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Beyond borders: A decade of change in Europe's Saker Falcon (*Falco cherrug* Gray, 1834) population (2012–2022)

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Abstract The westernmost population of the globally endangered Saker Falcon *(Falco cherrug)* resides in Europe. Despite its small size, this European population is fragmented by political borders, complicating a holistic understanding of its demographic processes, ecology, and threats at the population level. Prior research has predominantly focused on national-level data, summarizing the numbers of breeding pairs in various countries without conducting a unified analysis. This study aims to consolidate and examine the aggregated national datasets from 2012 to 2022, providing a comprehensive overview of the status of European Saker Falcon breeding population, its trends, and demographic processes. We estimate the European population at 535–700 pairs and identify three distinct subpopulations: the interconnected and growing yet demographically diverse western and eastern subpopulations in Central Europe, and the declining Eastern European (Black Sea) subpopulation, which has limited connection to the two Central European subgroups. The results highlight the necessity of continued large-scale conservation efforts, particularly for the Eastern European subpopulation. Furthermore, cross-border cooperation is crucial for the development and implementation of joint research and conservation strategies.

Keywords: Saker Falcon, Europe, *Falco cherrug*, population, demography

Összefoglalás A globálisan veszélyeztetett kerecsensólyom *(Falco cherrug)* legnyugatibb populációja Európában található. Annak ellenére, hogy kicsi, ez az európai populáció politikai határok által tagolt, ami megnehezíti a demográfiai folyamatok, az ökológia és a populációs szintű fenyegetések egészének megértését. A korábbi kutatások főként az országos szintű adatokra összpontosítottak, a különböző országok költőpárjainak számát összegezték anélkül, hogy egységes elemzést végeztek volna. Ez a tanulmány arra törekszik, hogy összegyűjtse és egységben elemezze a 2012–2022 közötti országos adatokat, így átfogó képet alkotva az európai kerecsensólyom-állomány állapotáról, trendjéről és demográfiai folyamatairól. Az eredményeink alapján, az európai populáció 535–700 pár között van, és három különálló alpopuláció különíthető el: az egymással kapcsolatban álló és növekvő, de demográfiai szempontból változatos nyugati és keleti alpopulációk Közép-Európában, valamint a csökkenő kelet-európai (fekete-tengeri) alpopuláció, amelynek nagyon kevés kapcsolata van a közép-európai állományokkal. Az eredmények egyértelműen jelzik a nagyléptékű természetvédelmi erőfeszítések szükségességét, különösen a kelet-európai alpopuláció esetében. Emellett a határokon átnyúló együttműködés elengedhetetlen a kutatások és a természetvédelmi stratégiák kidolgozásához és megvalósításához.

Kulcsszavak: kerecsensólyom, Európa, *Falco cherrug,* állomány, demográfia

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Introduction

As apex predators, birds of prey play a crucial role in ecosystem dynamics and serve as indicators of ecosystem health. The global overview of their conservation status presents a grim picture: more than half (52%) of the 557 species are experiencing population declines, with 18% on the brink of extinction (McClure *et al.* 2018). Their decline also signals underlying ecosystem issues that often have repercussions for humans, as evidenced by the disappearance of vultures in India (Markandya *et al.* 2008). Viewed from another perspective, birds of prey serve as umbrella and flagship species as their protection benefits numerous other species within the same ecosystem.

At the same time, the study and conservation of migratory and transboundary distributed wildlife species, including avian species, pose unique challenges in ecological research and conservation initiatives. The national approaches often adopted in these studies, segmented by national jurisdictions, frequently limit our understanding of the true ecological dynamics of these species. Data quality and quantity vary considerably across species distribution range. Moreover, monitoring data and observed population trends in individual countries may not accurately reflect the overall demographic processes of the entire population across borders.

This disparity has been recognized for some time, leading to the establishment of various international efforts, from local transboundary initiatives to intergovernmental and interorganizational conventions and treaties. Notable examples include the Convention on Migratory Species of Wild Animals (http://www.cms.int), the Global Snow Leopard & Ecosystem Protection Programme (http://globalsnowleopard.org), and the European Union's multi-country Species Action Plans (http://tinyurl.com/sapeu). These initiatives exemplify collective efforts to address conservation challenges. Meanwhile, numerous smaller-scale transboundary projects, both regional and local, are also implemented globally, focusing on assessing population status and conserving species within specific areas and typically targeting a well-defined segment of a larger population.

However, in most cases, status assessments are merely summaries of national or subnational population counts, lacking coherent analyses of the functional connections between cross-border populations. This can lead to gaps in understanding and potential inefficiencies in conservation strategies. Despite this, there are commendable instances where a more holistic population approach has been successfully applied for data management and analysis. Examples include the conservation of the Red Kite *(Milvus milvus)* in Europe (Mattsson *et al.* 2022), the Andean Condor *(Vultur gryphus)* in South America (Lambertucci *et al.* 2014), and the Gyrfalcon *(Falco rusticolus)* and Peregrine Falcon *(F. peregrinus)* across the Arctic (Franke *et al.* 2020), Multi-species Action Plan to Conserve African-Eurasian Vultures (Botha *et al.* 2017). These cases demonstrate how a comprehensive understanding of species' population dynamics across their entire range can significantly enhance conservation outcomes.

The conservation of the European population of the Saker Falcon (*F. cherrug*; hereinafter Saker) faces similar challenges. The Saker, a characteristic species of the Eurasian steppe zone, has a range that extends from East China to the westernmost part of the Pannonian Basin in Central Europe (Cade 1982, Baumgart 1991, Kovács *et al.* 2014). The global population is estimated to be between 6,400 and 15,400 pairs, but the European population is considerably smaller, estimated to be only a few hundred pairs (Orta *et al.* 2020). The once continuous Eurasian range has been significantly fragmented by today, primarily due to changes in land use combined with other factors (e.g. illegal trapping, use of pesticides, declining prey populations, etc.) causing marked population declines in Kazakhstan and Russia from the late 20th to the early 21st centuries (Nikolenko *et al*. 2014) – a decline that continues to this day (Karyakin *et al*. 2022, 2023). While Saker populations have consistently decreased across much of their range, Central Europe has witnessed an increase in the past decades, in stark contrast to the situation in Eastern Europe (Kovács *et al.* 2014).

Since the 1980s, the population status of Saker has been meticulously recorded in most Central European countries. The national datasets are results of annual monitoring programs (e.g. Bagyura *et al*. 2012, 2017, 2025, Chavko & Deutschová 2012, Chavko *et al.* 2014, 2019, 2024, Hegyeli *et al.* 2017, Lazarova *et al.* 2021, Prommer *et al.* 2025), and there are also a few review articles on the European population (Nagy & Demeter 2006, Dixon 2007, Kovács *et al.* 2014). Although high-quality data exists for populations in nearly all Central European countries, there has been a lack of comprehensive analyses that consolidate trends and demographic factors, treating the Central European population as a cohesive unit rather than a simple compilation of breeding pairs by country. Additionally, the less conspicuous metapopulation structure in Central Europe must be acknowledged. The population reached its lowest point in the 1970s and 1980s, surviving in two distinct core areas: the mountains of Hungary and the mountains of Slovakia. The current Central European population originates from the later expansion of these refugial areas. While the eastern and western groups (subpopulations) are connected, their breeding ranges remain geographically disjunct, which may lead to differences in population dynamics.

This study pioneers a cohesive approach to understanding the European Saker population by integrating national data providing a more accurate and comprehensive understanding of the species' regional status and demographic trends, as opposed to simply reporting the results of national programs. Acknowledging the importance of viewing the European

Saker population as a coherent entity undivided by political borders, while considering finer metapopulation structure in Central Europe, the current research sets out to: (i) compile data and evaluate trends across the European Saker population from 2012 to 2022; and (ii) investigate the metapopulation structure and demographic characteristics of Saker within Europe.

Materials and Methods

Study area

The study area encompasses the breeding distribution of Saker in Europe, extending from the eastern regions of the Czech Republic and Austria, through southern Slovakia, most of Hungary (excluding the southwestern parts), northern Serbia, and western Romania in Central Europe. In Eastern Europe, the range comprises southwest Russia, southern Ukraine, Moldova, eastern Romania, and Bulgaria (as depicted in *Figure 1*). This study does not cover Türkiye, partly because it does not strictly fall within the defined geographical region and partly due to the absence of country data.

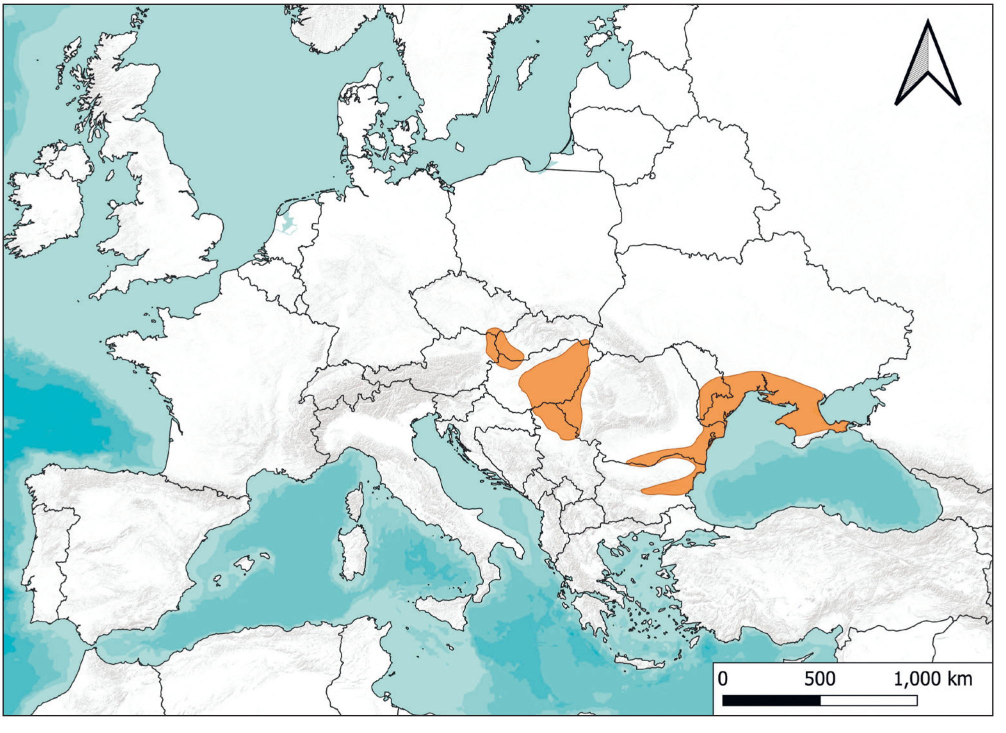


Figure 1. Approximate breeding distribution range of the Saker Falcon in Europe (highlighted in orange) in the study period (2012–2022)

1. ábra A kerecsensólyom európai fészkelőállományának hozzávetőleges elterjedési területe (narancssárgával kiemelve) a vizsgált időszakban (2012–2022)

Unlike the past decades when Sakers nested in hills and low mountain areas (Bagyura *et al.* 2012, Chavko & Deutschová 2012), the European breeding range of the species is now almost exclusively confined to lowland areas. The breeding grounds of Central and Eastern European pairs are distinct, geographically separated by the Carpathian Mountains. The Central European population inhabits the Carpathian Basin, while the Eastern European population occupies the northern and western coastal areas of the Black Sea, the Crimean, Bessarabia, Dobrudja, and the Lower Danube. Furthermore, the Central European breeding pairs belong to the Pannonian Biogeographic Region, while the Eastern European pairs are part of the Steppic and, to some extent, the Continental Biogeographic Regions, based on the delineation of these regions by the European Union's Habitats Directive, as outlined by the European Environmental Agency (Roekaerts 2002).

As for the climate, Central Europe experiences a milder temperate climate, while Eastern Europe has a more pronounced temperate continental climate, with hot summers and mild to cold winters (Peel *et al.* 2007). Historically characterized by steppe, forest-steppe, and partly deciduous forest, these landscapes have been extensively converted into arable land and pastures throughout most of the species range.

Data collection

For analyzing the population dynamics in Central Europe, we utilized data from Austria (Zink *et al.* 2025), the Czech Republic (Škorpíková *et al.* 2025), Hungary (Bagyura *et al.* 2022, 2025), western Romania (Prommer *et al.* 2025), and Slovakia (Chavko *et al.* 2025). These datasets were derived from regular annual population monitoring carried out in these countries. In the calculations presented in this study, we assumed the detection probability to be close to one, and therefore only considered the number of confirmed pairs, disregarding estimates for suggested but non-localized pairs. For Serbia, detailed data were available only for the period 2020–2022 (Puzović 2025); we therefore analyzed the European population trends excluding Serbia for the period 2012–2022, adding the country data in a separate analysis for the period 2020–2022. Country-specific articles, also used for the current study, are featured in the same issue of Ornis Hungarica 33(1). Ringing and recovery data from the Hungarian Bird Ringing Centre (retrieved from www.tringa.mme.hu) were used to assess natal dispersal and connectivity between the two Saker subpopulations in Central Europe. Ringing data from other countries were excluded from our analysis due to lack of recoveries of breeding adults. References for the data used to assess the Eastern European population (southwest Russia, southern Ukraine, Moldova, eastern Romania, and Bulgaria) can be found in the relevant sections of the text.

Data analysis

To compare the eastern and western subpopulations in Central Europe, we categorized the pairs as follows: the larger eastern subpopulation included breeding pairs from eastern Slovakia, central and eastern Hungary, western Romania, Serbia, and Croatia. Meanwhile, breeding pairs located in western Slovakia, the Czech Republic, eastern Austria, and western Hungary were classified as the western subpopulation *(Figure 1)*. Detailed data about eastern and western subpopulations in Central Europe can be found in *Appendix 1*. To avoid confusion between the eastern subpopulation in Central Europe and the Eastern European population, we will refer to the latter, from this point forward, simply – though somewhat inaccurately – as the 'Black Sea population'.

As territory-level occupancy and nesting data were unavailable, we relied on national summaries from annual population monitoring. This limited our ability to perform more in-depth statistical analyses. To assess differences in breeding success, brood size, and productivity between the eastern and western subpopulations of Central Europe, we calculated country-weighted means for each metric. This weighting ensures that larger core populations, which contribute more substantially to the overall population dynamics, are appropriately reflected in the regional averages. We applied Welch's two-sample t-test to compare the means of the metrics between the eastern and western subpopulations in Central Europe. Due to lack of datasets covering at least half of the study period, the datasets available from Serbia and Croatia were excluded from that assessment.

Due to the lack of systematic monitoring data, assessing the Black Sea population is challenging. Consequently, we relied on the most recent available information for this subpopulation. In the case of Ukraine, which hosts the largest number of breeding pairs in the region, the last countrywide assessment was conducted in 2012. To estimate the current population in Ukraine, we propose two hypothetical scenarios for the period 2012–2022: (a) no change since the latest countrywide assessment as reported by Milobog 2012, and (b) a 32% decrease over two generations, as estimated for the entire European population, with a generation time of 6.1 years (BirdLife 2021b). Given recent surveys in neighboring Moldova (Ajder *et al.* 2025) and Romania (Fântânâ *et al.* 2025), and the absence of a known breeding population in the neighboring areas in European Russia (Karyakin 2005, 2008), any positive trend for the Ukrainian population is highly unlikely; thus, we did not consider such a scenario.

In our analysis of ring recoveries, we only considered data for individuals older than 730 days (in their 3rd calendar year), which is the age identified as the threshold for breeding maturity in Sakers (Baumgart 1991). While the ring recoveries do not conclusively demonstrate that the individuals were breeding, their age, coupled with the sedentary nature of territory-occupying Sakers, suggests a probable pattern of natal dispersal.

We used the R programming language (R Core Team 2023) and Microsoft Excel for statistical analysis and result visualization. Maps were created using QGIS 3.22.3 "Białowieża" (QGIS Development Team 2021).

To estimate the parameters displayed on the graphs, linear regression analysis was conducted separately for each subpopulation and variable over the study period (2012–2022). The slopes (rate of change per year) and intercepts were calculated along with the coefficient of determination (R^2), providing a measure of the fit's explanatory power (Montgomery *et al.* 2012). These regression equations summarize trends in the data and are presented directly on the figures for clarity.

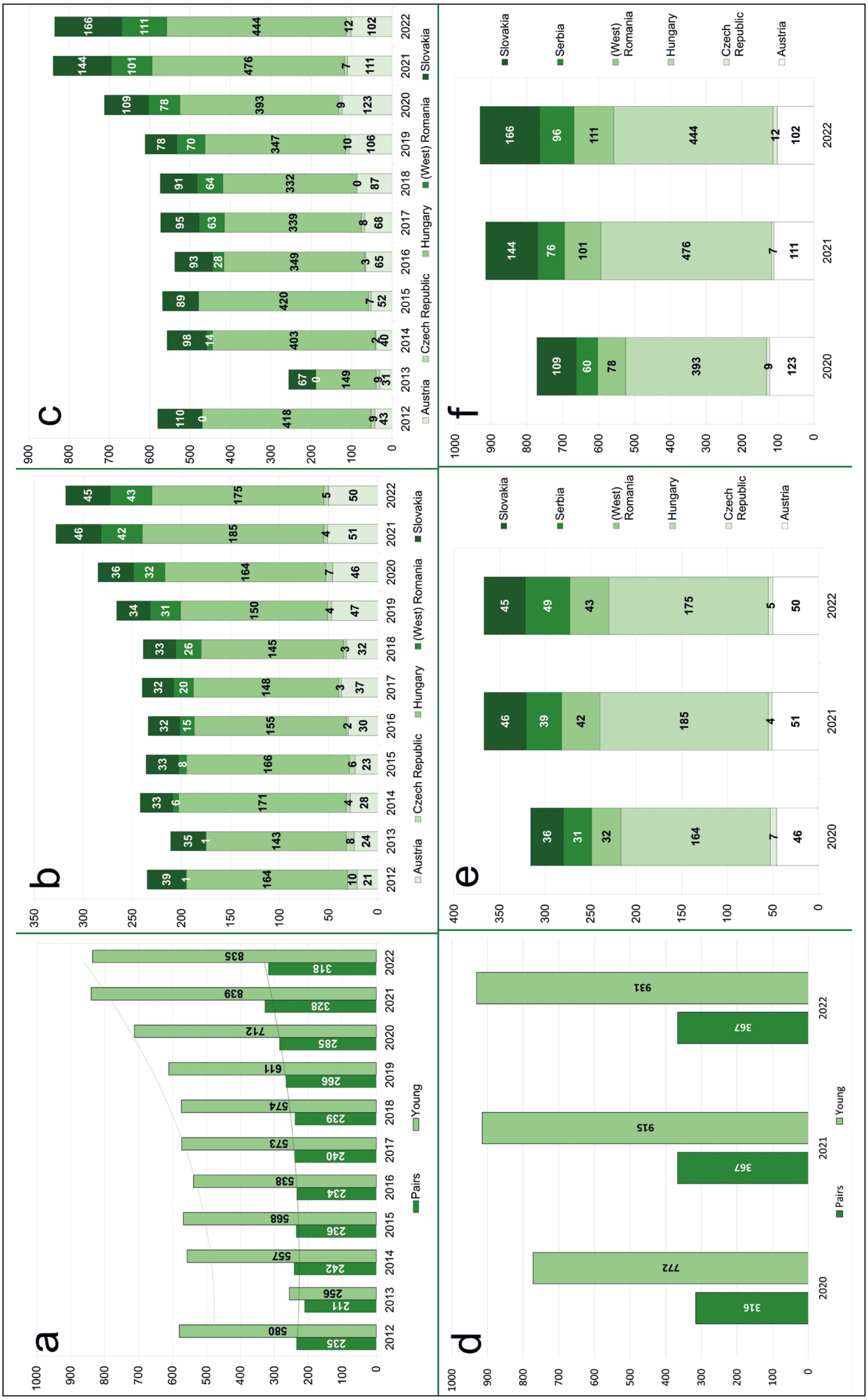
Results

Population analysis by country

First, for the sake of compatibility with previous status assessments, we take a conventional approach and provide an overview of the latest country-level data. The Central European population of the Saker showed an overall increase from 2012 to 2022, yet this trend was not uniform across the region. The Czech population experienced a decline from 10 pairs in 2012 to 4 in 2021, followed by a recovery to 10 pairs again in 2022 (Škorpiková *et al.* 2025). In contrast, Croatia's breeding pairs dwindled from two to none, with the caveat that the absence of systematic monitoring could mean some pairs remain undetected (Krešimír Mikulić *pers. comm.*). In Hungary and Slovakia, the rapid population growth that began in the 1980s ceased in the early 2010s (Chavko *et al.* 2019, Bagyura *et al.* 2025), and it was followed by a modest and non-linear increase continued between 2012 and 2021 (Bagyura *et al.* 2022, Chavko *et al*. 2025). At the same time, Austria and western Romania saw significant rises, especially after the installation of nest boxes within several targeted LIFE-funded projects (Prommer *et al.* 2025, Zink *et al.* 2025). Excluding Serbia (due to lack of credible data for that period), the Saker population in Central Europe expanded from 235 to 328 pairs between 2012 and 2021, followed by a slight decline to 318 in 2022. Number of juveniles per year also grew from 256 to 856, with a total of 6,664 young reported from 2012 to 2022. Including the most recent Serbian dataset (Pužović 2025), the total Central European population grew from 316 to 367 pairs between 2020 and 2022, and the annual number of juveniles from 649 to 829. Detailed population data by country are shown in *Figure 2*.

Figure 2. Variation in the number of breeding pairs and offspring by country in Central Europe from 2012 to 2022, excluding Serbia, and from 2020 to 2022 including the Serbian population. Due to the lack of reliable data for Serbia between 2012 and 2019, we have created two distinct sets of diagrams for better comparability
(a) The change of population in Central Europe (without Serbia) from 2012 to 2022
(b) Number of known breeding pairs by country
(c) Number of young per country
(d) The change of population in Central Europe with Serbia from 2020 to 2022
(e) Number of known breeding pairs per country
(f) Number of young per country

2. ábra A fészkelőpárok és a fiatalok számának változása országonként Közép-Európában 2012 és 2022 között, Szerbia nélkül, valamint 2020 és 2022 között a szerbiai populációval együtt. Mivel Szerbiában 2012 és 2019 között nem állt rendelkezésre megbízható adat, két külön diagram sort készítettünk a jobb összehasonlíthatóság érdekében.
(a) A populáció változása Közép-Európában (Szerbia nélkül) 2012 és 2022 között
(b) Az ismert költőpárok száma országonként
(c) A fiatalok száma országonként
(d) A populáció változása Közép-Európában Szerbiával együtt 2020 és 2022 között
(e) Az ismert költőpárok száma országonként
(f) A fiatalok száma országonként


a
b
c
d
e
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Pairs
Young
Austria
Czech Republic
Hungary
(West) Romania
Serbia
Slovakia

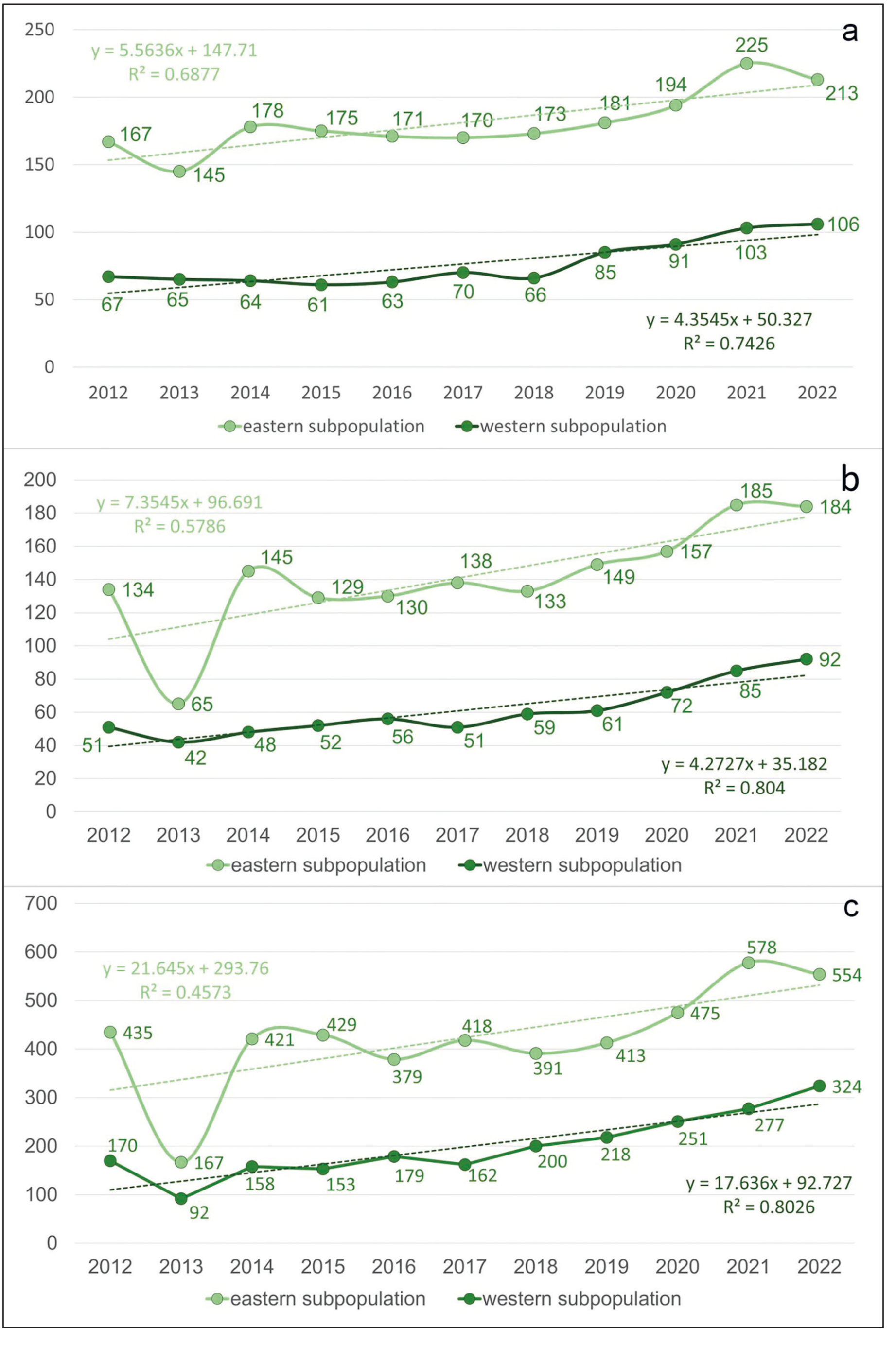


Figure 3. Trends of demographic data – number of breeding pairs (a), number of successful pairs (b), and number of young (c) – in the eastern and western subpopulations in Central Europe

3. ábra Az egyes demográfiai adatok – párok száma (a), sikeresen fészkelő párok száma (b) és a fiatalok száma (c) – trendje a közép-európai keleti és nyugati alpopulációkban

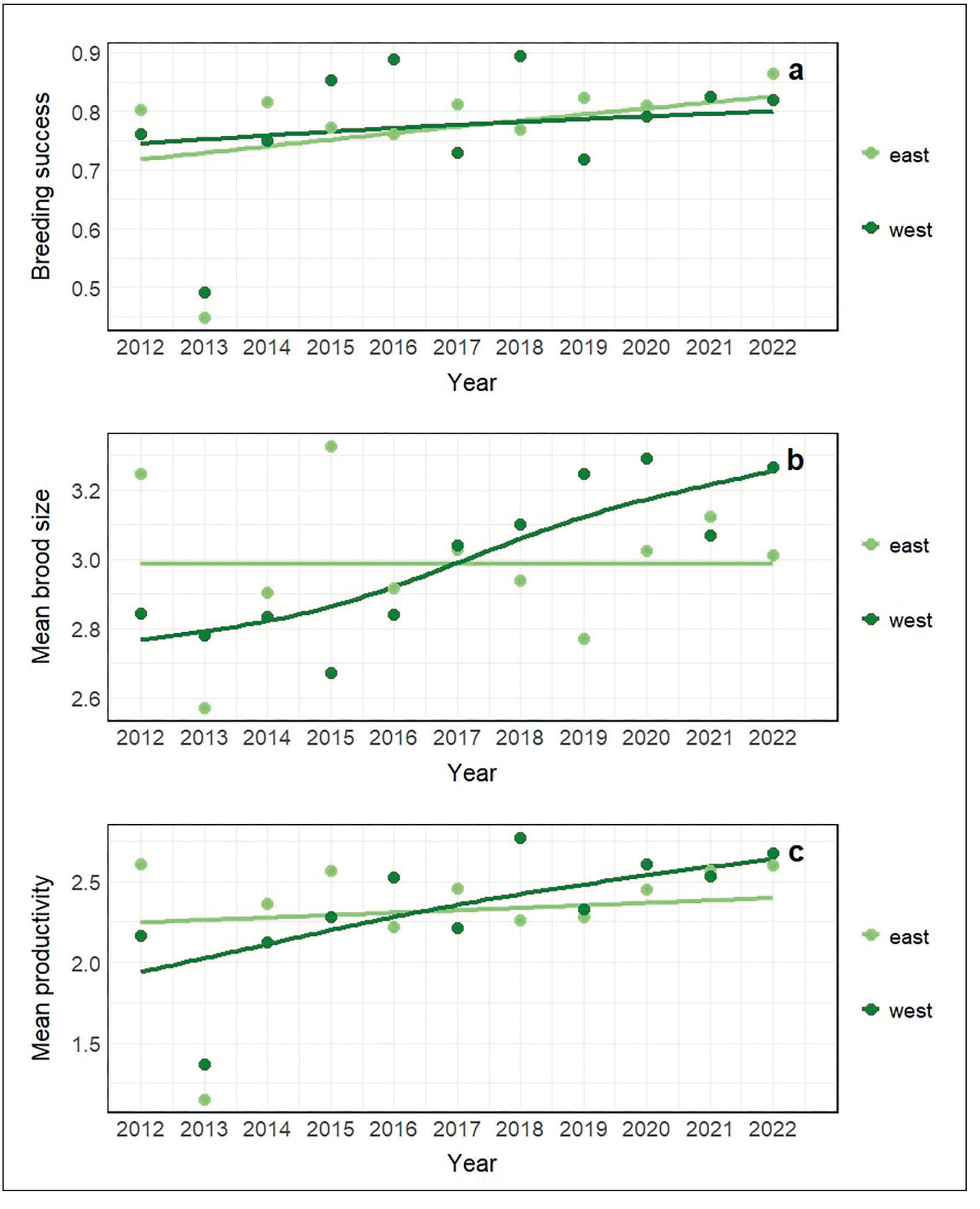


Figure 4. Trends of demographic parameters – probability of breeding success (a), mean brood size (b), and mean productivity (c) – in the eastern and western subpopulations in Central Europe. Means are weighted by country, and a smoothing function using Generalized Additive Models (GAM) was applied to capture and visualize non-linear trends in the data

4. ábra. A demográfiai paraméterek trendjei – a költési siker valószínűsége (a), az átlagos fiókaszám (b) és az átlagos produktivitás (c) – Közép-Európa keleti és nyugati részpopulációiban. Az átlagok országok szerinti súlyozással lettek kiszámítva, és a Generalizált Additív Modellek (GAM) segítségével egy simító függvényt alkalmaztunk az adatok nemlineáris trendjeinek megjelenítésére

Considering the entire study period (2012–2022) annual productivity (calculated as the mean number of young per breeding attempt) was ~2.5 young in most countries. However, in the same period, Slovakia stood out with remarkably high productivity (>3 young per breeding attempt), while productivity of pairs in Serbia's remained below two young per breeding attempt.

Population in Central Europe

The Central European Saker population showed a slight increase in the study period 2012–2022. The mean probability of successful nesting or breeding success (calculated as successful pairs per all breeding attempts) in the total Central European population was μ_{NS} = 0.78±0.032 (n = 76), while the mean brood size (mean number of young per successful pairs) was μ_{BS} = 3.02±0.047 (n = 76), and the mean productivity was μ_{P} = 2.35±0.116 (n = 76).

Upon investigating the eastern and western subpopulations within Central Europe separately, we found that both exhibited a slight upward trend in the number of nesting pairs, successful pairs, and young produced (*Figure 3a, b, c*, respectively).The probability of nesting success was $\mu_{NSeastern}$ = 0.781±0.033 (n = 32) and $\mu_{NSwestern}$ = 0.777±0.049 (n = 44), and there was no significant difference between them (t = 0.436, df = 4.610, p = 0.682). The mean brood size ($\mu_{BSeastern}$ = 3.01±0.131, n = 32; $\mu_{BSwestern}$ = 3.04±0.364, n = 44) did not differ significantly either (t = 1.277, df = 3.456, p = 0.281). Productivity of the eastern subpopulation ($\mu_{Peastern}$ = 2.35±0.191, n = 32) was almost identical with that of the western subpopulation ($\mu_{Pwestern}$ = 2.36±0.338, n = 44), without significant difference (t = 1.137, df = 4.154, p = 0.317).

The annual trend of mean probability of breeding success was similar and showed a slight increase for both subpopulations *(Figure 4a)* in the study period. The trend of mean brood size, however, was markedly different: while remaining stable in the eastern subpopulation, mean brood size increased by ~0.4 young per successful pair between 2012 and 2022 in the western subpopulation *(Figure 4b)*, also reflected in productivity trends *(Figure 4c)*.

Breeding connectivity within the Central European subpopulations

From the initial 95 recoveries of ringed Sakers that aligned with our criteria, we refined the dataset down to 77 records by filtering out repeated recoveries of the same individuals and excluding records not pertaining to Sakers ringed as nestlings. The latter helped distinguish between breeding and natal dispersal. Out of these, sex was determined for a total of 54 individuals. The findings indicate that females dispersed on an average of 109.8 km, while males tend to remain close to their fledging sites, displaying an average dispersal distance of 47.1 km. Despite settling at greater distances than males, most females remained within the range of their original subpopulation.

However, only a mere 7.7% of the recoveries – exclusively females, as shown in *Table 1* – displayed instances of natal dispersal that had the potential to connect the two subpopulations, suggesting a low level of breeding connectivity *(Figure 5)*. The average post-fledging dispersal distance for those six female birds was 216.6 kilometers.

Table 1. Recovery data of individuals suggesting natal dispersal that connects the two Central European subpopulations

1. táblázat A két közép-európai részállományt összekötő diszperziót mutató egyedek megkerülési adatai

Ring number	Country of ringing	Country of recovery	Sex	Direction of natal dispersal	Elapsed time (days)	Distance (km)
501541	Hungary (east)	Hungary (west)	female	east to west	790	103
516122	Hungary (west)	Hungary (east)	female	west to east	1,843	333
521681	Hungary (east)	Slovakia (west)	female	east to west	3,613	251
522181	Hungary (east)	Slovakia (west)	female	east to west	2,039	229
D2477	Slovakia (west)	Hungary (east)	female	west to east	1,579	143
LY00698	Hungary (east)	Austria	female	east to west	2,041	238

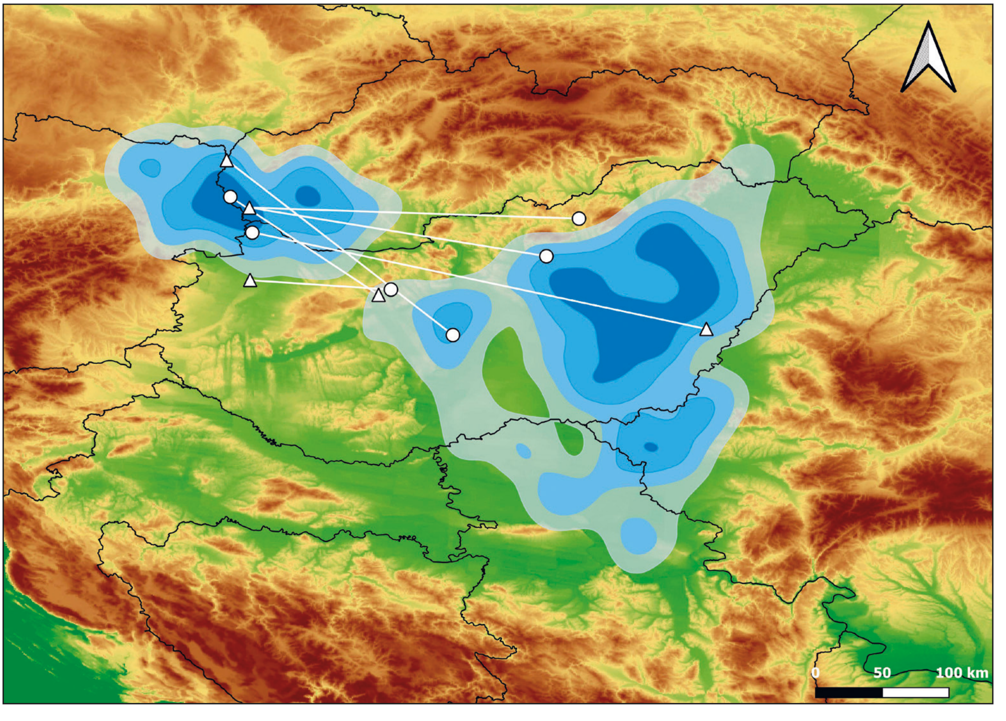


Figure 5. Ring recoveries indicating presumed natal dispersal connecting the two Central European subpopulations. The arrows indicate the direction of dispersal (○ = place of fledging, △ = place of assumed breeding). All recovered individuals on the map were adult, female and were ringed as nestlings

5. ábra A két közép-európai részállományt összekötő, feltételezett diszperzió a gyűrűzési-megkerülési adatok alapján. A nyilak az elvándorlás irányát mutatják (○ = kirepülés helye, △ = feltételezett fészkelés helye). Minden, a térképen jelölt egyed ivarérett tojó volt, és fiókaként lett meggyűrűzve

Black Sea population

As opposed to the Central European population, where regular counts have been taking place since the 1980s, the Black Sea population can only be assessed based on sporadic data and historical overviews. This population historically extended from the Lower Danube River in the west, through Dobrudzha and the Danube Delta, to the Eastern European steppes encompassing Moldova, Ukraine, and Russia (Baumgart 1991). By the early 21st century, Saker had practically vanished from European Russia (Karyakin 2008), with Ukraine hosting the largest known Eastern European breeding population, estimated at 285–312 pairs in 2012, out of which 115–127 pairs reported in Crimea (Milobog 2012). That estimate was already lower than the previous one done in 2010, when the total number of breeding pairs were projected at 350–400 pairs in Ukraine (160–180 pairs in Crimea). The same study estimated 10–15 pairs in Moldova, and 20–40 pairs suggested for (European) South Russia – although in the latter area expeditions did not find a single breeding pair that year (Milobog *et al.* 2010). There was no regular monitoring after 2012, and small-scale ad-hoc surveys in south and southwest Ukraine showed a gradual decrease of the population (Yuri Milobog *pers. comm.*). In 2015, a population census in Crimea estimated the Saker population to 145–184 breeding pairs (Karyakin & Nikolenko 2015), which was higher than the 2012 estimate, but agreed with the former estimation in 2010. It is, however, difficult to compare that result with the one in 2012 as census methods differed, and comprehensive and systematic monitoring, particularly along power lines, was still lacking. At the same time, isolated monitoring of known nests on the Tarkhankut Peninsula indicates that the local Saker breeding population has remained stable through the late 2010s (Miroslav Babushkin *pers. comm.*). The lack of population data from the past decade makes any estimation difficult. Using the approach described in the Materials and Methods section – no population change since the last countrywide assessment, as published by Milobog 2012, versus a 32% decline over two generations, as estimated by BirdLife International for the entire European population (BirdLife 2021b), we estimate the Saker population in Ukraine to be between 194 and 312 pairs in 2022. The results are from taking the higher end of the no change hypothesis (285–312 pairs), and the lower end of the 32% decrease in two-generation hypothesis (194–212 pairs).

In European Russia, regularly breeding Sakers are reported to persist only in the Republic of Dagestan, with a small population of 3–5 pairs (Ismailov *et al.* 2008, Karyakin 2021). Breeding pairs in the Republic of Moldova, historically low, represented the periphery of the Ukrainian population. Their maximum estimate of 10–12 pairs (Milobog *et al.* 2010) dwindled to extinction by 2021 (Ajder *et al.* 2025). In the period 2016–2022, extensive field surveys covered the Lower Danube region and Dobrudja in eastern Romania, but only a few pairs were found, and now the estimated population in southeast Romania is 4–8 pairs (Fântânâ *et al.* 2025). In Bulgaria, Saker Falcon disappeared from the breeding avifauna after 2006. However, due to active reintroduction efforts initiated in 2011, the first breeding pair was successfully formed in 2018 (Lazarova *et al.* 2021). This pair remained until 2022, when a second pair was established and successfully bred (Klisurov 2022).

Based on all sources listed above, we can only provide a snapshot of the total Black Sea population, estimated at 203–327 pairs in 2022. Consequently, when considering it together with the Central European population, we estimate the total European population to be 570–694 pairs in 2022.

Connectivity between the Central European and the Black Sea populations

Although satellite-tracking (Gamauf & Dosedel 2012, Prommer *et al.* 2012, Nemček *et al.* 2014), and ring recoveries (Zmievskiy 2020, Hungarian Bird Ringing Centre 2023) proved the connection between the Central European and the Black Sea populations, most of those birds were roaming juveniles or immature individuals. There is only one recorded instance of breeding connectivity: a West Romanian 2cy female mounted with a satellite-tracking device in 2013 bred in Crimea the following year (https://sakerlife2.mme.hu/en/content/romanian-saker-breeds-crimea/). Despite satellite-tracking and ringing efforts for Sakers in Ukraine, there have been no recorded instances of these birds visiting Central Europe (Prommer *et al*. 2014). The captive-bred Sakers released in Bulgaria's reintroduction program showed similar patterns and stayed in Eastern Europe (Dixon *et al.* 2020).

Discussion

Population data and trends

In summary, the total European Saker population in 2022 is estimated to be between 570 and 694 breeding pairs. This estimate includes the well-documented Central European population, which consists of two subpopulations totaling 367 known pairs with increasing population trends. The Black Sea population estimate, limited by data scarcity, ranges from 203 to 327 pairs. The overall figure reflects a combination of robust data from Central Europe and more speculative estimates about the Black Sea population and hence the considerable range.

Although there have been several assessments of the European Saker Falcon population in the past 20 years, they primarily summarized national data without evaluating the population as a unified and continuous natural entity. The current study does not only assess populations in various countries but also attempts to evaluate breeding pairs and current population trends, highlighting the geographic and functional connections between coherent subpopulations, regardless of the individual political boundaries. As for the overall projections, we estimate the total European population of Saker Falcon to 535–700 pairs in 2022. This value does not show a strong difference from the previous assessments: 584–686 pairs (Nagy & Demeter 2006), 579–812 pairs (Dixon 2007), 637–823 pairs (Kovács *et al.* 2014), and 430–630 pairs (BirdLife International 2021a). We must note, however, that those assessments – except for Kovács *et al.* 2014 – also include Türkiye, which we did not consider in this study because no well-founded population estimates have been published for the study period. Also, while historical data and our current estimates suggest similar numbers of breeding pairs in Europe, we observe opposite trends in the European populations – a slowly increasing population in Central Europe and a likely decreasing Black Sea population – ultimately resulting in similar assessments for the overall European Saker population.

Historically, the European Saker population was a fraction of the Asian one and it has likely decreased further in the recent decades. BirdLife International (2021b) estimates the global population to be between 12,200 and 29,800 mature individuals. However, this number appears to have been derived directly from the Saker Falcon Global Action Plan (Kovács *et al.* 2014), where the global population is presented in breeding pairs (6,100–14,900). It is worth noting that these estimates do not account for floaters, which may constitute up to 40% of the population in large falcon species (Schaub & Kéry 2022). Even optimistically taking the higher estimate of the European Saker population at 694 pairs, this represents only about 4.7% to 11.4% of the global breeding population. This modest figure highlights the fragility of the population, especially given the ongoing decline of the Black Sea population and the limited potential for population expansion in Central Europe. The latter is particularly problematic, as European Sakers, under current environmental conditions, require larger breeding territories compared to their Asian counterparts (Prommer *et al.* 2018), and their home ranges do not overlap (Bold *et al.* 2023), further restricting their potential for population growth.

The decline of Black Sea population in Eastern Europe remains understudied. The reduction in mammalian prey began in the late 2000s, particularly in Eastern Ukraine and Southern Russia, for reasons still unclear (Vitalie Vetrov *pers. comm.*). Additionally, the illegal capture of young falcons in Ukraine (Yuri Milobog *pers. comm.*) and the removal of natural nests from power lines in Moldova by electric companies during maintenance work without providing alternatives have contributed to the decline (Ajder *et al.* 2025). Wind farm developments have also displaced the birds (Prommer & Bagyura 2015, Fantana *et al.* 2025). Comprehensive research into these threats is urgently needed to underpin targeted conservation efforts.

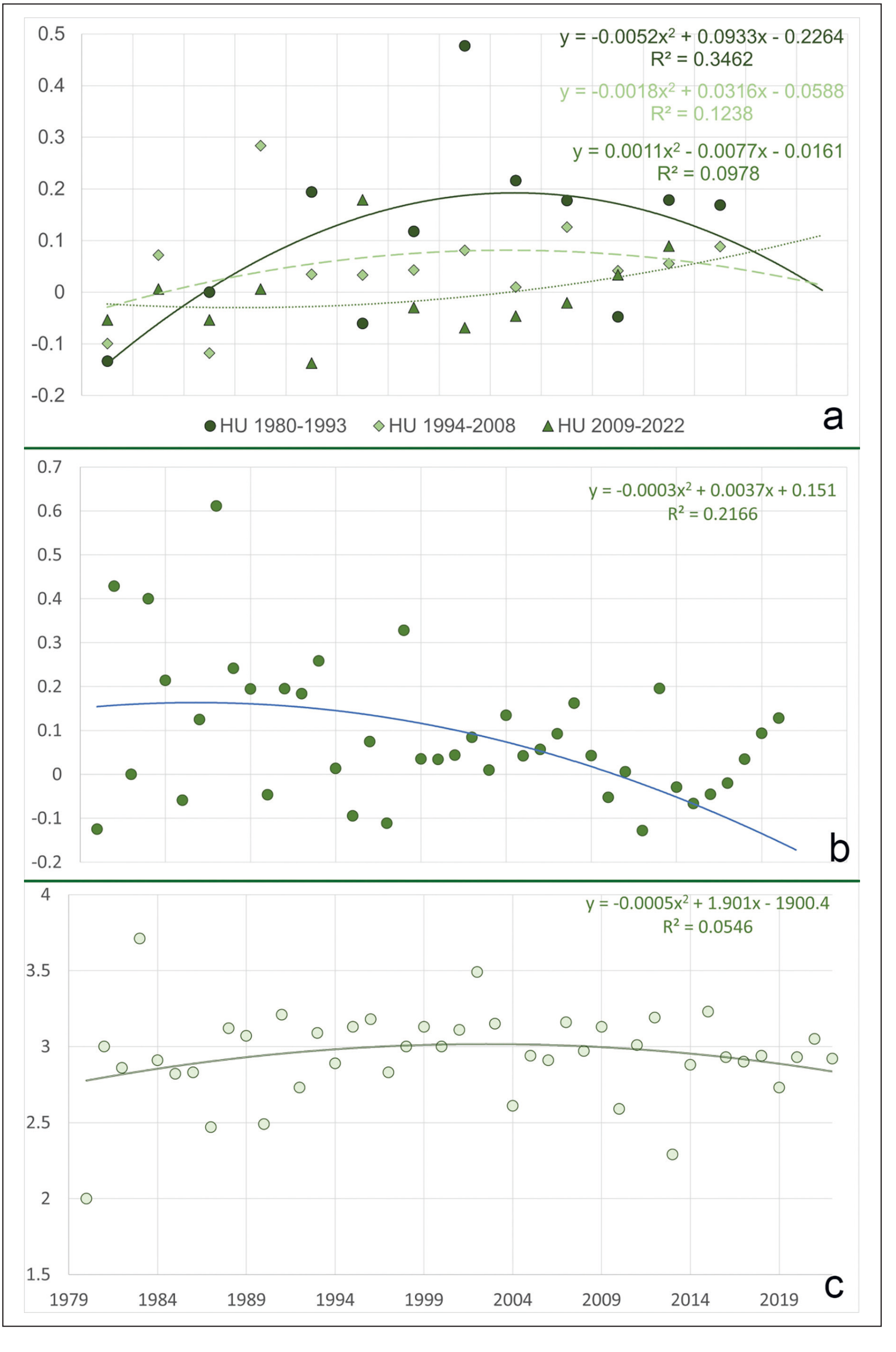
Metapopulation structure and demographic characteristics (Central Europe)

We found that, in addition to dividing the European Saker Falcon population into the Central European and the Eastern European 'Black Sea' groups, the Central European population can be further subdivided into eastern and western subpopulations. These two latter subpopulations are loosely connected and exhibit similar population trends but remain geographically disjunct. Population fragmentation driven by environmental factors is not an uncommon phenomenon. Such fragmentations are often results of events like populations retreat to disjunct refuge areas, as observed during glaciations (Cox *et al.* 2016) or they are due to anthropogenic impacts, as was the case with Peregrine Falcon *(F. peregrinus)* in the late 20th century (Cade *et al.* 1968). As a result of the latter reason, by the second half of the 20th century, the Central European range of the Saker had fragmented into two refuge areas: the Small Carpathians in Slovakia and the Northern Mountains in Hungary (Bagyura *et al.* 2022, Chavko *et al.* 2025). By the 1990s, populations from both refugia began to expand, gradually shifting from the mountainous regions to the lowlands. However, despite this population expansion, the breeding ranges of these populations have not yet fully converged. It must be explicitly noted that this does not imply that the two subpopulations are genetically distinct, as confirmed by genetic analyses (Gábor Sramkó *pers. comm.*).

Demographic parameters do not differ significantly either, but unlike the eastern subpopulation, the mean brood size changed remarkably in the western subpopulation. It is well-known that distinct subpopulations of raptors in the same geographic region can perform differently in terms of breeding due to different environmental conditions, which can affect conservation strategies (Wootton & Bell 1992, Kleinstäuber *et al.* 2018). Accordingly, differences in land use, with small-scale farming being more prevalent in the area of the western subpopulation, may positively influence the quality and quantity of available prey, which in turn positively affects brood size. There are also indications that larger brood size may be connected to a higher proportion of mammals in the diet (Karyakin *et al.* 2022, Zhang *et al.* 2024). Additionally, the western subpopulation may still be in a phase of rapid population growth, which the core area of the eastern subpopulation has already passed, as data from Hungary suggests *(Figure 6)*. Any of these factors, or a combination thereof, could explain the differences observed. However, identifying and explaining the exact reasons for these differences was beyond the scope of this study and will require further investigation and future systematic research.

Conclusions and main messages

In summary, the estimated Saker Falcon population in Europe appears stable, showing no significant changes from previous estimates. This stability is due to an increasing population in Central Europe and a declining one in Eastern Europe. Despite this, the species' conservation status remains precarious, particularly that of the Black Sea population in Eastern Europe. The relatively low number of breeding pairs in Central Europe increases the vulnerability and risk of a sudden population decline should a large-scale threat, such as avian flu, emerge. Factors like strong dependence on agricultural habitats, small population sizes, climate change, and ongoing armed conflicts exacerbate the vulnerability of the entire Saker population in Europe. As past examples have shown, even stable raptor populations can experience rapid declines under adverse conditions (Kéry *et al.* 2021, Ogada *et al.* 2022). Furthermore, recent studies have highlighted significant genetic differences between European and Asian populations of Saker (Pan *et al.* 2017, Hu *et al.* 2022, Zinevich *et al.* 2023), justifying increased conservation efforts. The unique European genetic pool, which still shows low levels of inbreeding (Gábor Sramkó *pers. comm.*), should be prioritized in line with modern conservation approaches that emphasize the preservation of genetic diversity (DeWoody *et al.* 2021). Expanded research and conservation efforts, particularly in Eastern Europe, and projects aimed at improving habitat quality and landscape connectivity to facilitate genetic exchange and resilience throughout the European breeding range are critical. Achieving this will require international coordination and a unified approach to monitoring, data analysis, and conservation planning across Europe.



y = -0.0052x² + 0.0933x - 0.2264
R² = 0.3462
y = -0.0018x² + 0.0316x - 0.0588
R² = 0.1238
y = 0.0011x² - 0.0077x - 0.0161
R² = 0.0978
HU 1980-1993
HU 1994-2008
HU 2009-2022
a
y = -0.0003x² + 0.0037x + 0.151
R² = 0.2166
b
y = -0.0005x² + 1.901x - 1900.4
R² = 0.0546
1979 1984 1989 1994 1999 2004 2009 2014 2019
c

Figure 6. The growth rate (***r***) of the Hungarian Saker Falcon population from 1980 to 2022 is divided into three distinct phases (a) and shows the entire period (b). The variation in mean brood size (c) is not significant. It must be noted that the Saker Falcon populations in neighboring countries increased considerably between 2009 and 2022. *Note that the x-axis in plot 'a' does not correspond to actual years*

6. ábra A magyar kerecsensólyom-populáció növekedési rátája (***r***) 1980 és 2022 között, három különálló szakaszra bontva (a), valamint az egész időszakra vonatkoztatva (b). Az átlagos fiókaszám változása (c) nem jelentős. Meg kell jegyezni, hogy a szomszédos országokban a kerecsensólyom-populációk 2009 és 2022 között jelentősen növekedtek. *Fontos megjegyezni, hogy az ‚a' ábrán az x tengely nem a valós évszámoknak felel meg*

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Apendix 1. Detailed data about the Central European nesting population of Saker Falcon
1. melléklet A közép-európai kerecsensólyom populáció részletes költési adatai

Country	Year	Subpopulation	Number of pairs	Successful pairs	Number of young
Austria	2012	west	21	16	43
Austria	2013	west	24	5	31
Austria	2014	west	28	18	40
Austria	2015	west	23	19	52
Austria	2016	west	30	26	65
Austria	2017	west	37	25	68
Austria	2018	west	32	31	87
Austria	2019	west	47	33	106
Austria	2020	west	46	38	123
Austria	2021	west	51	41	111
Austria	2022	west	50	35	102
Czechia	2012	west	10	8	9
Czechia	2013	west	8	5	9
Czechia	2014	west	4	2	2
Czechia	2015	west	6	5	7
Czechia	2016	west	2	1	3
Czechia	2017	west	3	3	8
Czechia	2018	west	3	0	0
Czechia	2019	west	4	4	10
Czechia	2020	west	7	3	9
Czechia	2021	west	4	2	7
Czechia	2022	west	5	4	12
Hungary	2012	east	155	123	393
Hungary	2013	east	134	58	146
Hungary	2014	east	163	132	381
Hungary	2015	east	158	122	406
Hungary	2016	east	147	111	329
Hungary	2017	east	142	114	332
Hungary	2018	east	140	108	315
Hungary	2019	east	144	122	327
Hungary	2020	east	157	128	379
Hungary	2021	east	178	149	460
Hungary	2022	east	165	143	422
Hungary	2012	west	9	8	25
Hungary	2013	west	9	7	3
Hungary	2014	west	8	8	22
Hungary	2015	west	8	8	14
Hungary	2016	west	8	8	20

Country	Year	Subpopulation	Number of pairs	Successful pairs	Number of young
Hungary	2017	west	6	3	7
Hungary	2018	west	5	5	17
Hungary	2019	west	6	5	20
Hungary	2020	west	7	6	14
Hungary	2021	west	7	7	16
Hungary	2022	west	10	9	22
Romania	2012	east			
Romania	2013	east			
Romania	2014	east	6	6	14
Romania	2015	east			
Romania	2016	east	15	11	28
Romania	2017	east	20	17	63
Romania	2018	east	26	19	64
Romania	2019	east	31	21	70
Romania	2020	east	32	24	78
Romania	2021	east	42	31	101
Romania	2022	east	43	36	111
Slovakia	2012	east	12	11	42
Slovakia	2013	east	11	7	21
Slovakia	2014	east	9	7	26
Slovakia	2015	east	9	7	23
Slovakia	2016	east	9	8	22
Slovakia	2017	east	8	7	23
Slovakia	2018	east	7	6	12
Slovakia	2019	east	6	6	16
Slovakia	2020	east	5	5	18
Slovakia	2021	east	5	5	17
Slovakia	2022	east	5	5	21
Slovakia	2012	west	27	19	68
Slovakia	2013	west	24	15	46
Slovakia	2014	west	24	20	72
Slovakia	2015	west	24	20	66
Slovakia	2016	west	23	21	71
Slovakia	2017	west	24	20	72
Slovakia	2018	west	26	23	79
Slovakia	2019	west	28	19	62
Slovakia	2020	west	31	25	91
Slovakia	2021	west	41	35	127
Slovakia	2022	west	40	38	145