riječne erozije i krškog procesa. V. kongres geografa FNR Jugoslavije. Cetinje.
Sauro, U. 2012: Closed depressions in karst areas. Encyclopedia of Caves. Amsterdam. DOI: https://doi.org/10.1016/B978-0-12-383832-2.00133-X
Smart, P. L. 1986: Origin and development of glacio-karst closed depressions in the Picos de Europa, Spain. Zeitschrift für Geomorphologie 30-4. DOI: https://doi.org/10.1127/zfg/30/1987/423
Staut, M. 2003: Poskus razlage razvoja jame Kubik kot primera jame v flišu. Bilten: glasilo Jamarskega kluba Železničar 23-1.
Stepišnik, U. 2017: Dinarski kras: plitvi kras Zgornje Pivke. Ljubljana.
Stepišnik, U. 2020: Fizična geografija krasa. Ljubljana.
Stepišnik, U. 2021: Kraška polja v Sloveniji. Dela 53. DOI: https://doi.org/10.4312/dela.53.23-43
Sun, W, Song, J., Yang, W., Zheng, Y., Li, C., Kuang, D. 2020: Distribution of carbonate rocks and variation analysis of karst water resources in China. Carbonates and Evaporites 35-4. DOI: https://doi.org/10.1007/s13146-020-00657-7
Sweeting, M. M. 1973: Karst Landforms. New York.
Šarc, F., Otoničar, B., Gabrovšek, F., Martín-Pérez, A., Covington, M., Rohovec, J., Lupša, A. 2022: Cave in the Mežica mine. Speleology: 29th International Karstological School Classical Karst, Abstracts & Guide Book. Postojna.
Šerko, A. 1947: Kraški pojavi v Jugoslaviji. Geografski vestnik 19-1.
Šušteršič, F. 1991: Kras. Enciklopedija Slovenije. Ljubljana.
Temovski, M. 2012: Map of karst rock outcrops in Macedonia. Karst forms and processes: Guide book & abstracts, 20th International Karstological School Classical Karst. Postojna. DOI: https://doi.org/10.13140/2.1.2170.3040
Triglav Čekada, M., Bric, V. 2015: Končan je projekt laserskega skeniranja Slovenije. Geodetski vestnik 59-3.
White, W. B. 1988: Geomorphology and hydrology of karst terrains. Oxford.

White, W. B. 2002: Karst hydrology: recent developments and open questions. Engineering Geology 65-2,3. DOI: https://doi.org/10.1016/S0013-7952(01)00116-8
Zemljevid tipov kamnin. Geografski inštitut Antona Melika ZRC SAZU, različica 2012. Ljubljana.
Žebre, M., Stepišnik, U. 2015a: Glaciokarst landforms and processes of the Southern Dinaric Alps. Earth Surface Processes and Landforms 40-11. DOI: https://doi.org/10.1002/esp.3731
Žebre, M., Stepšinik, U. 2015b: Glaciokarst geomorphology of the Northern Dinaric Alps: Snežnik (Slovenia) and Gorski Kotar (Croatia). Journal of Maps 12-5. DOI: 10.1080/17445647.2015.1095133
Žlebnik, L. 1978: Kras na konglomeratnih terasah ob Zgornji Savi in njenih pritokih. Geologija 21-1.

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Research articles should have the following structure:

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Articles can be submitted in English or Slovenian.

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- Fridl, J., Urbanc, M., Pipan, P. 2009: The importance of teachers' perception of space in education. Acta geographica Slovenica 49-2. DOI: https://doi.org/10.3986/AGS49205
- Gams, I. 1994a: Types of contact karst. Geografia Fisica e Dinamica Quaternaria 17.
- Gams, I. 1994b: Changes of the Triglav glacier in the 1955-94 period in the light of climatic indicators. Geografski zbornik 34.
- Van Hall, R. L., Cammeraat, L. H., Keesstra, S. D., Zorn, M. 2016: Impact of secondary vegetation succession on soil quality in a humid Mediterranean landscape. Catena, In press. DOI: https://doi.org/10.1016/j.catena.2016.05.021 (25. 11. 2016).
- De Kerk, G. V., Manuel, A. R. 2008: a comprehensive index for a sustainable society: The SSI – The Sustainable Society Index. Ecological Economics 66-2,3. DOI: https://doi.org/10.1016/j.ecolecon.2008.01.029
- Perko, D. 1998: The regionalization of Slovenia. Geografski zbornik 38.
- Urry, J. 2004: The 'system' of automobility. Theory, Culture and Society 21-4,5. DOI: https://doi.org/10.1177%2F0263276404046059
- Yang, D. H., Goerge, R., Mullner, R. 2006: Comparing GIS-based methods of measuring spatial accessibility to health services. Journal of Medical Systems 30-1. DOI: https://doi.org/10.1007/s10916-006-7400-5

5.2 Citing books

- Cohen, J. 1988: Statistical power analysis for the behavioral sciences. New York.
- Fridl, J., Kladnik, D., Perko, D., Orožen Adamič, M. (eds.) 1998: Geografski atlas Slovenije. Ljubljana.
- Hall, T., Barrett, H. 2018: Urban geography. London. DOI: https://doi.org/10.4324/9781315652597
- Hall, C. M., Page, S. J. 2014: The geography of tourism and recreation: Environment, place and space. New York. DOI: https://doi.org/10.4324/9780203796092
- Luc, M., Somorowska, U., Szmańda, J. B. (eds.) 2015: Landscape analysis and planning. Springer Geography. Heidelberg. DOI: https://doi.org/10.1007/978-3-319-13527-4
- Nared, J., Razpotnik Visković, N. (eds.) 2014: Managing cultural heritage sites in southeastern Europe. Ljubljana. DOI: https://doi.org/10.3986/9789610503675

5.3 Citing chapters of books or proceedings

- Gams, I. 1987: A contribution to the knowledge of the pattern of walls in the Mediterranean karst: A case study on the N. island Hvar, Yugoslavia. Karst and Man, Proceedings of the International Symposium on Human Influence in Karst. Ljubljana.
- Hrvatin, M., Perko, D., Komac, B., Zorn, M. 2006: Slovenia. Soil Erosion in Europe. Chichester. DOI: https://doi.org/10.1002/0470859202.ch25
- Komac, B., Zorn, M. 2010: Statistično modeliranje plazovitosti v državnem merilu. Od razumevanja do upravljanja. Naravne nesreče 1. Ljubljana.
- Zorn, M., Komac, B. 2013: Land degradation. Encyclopedia of Natural Hazards. Dordrecht. DOI: https://doi.org/10.1007/978-1-4020-4399-4_207

5.4 Citing expert reports, theses, dissertations and institutional reports

- Breg Valjavec, M. 2012: Geoinformatic methods for the detection of former waste disposal sites in karstic and nonkarstic regions (case study of dolines and gravel pits). Ph.D. thesis, University of Nova Gorica. Nova Gorica.

- Holmes, R. L., Adams, R. K., Fritts, H. C. 1986: Tree-ring chronologies of North America: California, Eastern Oregon and Northern Great Basin with procedures used in the chronology development work including user manual for computer program COFECHA and ARSTAN. Chronology Series 6. University of Arizona, Laboratory of tree-ring research. Tucson.
- Hrvatin, M. 2016: Morfometrične značilnosti površja na različnih kamninah v Sloveniji. Ph.D. thesis, Univerza na Primorskem. Koper.
- Šifrer, M. 1997: Površje v Sloveniji. Elaborat, Geografski inštitut Antona Melika ZRC SAZU. Ljubljana.
- World commission on environment and development 1987: Our common future: Brundtland report. Oxford.

5.5 Citing online materials with authors

- Tiran, J. 2021: Slovenija se je v celoti odela v modro. Metina lista. Internet: https://metinalista.si/slovenija-se-je-v-celoti-odela-v-modro/ (3. 11. 2021).
- Davies, G. 2017: The place of data papers: Producing data for geography and the geography of data production. Geo: Geography and Environment. Internet: https://blog.geographyandenvironment.com/2017/09/27/the-place-of-data-papers-producing-data-for-geography-and-the-geography-of-data-production/ (8. 11. 2021).

5.6 Citing websites without authors (e.g. websites of projects and institutions)

Use in-text citations only. It is not necessary to include a citation in the reference list. The in-text citation should include the URL.

5.7 Citing publicly archived data (e.g. statistical data)

Use in-text citations only. It is not necessary to include publicly archived datasets in the reference list. The in-text citation should include the name of the dataset, the institution providing the data and the time frame of the data used.

When the data you cited were published as a report, add it to the reference list and use the following format:

- Popis prebivalstva, gospodinjstev, stanovanj in kmečkih gospodarstev v Republiki Sloveniji, 1991 – končni podatki. Zavod Republike Slovenije za statistiko. Ljubljana, 1993.
- Agriculture, forestry and fishery statistics. 2020 edition. Publications Office of the European Union. Luxembourg, 2020.

5.8 Citing geospatial data and cartographic materials

Geospatial data used in maps should be cited in the colophon on the map (see the Table and Figures section of the Authors' Guidelines). It is not necessary to include geospatial data in the reference list.

When cartographic materials are published as an independent monograph, add it to the reference list and use the following format:

- Buser, S. 1986: Osnovna geološka karta SFRJ 1 : 100.000, list Tolmin in Videm (Udine). Savezni geološki zavod. Beograd.
- Državna topografska karta Republike Slovenije 1 : 25.000, list Brežice. Geodetska uprava Republike Slovenije. Ljubljana, 1998.
- Franciscejski kataster za Kranjsko, k. o. Sv. Agata, list A02. Arhiv Republike Slovenije. Ljubljana, 1823–1869.
- The vegetation map of forest communities of Slovenia 1:400,000. Biološki inštitut Jovana Hadžija ZRC SAZU. Ljubljana, 2002.

5.9 Citing legal sources

Use in-text citation. It is not necessary to include a citation in the reference list. The in-text citation should include the title of legal document and the year.

5.10 In-text citation examples

All references in the reference list are cited in the text. In-text citations should include the last name of the author(s) or the name of the institution, and the year of publication. Separate individual citations by semicolons, arrange citations by year of publication, and separate the page information from author(s)' names and years by a comma; for example: (Melik 1955), (Melik, Ilešič and Vrišer 1963; Gams 1982a; Gams 1982b; World Commission on Environment and Development 1987). For references with more than three authors, cite only the first, followed by et al.: (Melik et al. 1956). Give page numbers only for direct quotations. Narrative citations: Perko (2016, 25) states: »Hotspots are …« or parenthetical citation (Kokole 1974, 7–8).

When citing online materials without authors, such as project or institutional websites, the URL should be included, for example: »The aim of the LABELSCAPE project is to develop mechanisms for integrating sustainability labels into tourism policy (https://labelscape.interreg-med.eu).«

When citing publicly archived data, such as statistical data, inform the reader in the text with the name of dataset, the time frame, and the institution that provides the data: »The 2000–2020 population data used in the analysis were provided by the Eurostat«. If the statistical data were published as a report, cite the document, e.g. (Popis prebivalstva … 1993).

When citing legal sources such as legislative acts, white papers, etc., you should provide (short formal) title and the year, for example: »… The European Commission's White paper on transport (2011) sets out ten strategic goals for a competitive and resource-efficient transport system: …«

5.11 Reference list

Arrange references alphabetically and then chronologically if necessary. Identify more than one reference by the same author(s) in the same year with the letters *a*, *b*, *c*, etc., after the year of publication: (1999a; 1999b). Use this format for indirect citations: (Gunn 2002, cited in Matei et al. 2014).

Include the Digital Object Identifier (DOI) in the reference if available. Format the DOI as follows: https://doi.org/… (for example: https://doi.org/10.3986/AGS.1812).

6 Tables and figures

Number all tables in the article uniformly with their own titles. The number and the text are separated by a colon, and the caption ends with a period. Example:

Table 1: Number of inhabitants of Ljubljana.

Table 2: Changes in average air temperature in Ljubljana (Velkavrh 2009).

Tables and figures must be indicated in the main text in parentheses, for example »(Table 1)«, or as a part of the sentence, for example »… as can be seen in the Table 1«.

Tables should contain no formatting and should not be too large; it is recommended that tables not exceed one page.

Upload figures to the OJS as separate files in digital form. If the files prepared cannot be uploaded using these programs, consult the editorial board (ags@zrc-sazu.si) in advance.

Number all figures (maps, graphs, photographs) in the article uniformly with their own titles. Example:

Figure 1: Location of measurement points along the glacier.

All graphic materials must be adapted to the journal's format. Illustrations should be exactly 134 mm wide (one page) or 64 mm wide (half page, one column), and the height limit is 200 mm.

To make anonymous peer review possible, include the name of the author(s) with the title of the illustration in the file metadata, but not in the article text.

Maps should be made in digital vector form with Corel Draw, Adobe Illustrator, or a similar program, especially if they contain text. They can exceptionally be produced in digital raster form with at least 300 dpi resolution, preferably in TIFF or JPG format. For maps made with *CorelDraw* or *Adobe Illustrator*, two separate files should be prepared; the original file (.cdr or .ai format) and an image file (.jpg format).

For maps made with ArcGIS with raster layers used next to vector layers (e.g., .tif of relief, airborne or satellite image), three files should be submitted: the first with a vector image without transparency together with a legend and colophon (export in .ai format), the second with a raster background (export in .tif format), and the third with all of the content (vector and raster elements) together showing the final version of the map (export in .jpg format).

Do not print titles on maps; they should appear in a caption.

Save colors in CMYK, not in RGB or other formats.

Use Times New Roman for the legend (size 8) and colophon (size 6). List the author(s), scale, source, and copyright in the colophon. Write the colophon in English (and Slovenian, if applicable). Example:

Scale: 1:1,000,000
Content by: Drago Perko
Map by: Jerneja Fridl
Source: Statistical Office of the Republic of Slovenia 2002
© 2005, ZRC SAZU Anton Melik Geographical Institute

Graphs should be made in digital form using *Excel* on separate sheets and accompanied by data.
Photos must be in raster format with a resolution of 600 dpi, preferably in .tif or .jpg formats.

Figures containing a screenshot should be prepared at the highest possible screen resolution (Control Panel\All Control Panel Items\Display\Screen Resolution). The figure is made using Print Screen, and the captured screen is pasted to the selected graphic program (e.g., *Paint*) and saved as .tif. The size of the image or its resolution must not be changed.

Examples of appropriate graphic data formats: see the templates of maps in cdr and mxd files (available at https://ags.zrc.sazu.si) for a full-page map in landscape layout and an example of the correct file structure (available at https://ags.zrc.sazu.si) for submitting a map created with *ESRI ArcGIS*.

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As part of the submission process, authors are required to check off their submission's compliance with all of the following items, and submissions may be returned to authors that do not adhere to these guidelines.

- I, the corresponding author, declare that this manuscript is original, and is therefore based on original research, done exclusively by the authors. All information and data used in the manuscript were prepared by the authors or the authors have properly acknowledged other sources of ideas, materials, methods, and results.
- Authors confirm that they are the authors of the submitting article, which is under consideration to be published (print and online) in the journal *Acta geographica Slovenica* by Založba ZRC, ZRC SAZU.
- All authors have seen and approved the article being submitted.
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- The article has been checked for spelling and grammar.
- Figures are not embedded in the Word file and are provided as a graphic file: editable vector format (e.g., cdr, ai) for maps and illustrations; tif for photographs; xlsx for graphs. The Word file includes only figure captions.
- Tables are placed in the Word file with text at the appropriate place.
- The reference list was prepared following the guidelines.
- All references in the reference list are cited in the text.
- Where available, URLs and DOI numbers for references are provided.
- Graphic files are in one .zip file.
- Authors agree that any costs of English proofreading are borne by the author(s). No additional costs are associated with the submission.
- The instructions for ensuring a double-blind review have been followed.

ACTA GEOGRAPHICA SLOVENICA EDITORIAL REVIEW FORM

This is a review form for editorial review (version 14) of an article submitted to the AGS journal.

This is an original scientific article.
(The article is original and the first presentation of research results with the focus on methods, theoretical aspects or a case study.)

- Yes
- No

The article follows the standard IMRAD/ILRAD scheme.

- Yes
- No

The article's content is suitable for reviewing in the AGS journal.
(The article is from the field of geography or related fields of interest, the presented topic is interesting for the readers of *Acta geographica Slovenica* and well presented. In case of negative answer add comments below.)

- Yes
- No

Editorial notes regarding the article's content.

The reference list is suitable (the author cites previously published articles with similar topics from other relevant geographic scientific journals).

- Yes, the author cited previously published articles on a similar topic.
- No, the author did not cite previously published articles on a similar topic.

Notes to editor-in-chief regarding previously published scientific work.

Is the language of the article appropriate and understandable?

RECOMMENDATION OF THE EDITOR
- The article is accepted and can be sent to the review process.
- Reconsider after a major revision (see notes).
- The article is rejected.

ACTA GEOGRAPHICA SLOVENICA REVIEW FORM

This is *Acta geographica Slovenica* review form (version 7).

1 RELEVANCE

Are the findings original and the article is therefore a significant one?
- yes
- no
- partly

Is the article suitable for the subject focus of the AGS journal?
- yes
- no

2 SIGNIFICANCE

Does the article discuss an important problem in geography or related fields?
- yes
- no
- partly

Does it bring relevant results for contemporary geography?
- yes
- no
- partly

What is the level of the novelty of research presented in the article?
- high
- middle
- low

3 ORIGINALITY

Has the article been already published or is too similar to work already published?
- yes
- no

Does the article discuss a new issue?
- yes
- no

Are the methods presented sound and adequate?

- yes
- no
- partly

Do the presented data support the conclusions?

- yes
- no
- partly

4 CLARITY

Is the article clear, logical and understandable?

- yes
- no

If necessary, add comments and recommendations to improve the clarity of the title, abstract, keywords, introduction, methods or conclusion:

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Is the article technically sound? (If not, the author should discuss with the Editorial Board [ags@zrc-sazu.si] for assistance.)

- yes
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Propose amendments, if no is selected:

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Which tables are not necessary?
Which figures are not necessary?

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Comments of the reviewer on the contents of the article:
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PUBLISHER

Anton Melik Geographical Institute
Research Centre of the Slovenian Academy of Sciences and Arts
PO Box 306
SI–1001 Ljubljana
Slovenia

SOURCES OF SUPPORT

The journal is subsidized by the Slovenian Research Agency and is issued in the framework of the Geography of Slovenia long-term core research programme (P6-0101). The journal is also supported by the Slovenian Academy of Sciences and Arts.

JOURNAL HISTORY

Acta geographica Slovenica (print version: ISSN: 1581-6613, digital version: ISSN: 1581-8314) was founded in 1952. It was originally named *Geografski zbornik / Acta geographica* (print ISSN 0373-4498, digital ISSN: 1408-8711). Altogether 42 volumes were published. In 2002 *Geographica Slovenica* (ISSN 0351-1731, founded in 1971, 35 volumes) was merged with the journal.

Since 2003 (from volume 43 onward) the name of the joint journal has been *Acta geographica Slovenica*. The journal continues the numbering system of the journal *Geografski zbornik / Acta geographica*.

Until 1976, the journal was published periodically, then once a year, from 2003 twice a year and from 2019 three times a year.

The online version of the journal has been available since 1995. In 2013, all volumes of the magazine were digitized from the beginning of its publication to 1994 inclusive.

All articles of the journal are available free of charge in digital form on the journal website http://ags.zrc-sazu.si.

Those interested in the history of the journal are invited to read the article »The History of *Acta geographica Slovenica*« in volume 50-1.

ISSN: 1581-6613
UDC – UDK: 91
ACTA GEOGRAPHICA SLOVENICA
GEOGRAFSKI ZBORNIK

63-1
2023

2023, ZRC SAZU, Geografski inštitut Antona Melika
Print/tisk: Present, d. o. o.

Ljubljana 2023

ACTA GEOGRAPHICA SLOVENICA
GEOGRAFSKI ZBORNIK
63-1 • 2023

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ISSN 1581-6613
9 771581 661010