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Ornis Hungarica 2025. 33(1): 1–25.
DOI: 10.2478/orhu-2025-0001

Field protocol for the population monitoring of Saker Falcons *(Falco cherrug)* in Hungary

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Received: July 26, 2024 – Revised: November 11, 2024 – Accepted: November 12, 2024

Bagyura, J., Szitta, T., Prommer, M. & Horváth, M. 2025. Field protocol for the population monitoring of Saker Falcons *(Falco cherrug)* in Hungary. – Ornis Hungarica 33(1): 1–25. DOI: 10.2478/orhu-2025-0001

Abstract The Saker Falcon population in Europe is divided into two main blocks: the Central European and Eastern European populations. Although these groups are somewhat connected, they do not form a single reproductive population. The Eastern European population is highly fragmented and spreads across a vast area, posing significant challenges for monitoring due to geographical and political barriers. In contrast, the Central European population is more compact but extends across seven countries, making cross-border coordination essential. Despite ongoing monitoring programmes in the countries in question, there is a lack of harmonisation in the methods and terminology used, complicating efforts to collect, compare and interpret data effectively on European level. This article draws on decades of experience from Hungary, where a comprehensive monitoring protocol for the Saker Falcon has been developed and refined over the years. Based on this experience, the authors propose common standards covering various aspects of monitoring, including field visits, ringing, satellite tracking, sampling, health and safety, and documentation. These standards are not intended to replace existing methodologies but serve as a base for harmonised Saker Falcon monitoring across Europe. Standardization is critical to ensure that data from different countries are compatible and continuous, enabling more accurate assessments of the species' conservation status and more effective planning of conservation measures at a European level. The authors emphasize that their goal is not to prescribe the only effective methods but to highlight the need for agreed-upon terminology and harmonised monitoring methods. This article aims to initiate a discussion among Saker Falcon experts across Europe, encouraging collaboration to develop consistent and compatible methodologies that will enhance coordinated conservation efforts for this endangered species.

Keywords: Saker Falcon, raptor, endangered species, monitoring, conservation, protocol

Összefoglalás A kerecsensólyom európai állománya közép-európai és kelet-európai populációkra oszlik. Bár ezek bizonyos mértékig kapcsolódnak egymáshoz, nem alkotnak összefüggő állományt. A kelet-európai populáció erősen széttagolt, és elterjedési területe hatalmas, ami földrajzi és politikai okokból jelentős kihívást jelent a monitorozás szempontjából. Ezzel szemben a közép-európai populáció kompaktabb, de hét országot ölel fel, ami elengedhetetlenné teszi a határokon átnyúló koordinációt. Bár a szóban forgó országokban folynak a monitoring programok, a módszerek és a terminológia egységességének hiánya európai szinten megnehezíti az adatok hatékony gyűjtését, összehasonlítását és értelmezését. Ez a cikk a magyarországi évtizedes tapasztalatokat dolgozza fel, ahol az évek során kidolgozták és finomították a kerecsensólyom átfogó monitoring protokollját. Ezen tapasztalatok alapján a szerzők közös módszertant javasolnak a monitoring különböző elemeire, beleértve a fészekellenőrzéseket, a gyűrűzést, a műholdas nyomkövetést, a mintavételt, az egészségügyi és biztonsági előírásokat, valamint a dokumentációt. Ez a módszertan nem kívánja felváltani a már meglévőket, hanem inkább alapot kíván adni a kerecsensólyom monitorozásának harmonizálására. Az egységesítés elengedhetetlen ahhoz, hogy a különböző országokból származó adatok kompatibilisek és folyamatosak legyenek, lehetővé téve a faj védelmi helyzetének pontosabb felmérését és hatékonyabb védelmi intézkedések megtervezését európai szinten. A szerzők hangsúlyozzák, hogy a céljuk nem egy egyedüli hatékony módszertan leírása, hanem a figyelmet szeretnék felhívni a közös terminológia és az egységes monitoring módszerek szükségességére. E cikk célja, hogy párbeszédet indítson el a kerecsensólyom európai szakértői között, ösztönözve az együttműködést a következetes és összehangolt módszertan kidolgozása érdekében, amely segíti az összehangolt védelmi erőfeszítések megvalósítását e veszélyeztetett faj megóvása érdekében.

Kulcsszavak: kerecsensólyom, ragadozómadár, veszélyeztetett faj, monitoring, természetvédelem, protokoll

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Introduction

Population monitoring and individual marking methods are essential elements of raptor research and conservation, as many biologically important parameters can only be evaluated with the help of such long-term datasets (Newton 1979). However, these research methods, which usually require approaching nesting sites at great height, and capturing and handling birds, are inevitably posing risks to both the birds and the personnel involved. Therefore, such research should be carried out within well-planned and coordinated frameworks, using the most efficient methods and utmost caution (Hardey *et al.* 2013).

The Saker Falcon *(Falco cherrug)* is a globally endangered Eurasian bird species, which suffered population decrease and range reduction in the past decades (BirdLife International 2021). Europe holds only about ~10% of the global population or even less (BirdLife International 2021, Prommer *et al.* 2024a), but this small European population is significantly different genetically from the Asian Sakers (Zinevich *et al.* 2023). The European population consists of two distinct (sub)populations: one in Central Europe (Austria, Croatia, Czechia, Hungary, Serbia, Slovakia and Western Romania) and one in Eastern Europe (Armenia, Bulgaria, Moldova, Eastern Romania, Türkiye and Ukraine) (Prommer *et al.* 2025). While the continuous Central European subpopulation is increasing and well-studied, the eastern subpopulation is fragmented and has been declining dramatically over the past decades. Additionally, our knowledge of that subpopulation can be considered scarce (Aghababyan *et al.* 2025, Ajder *et al.* 2025, Arkumarev *et al.* 2025, Fântână *et al.* 2025, Prommer *et al.* 2025). Regular monitoring of Saker Falcon breeding populations is ongoing in several European countries, such as Slovakia (Chavko *et al.* 2025), Austria (Zink *et al.* 2025), Czech Republic (Škorpíková *et al.* 2025), and less regularly in Armenia (Aghababyan *et al.* 2025), Bulgaria (Arkumarev *et al.* 2025), Moldova (Ajder *et al.* 2025), Romania (Fântână *et al.* 2025) and Serbia (Puzović 2024). Although those population surveys follow more-or-less detailed monitoring protocols in each country, no detailed methodology and suggested practices have been published until now. Consequently, the potential inconsistencies in methodology and/or terminology can hamper the comparison, aggregation and interpretation of national datasets. Therefore, harmonisation of monitoring methods and terminology across the European breeding range is more than desirable. It is especially important in Central Europe, where a single continuous population expands beyond political borders to several countries.

This paper attempts to give a suggestion for such harmonisation by providing an example through one of the longest running Saker Falcon monitoring programmes globally. The article summarizes the practical experience gathered during the field monitoring of the species in Hungary over the past five decades and introduces a methodological protocol that can serve as a reference for national and international monitoring programmes focusing on the Saker Falcon.

Methods

In the past five decades, conservation efforts in Hungary that have been largely based on the annual population surveys, played a crucial role in the survival of the species in Europe (Bagyura *et al.* 2012). Monitoring of raptor populations has a long tradition in Hungary and monitoring schemes for most of the strictly protected species have already been running for several decades (Haraszthy & Bagyura 1993, Kovács *et al.* 2012). Those schemes result in detailed datasets that can be used for analysing population dynamics and ecology, as well as breeding biology (e.g. Horváth *et al.* 2014). Accordingly, the Saker population in Hungary is the largest and one of the longest monitored populations in the European Union (Kovács *et al.* 2014).

The first significant population surveys and focussed conservation efforts for the Saker Falcon began in 1974 in Hungary, when MME BirdLife Hungary (Hungarian Ornithological and Nature Conservation Society) was founded. By 1980, these surveys had become regular, and the monitoring methodology was continuously developed over the following decades in close cooperation with national park directorates, the ranger service, and various non-governmental and governmental organisations (Bagyura *et al.* 2022, Bagyura *et al.* 2025). As the bulk of the Saker Falcon population has been breeding on the high-voltage (120–400 kV) powerline network since the mid-1990s, the MAVIR Zrt. (Hungarian Transmission System Operator Company Ltd.) and distribution system operator companies became key partners in the monitoring programme.

The Saker monitoring and research are coordinated on national level to minimise disturbance and standardise data collection. All research activities must be pre-agreed and harmonised with the relevant national park directorates, as well as with the Saker Falcon conservation coordinator appointed by the MME Raptor Protection Group and the Hungarian Raptor Conservation Council. The execution of the work is facilitated by cooperation agreements between MME, the National Park Directorates and MAVIR Zrt.

The "traditional" field monitoring of nesting sites has been undertaken since the beginning of the programme, which included observations of nesting sites several (usually 2−5) times during the breeding season and ringing activities once a year at selected nesting sites (Bagyura *et al.* 2019a, Bagyura *et al.* 2023). Modern technology has enabled the application of new methods, such as satellite tracking since 2006 (Prommer & Bagyura 2009, 2010, 2023), camera traps since 2011 (Bagyura *et al.* 2014), genetic analyses since 2016 (Bagyura *et al.* 2019b) and drones since 2020.

The presented methods were elaborated to gather datasets annually, to answer the following biological and conservation questions, and monitor their trends in long-term:

– What is the size of the breeding population and breeding success? (population dynamics)

– What is the extent of the distribution area and what are the habitats preferred for nesting? (habitat selection)
– What are the survival rates of different age groups and sexes? (survival)
– What is the significance of various mortality causes? (mortality)
– What is the proportion of different prey species? (foraging ecology)
– When, how far, and in what direction do young birds choose nesting sites relative to their fledging site? (natal dispersal)
– How regularly and how far do breeding birds switch nesting sites? (breeding dispersal)
– What areas and habitats do non-breeding birds use? (temporary settlement areas, migration routes, wintering areas)
– What areas and habitats do breeding birds use during and outside the breeding season? (home range)

Results

Definition and monitoring of breeding stages

The breeding season of Saker Falcons in Hungary is between February and July, and territorial birds usually spend the whole year within or close to their territories. We suggest not to handle those territories as "active" for a given breeding season, where the presence of birds/pairs was only detected before mid-March or where only single birds were observed during the breeding season without the proof of breeding. Similarly, observations in a territory only after mid-June can be also misleading, because by this time both adults and juveniles can appear further from their active/natal nests. The dependence period (when nestlings are depending on their parents for food) lasts usually till mid-July, by when most of the juveniles will leave the natal territories eventually.

To gather data from each main breeding stages (i.e. territory occupancy, incubation, rearing and fledging) usually five inspections are suggested between March and June *(Figure 1)*. We apply the following categories and timing to monitor nest status at the various stages (the monitored parameters are given in *italics*):

(1) Territory occupation stage *(territorial pairs, TP)*: The best period to locate active nesting sites is middle or second half of March, when the birds are starting or just before egg-laying and should be around the nest sites most of the day. This period is also suitable for searching tree-nesting pairs as nests are usually well-visible on leafless deciduous trees. Like other falcons, Saker Falcons do not actively build or renovate nests. However, territorial pairs may visit and inspect several available nests within their territory before egg-laying. Therefore, we suggest not to define a separate "nesting" stage, due to overlapping behaviour and timing (in contrast to most accipitrid raptors, which build or renovate their own nests, therefore nesting can be usually distinguished objectively both from territory occupancy and breeding).

(2) Incubation stage *(breeding pairs, BP)*: Egg-laying can be detected most precisely in the beginning of April. Most of the pairs already start the incubation in middle or late March, but some pairs usually start egg-laying a few weeks later. The incubation lasts for 34–35

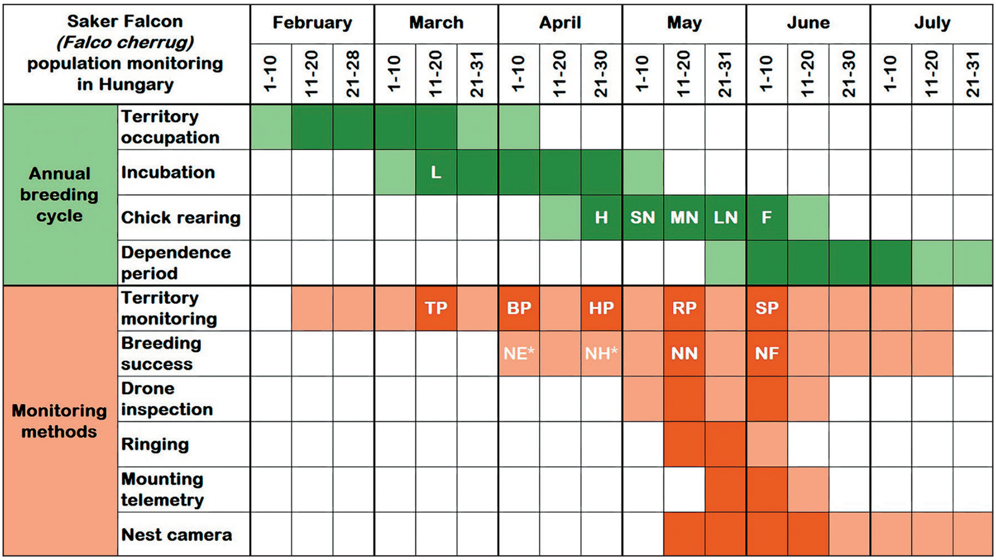

Figure 1. Annual breeding cycle and suggested timing of monitoring methods for Saker Falcons in Hungary. Darker colour represents the main periods, while lighter colours the possible but not usual timing. The most common timing of main breeding stages is indicated within the breeding cycle: egg-laying (L), hatching (H), small nestlings (SN), medium-aged nestlings (MN), large nestlings (LN) and fledglings (F). The suggested breeding parameters to be monitored are indicated within the monitoring methods: territorial pairs (TP), breeding pairs (BP), hatching pairs (HP), nestling rearing pairs (RP), successful pairs (SP), number of eggs (NE), number of hatchlings (NH), number of medium-aged nestlings (NN), number of fledglings (NF). *: NE and NH are not suggested to be monitored in the frame of general population monitoring (see notes in the text)

1. ábra Kerecsensólymok éves költési ciklusa és a monitoring módszerek javasolt időzítése Magyarországon. A sötétebb színek a legjellemzőbb, míg a világos színek a kevésbé gyakran előforduló időszakokat jelzik. A legjellemzőbb költési időszakok a költési cikluson belül: tojásrakás (L), kelés (H), kis fiókák (SN), középkorú fiókák (MN), nagy fiókák (LN) és kirepült fiókák (F). A monitorozásra javasolt költési paraméterek a monitoring módszereken belül: territoriális párok (TP), költő párok (BP), keltető párok (HP), fiókanevelő párok (RP), sikeres párok (SP), tojások száma (NE), kikelt fiókák száma (NH), középkorú fiókák száma (NN), kirepült fiókák száma (NF). *: az NE és NH paramétereket nem javasoljuk monitorozni az általános populációs monitoring során (ld. megjegyzéseket a szövegben)

days in average in Hungary (Bagyura *et al.* 2022), therefore early April is the period when almost all the breeding pairs are incubating. This period is also suitable to check alternative nesting sites within the territory (within 5–10 km radius) if the nests used in previous years have been abandoned, and pairs were not present nearby. We do not suggest monitoring the *number of eggs (NE)* in the frame of general population monitoring, to avoid unnecessary disturbance and threat posed by chasing the parents from their nests. Therefore, we suggest defining breeding pairs indirectly based on the behaviour of parents, i.e. when one of the parents is lying horizontally in the nest almost constantly and they do not leave the eggs unattended for more than 30 minutes. In case of longer observations, the care and/or turning of the eggs in the nest cup can be also detected. Unfortunately, *NE* cannot be estimated indirectly, as the chances to detect the remains of the unhatched/rotten eggs in later stages is incidental. After a while they explode, and the eggshell pieces deteriorate into the nest material among other prey remains.

(3) Hatching stage *(hatching pairs, HP)*: In the end of April, presence of nestlings can already be detected in most of the cases, either by direct observation or indirectly by the behaviour of parents. Although brood size usually cannot be determined accurately at this stage, we do not recommend to monitor *number of hatchlings (NH)* in the frame of general population monitoring either, because chasing away the parents could decrease the survival of hatchlings or eggs (as incubation can still be ongoing in case of late-breeding pairs, and there can be up to a several days difference in hatching between the first and last hatching in case of larger broods Bagyura *et al.* 2022). The time of return of parents after such an intervention is unpredictable and even a short time exposure of hatchlings/eggs to direct sun, cold, rain or predators – as a result of the absence of parents – increases the chance of mortality. Similarly to the *number of eggs* (*NE),* the number of hatchlings cannot be estimated indirectly either, as the chances to detect the carcasses of hatchlings in later stages is minimal. Parents can take them out, siblings can eat them, or they simply decay, and their small remnants are incorporated into the nest material among other prey remains.

(4) Nestling rearing stage *(rearing pairs, RP)*: Mid-May is the first period when there is a good chance to determine brood-size by the *number of medium-aged nestlings (NN)*, when the nestlings are about 15–25 days old in average. This period is also the peak season for ringing and/or drone inspection, which are the most accurate methods to determine NN (see below).

(5) Fledging stage *(successful pairs, SP)*: Juveniles start fledging usually in early June and at this stage the brood can be usually observed inside or close to the nest. Although, brood size sometimes cannot be determined accurately and a proportion of juveniles can be missed at this stage as well, unless long-term surveillance (e.g. nest camera or nest-guarding) is applied during the last weeks of breeding. Some juveniles can perch further away from the nests or can hide in the vegetation on the ground, where they spend significant time after fledging. Moreover, some juveniles could be already dead even a few days after fledging, as post-fledging mortality could be significant, and these carcasses are extremely rarely found (unless telemetry and dog-unit is applied). The remains (especially feathers) of large nestling – i.e. which died since mid-May – can be usually detected inside or under the nests, if drone inspection or climbing can be applied (climbing into the nests is not suggested at this stage if fledglings/juveniles are still around the nest). Therefore, if there is no possibility for long-term surveillance of the total population (which is usual for field studies focusing on larger raptor populations), we suggest estimating indirectly the *number of fledglings (NF)* by extracting the detected number of dead nestlings from the number of *middle-aged nestlings (NN)*. Similarly, *successful pairs (SP)* can be estimated by extracting the detected number of breeding failures (i.e. mortality of the total brood of large nestlings) from *rearing pairs (RP)*. Although it should be considered that these estimations could be also biased, as a proportion of dead nestlings can disappear from the nest without any visible signs. Nevertheless, we propose that this indirect estimation is less biased than simply using the number of observed juveniles outside the nest during one or two short-term visits after fledging.

In case the desired number of visits (five occasions) is not possible due to limited capacity, we suggest focusing on three visits (the 1st, 2nd and 4th) to gather cost-effectively the most crucial data for population monitoring. We suggest applying the following three parameters to assess breeding performance for long-term population monitoring:

– *success rate* (*SP/TP*);
– *brood size* (*NF/SP*);
– *productivity* (*NF/TP*).

Other calculation methods can be also applied depending on the available and most reliable parameters (e.g. *BP* instead of *TP*), but the selected method should be applied universally for the whole dataset and the limitations of the methodology (e.g. underestimated pre-fledging mortality of large nestlings) must be clearly mentioned.

Definition of nestling age categories

A guide to determining the age of the nestlings is summarized in *Figure 2* based on the following categories (commonly used wider umbrella terms are indicated in brackets):

Figure 2. Age estimation (days after hatching) of Saker Falcon nestlings in Hungary based on average development. See notes in the text (Photo: Márton Horváth & Gábor Tihanyi)

2. ábra Kerecsensólyom-fiókák korbecslése (kelés után eltelt napban) az átlagos fejlődési ütem alapján. További megjegyzéseket lásd a szövegben (Fotó: Horváth Márton és Tihanyi Gábor)

– Days 1–5 *(hatchlings)*: Newly hatched, small downy nestlings primarily lie curled up in the nest. Their eyes are still closed, and heads are large compared to their bodies, and they can barely hold them.
– Days 6–10 *(small nestlings)*: Fully downy nestlings, with heads still large in proportion to their bodies, but they can now sit stably. Their eyes are open, and they have begun to grow their second set of down feathers.
– Days 11–15 *(small nestlings)*: Fully downy nestlings, with head-to-body proportions approaching that of older nestlings. They have grown their second set of down feathers, resulting in dense downy plumage.
– Days 16–18 *(medium-aged nestlings)*: The first brown feathers start to appear on the body, visible on the growing primary flight feathers and tail feathers.
– Days 19–21 *(medium-aged nestlings)*: In addition to the clearly visible flight and tail feathers, the shoulder coverts also start growing, forming a brown V shape on the back. Besides, first brown feathers also begin to appear on the sides of the chest.
– Days 22–24 *(medium-aged nestlings)*: Wing, back, and tail coverts start to grow, and facial feathers begin to emerge, giving the nestlings a mottled appearance, though white down is still more prevalent than brown contour feathers.
– Days 25–27 *(medium-aged nestlings)*: Feather growth intensifies across the entire body, with brown feathers becoming dominant, though down is still visible. During this period, the nestlings begin moulting their down feathers, which can often be seen in and around the nest.
– Days 28–30 *(large nestlings)*: Down is still visible among the primarily brown body feathers, and the head begins feathering, though the crown remains downy.
– Days 31–35 *(large nestlings)*: Only a few down feathers remain visible on the body, and the crown is feathering, but still noticeably downy.
– Days 36–40 *(large nestlings)*: Down feathers disappear from the entire body, with only the last few remaining on the crown.
– Days 41–45 *(large nestlings)*: The fully feathered nestlings no longer show any down feathers, but the flight and tail feathers are still growing. Their wings and tails are shorter than those of adult birds, they can already flight shorter distances if forced, but they do not yet leave the nest on their own.
– Days 46–55 *(fledglings)*: During this period, the primary flight and tail feathers reach their final length. The nestlings begin to leave the nest at varying times and intensities, taking their first flights but still regularly returning to the nest.

It must be mentioned that the categories listed above represent the average development of Saker Falcon nestlings in the Pannonian Region, therefore the development of some individuals can be slower caused by their poor feeding condition or health status. Similarly, the development of nestlings can be slightly different in other geographical populations in East Europe or Asia.

Based on the average development of the oldest nestling within a brood (in case of nestlings which are less than 46 days old) and the average incubation time (34–35 days), the date of egg-laying can be estimated usually within a ±3 days interval for a given breeding attempt.

Field monitoring of nesting sites

Observations of the nesting sites during field visits should generally be conducted from 500–1,000 m, preferably by using a tripod-mounted spotting scope with 20–60× magnification. Under normal visual conditions, and from a good viewpoint, this distance is usually suitable to check the breeding stage and determine the number of medium- or large-sized nestlings. At the same time, this distance is sufficient to avoid any disturbance to the breeding birds. However, regardless the distance, if we observe that our presence is disturbing the parents, particularly if they leave the nest site during incubation or when the nestlings are small (not older than 12–14 days), we should immediately leave the area to allow parents to return as soon as possible.

It should be noted that during a single, brief observation, the presence of breeding birds might be missed, or – especially in the case of nest boxes on high-voltage power line pylons – the brood size could be easily underestimated. Therefore, we recommend conducting observations over relatively longer intervals (30–60 minutes), repeating the observation during the second half of the rearing period, and combining it with drone surveys to obtain a more accurate determination of brood size. Early morning and late afternoon/evening hours are generally better for observation, as the falcons are more active during these times of the day. In contrast, there may be little to no movement in the middle of the day, especially during the later stages of breeding.

Use of drones in nest monitoring

In recent years, advanced drone technology has become widespread and easily accessible, providing significant assistance in inspecting raptor nests (Gallego García & Sarasola 2021, Bird *et al.* 2024). Visiting nests with drones helps estimating brood size and age of young more accurately than observations from the distance using binoculars or spotting scopes. In most cases, one or two drone visits during the breeding season are sufficient to determine the number and age of nestlings, ideally conducted between 15 and 25 May. Experience suggests that drones equipped with telephoto or zoom lenses are much less invasive and more effective for observing nestlings than those with wide-angle primary lenses. However, it has been observed that brood size can still be underestimated by one or two nestlings, particularly in the early nestling stage and at larger broods (4–5 nestlings) where the nestlings may completely cover each other. Therefore, we recommend taking photos/videos from different angles, repeating the observation during the second half of the rearing period, and always conducting distant scope observations as well to achieve a more accurate determination of brood size.

It is crucial to emphasize that the use of drones also causes significant disturbance to birds, so it should be applied only within the frame of national monitoring programme, and it must be agreed in advance with the species conservation coordinator, or a species expert, and the relevant conservation authority or management (national park directorates in Hungary). Before departure, the pilot should approach the nest as closely as possible (preferably within 100 metres) and maintain a clear view of the drone and its surroundings throughout the flight. Although there is no available data or experience suggesting that Saker Falcons have ever attacked a drone, we recommend paying extra attention if a bird approaches. If aggressive behaviour is observed toward the drone, it should be moved farther away or landed immediately. The flight should be efficient and brief, with the drone landing or moving away from the nest as soon as the necessary information has been gathered and recorded.

One must pay special attention to avoiding accidents during flight (especially steering clear of people, birds and objects such as power lines). It is also important to note that in the European Union, only pilots with the necessary licenses are permitted to operate drones. Drone operators must comply with all safety regulations and legal requirements, and they must obtain temporary airspace use permits wherever and whenever required.

Approaching the nests

If a particular nest is selected for ringing or telemetry research, it should be climbed only once during the breeding season to minimize disturbance to the birds. The age of the nestlings should be between 15 and 40 days in these nests, in order to avoid significant negative effects on breeding performance.

There can be significant differences, sometimes as much as a month, in the timing of individual breeding attempts. Therefore, it is crucial to assess the progress of each pair's breeding during the nest visits preceding climbing to determine the appropriate timing. Proper timing ensures that the nestlings are not too young to be ringed (see details under *Ringing the nestlings*), thereby avoiding the need for extra climbing and unnecessary disturbance. Additionally, proper timing is more economical, considering labour time and fuel costs.

When at the nest, a final check with a drone is strongly recommended to ensure that all conditions are met for climbing. This check allows us to determine the breeding stage, the number and age of nestlings, and to detect any special circumstances (e.g. a dead bird or a critical health condition). By evaluating the drone footage on the spot, we can make the final decision whether to climb the nest or not. This approach significantly reduces the chances of accidents and unnecessary time spent around the nest.

We avoid climbing to nests with eggs or small nestlings (completely downy, i.e. less than 12–14 days old) to prevent potential mortality from hypothermia or overheating if they are exposed to the sun due to the absence of adults caused by our disturbance. In such cases, we should leave the area as soon as possible to allow the parents to return. Similarly, we do not climb to nests with nestlings close to fledging (no visible downy feathers on the head, i.e. older than 40 days) to avoid forced premature fledging, which could increase mortality rates.

During nest visits for ringing or installing telemetry devices, we should spend only the necessary time within the immediate vicinity (<500 m) of the nest and leave it as soon as possible to minimize disturbing the birds' activities. In most cases, ringing can be completed within 30 minutes from arriving at the nest site, while attaching transmitters may take up to an hour depending on the brood size, but in any case, we advise under no circumstances should more than two hours be spent near the nest as a general precautionary rule.

Approaching a tree or cliff nest should only be done by experienced personnel with the necessary qualifications and equipment for tree or cliff climbing. During climbing, pay special attention to avoid accidents (especially for people under the tree or cliff and the birds), and comply with all safety regulations and legal requirements.

Conservation experts and network operators must work in close coordination to protect Saker Falcon nesting on high-voltage transmission line pylons. On the one hand, only trained and authorised personnel are permitted to climb nests on these pylons, and they must follow the network operators' rules and protocols. Everyone else is strictly prohibited from scaling these towers. On the other hand, network operators should avoid any non-urgent maintenance work on pylons with active Saker Falcon nests, as well as on the nearest pylons, between 15 February and 15 July, to prevent endangering breeding success. Therefore, any approach to such nests must be discussed and agreed upon by both network operators and conservation experts. If the network operator is unaware of active breeding in a nest, they should consult the relevant national park directorate before taking any action.

Handling the nestlings

Handling nestlings in the nest

Handling nestlings in the nest requires particular attention and experience. Nestlings are extremely vulnerable, and improper handling techniques can easily cause internal injuries or fractures (especially in the wings). Additionally, nestlings may attempt to free themselves, posing a risk of falling from the nest, which could be fatal. Therefore, only nature conservation experts or trained personnel (e.g. who have participated in training by nature conservation experts, receiving detailed practical guidance on the methods and risks of handling birds), should perform such operations.

Upon approaching the nest and entering the nestlings' line of sight, avoid sudden movements and, if possible, wait 1–2 minutes for the nestlings to calm down. When handling nestlings in the nest, constantly monitor the movement of all nestlings, with ground personnel assisting through binoculars or even continuous drone observation. Nestlings that are on the edge of the nest should be gently guided towards the nest's interior before handling.

In the case of nest boxes on pylons, particularly with larger nestlings, if the nest box has two open sides, it is advisable to cover one of the two open sides, positioning the climber at the only open side to minimize the chances of nestlings jumping out. If the climber or ground personnel assess that one or more nestlings cannot be removed without the risk of falling, the operation should be immediately halted, and the nesting site should be vacated.

Nestlings should be handled with both hands, positioning your thumbs on their backs, firmly (but not too tightly) pressing the birds' closed wings to their bodies with your palms, and pressing their legs against their abdomens with the rest of your fingers *(Figure 3)*. For larger nestlings, it may be necessary to hold the legs between your little and ring fingers to prevent scratching and uncontrolled movements. If necessary and with sufficient practice, larger nestlings can be securely held with one hand by gripping the base of their wings and tail with your thumb and index finger, while holding the legs between your other fingers

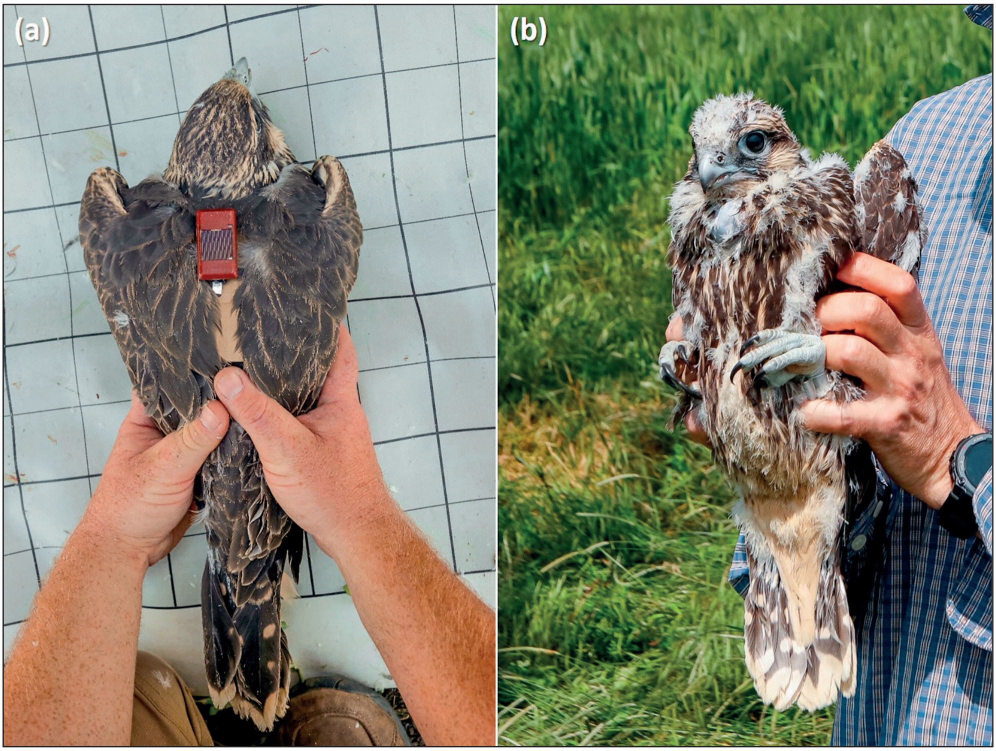

Figure 3. Proper handling of Saker Falcon nestlings: (a) dorsal view; (b) ventral view (Photo: Márton Horváth)

3. ábra Kerecsensólyom-fiókák megfelelő fogási technikája: (a) hátoldali nézet; (b) hasoldali nézet (Fotó: Horváth Márton)

(Figure 5a). It is crucial that nestlings should be never hold by their wings, legs, or feathers, as this can cause fractures, joint injuries, or permanent damage to developing feather follicles.

When handling large (>28 days old nestlings, juveniles or adults) Saker Falcons, it is advisable to bandage the bird's legs and place a falconer hood on its head to reduce stress and prevent injuries *(Figure 5b)*.

The risk of physical injuries can be minimised by following the guidelines described here. However, if an injury does occur, disinfect minor wounds and return the nestling to the nest. If there is significant bleeding, a fracture, dislocation, or abnormal behaviour, consult a veterinarian experienced with raptors and, if necessary, arrange for the bird to be transported to a nearby rescue station in consultation with the relevant national park directorate.

Ringing and infection risks

The ringing process carries a risk of spreading infection because the same personnel and equipment are used for multiple nests consecutively, often within the same day. Any young bird can be sick and contagious, even if it shows no visible symptoms, which could lead to the transmission of infectious diseases between broods and potentially increase mortality rates among nestlings and parent birds. To prevent the spread of disease from one brood to another, it is crucial to handle all young birds with strict adherence to the hygiene guidelines outlined in the human health considerations section below.

Transporting nestlings

After capturing nestlings in the nest, place them in a suitable carrier to prevent injury to each other. Preferably, nestlings should be placed individually into carriers unless they can be safely separated in stable compartments. During lowering, ensure the carrier does not accidentally hit the pylon or branches, as this could injure the nestlings. The carrier must be securely attached with a carabiner to the rope during lowering to prevent accidental falls, and it should be closable to ensure nestlings cannot escape while still allowing air circulation. It is important that the carrier is made of material that prevents the nestlings' talons from getting stuck in its walls or floor, as talons can break off, which would significantly impact the nestling's future survival.

Ringing the nestlings

The ideal age for ringing nestlings is between 18 and 28 days, which in Hungary generally occurs from 10 May to 10 June. Most nestlings reach this age between 15 and 25 May, so most ringing activities should be planned for this 10-day period. In exceptional cases, slightly younger (15–17 days old) or older (29–40 days old) nestlings can be ringed as well, but the risk of accidents or unsuccessful attempts is higher in both cases (see under *Mounting telemetry device*). Each young nestling should be individually assessed to ensure that its leg is large enough to keep the ring securely in place at the tarsus (i.e. it cannot slip down toward the toes).

Nestlings can be sexed from about 10 days of age at the earliest. Females typically have larger and stronger beaks and feet, thicker legs, but their heads are proportionally smaller compared to their bodies (in comparison to males). As they grow older, the differences between males and females become more pronounced. Males usually develop plumage faster and are the first to leave the nest. Sexing nestlings requires considerable experience, especially when the young are of the same sex or when there is only one nestling, making comparison impossible. It should be noted that large falcon species typically begin incubating after laying the third egg. As a result, any eggs laid afterward will hatch later, leading to differences in the developmental stages of the oldest and youngest nestlings. In the case of the Saker Falcon, this often results in one or two nestlings being at a different stage of development than the rest of the brood, which may further complicate sexing.

It is important to consider that during ringing, the parent birds cannot protect the nestlings from adverse weather conditions due to human presence. Therefore, nests with downy nestlings (less than 15 days old) should be completely avoided, and even older nestlings should not be approached during extreme weather conditions (e.g. storms, extreme cold or heat). Additionally, ensure continuous shading for nestlings in strong sunlight during the procedure to prevent them from falling out of the nest as they seek shelter from the scorching sun.

Only a licensed expert with the necessary ringing and research permits is authorised to ring nestlings. If possible, perform the ringing and associated measurements and sampling procedures on the ground under comfortable conditions. In Hungary, official aluminium ornithological rings with a unique number approved by the Hungarian Bird Ringing Centre should be placed on the nestlings' left leg. The ring should have an inner diameter of 14 mm (suitable for both larger females and smaller males) and a height of 10–20 mm. The numbers on the ring should be oriented so that they are readable when the bird is standing. It is important to ensure that the rings are properly closed on the tarsus of the birds, i.e. they do not remain even partially open, as it could increase the chance of accidents.

A coloured ring, which has a visible base colour and a few large characters for identification from a distance or in photos, may be placed on the right leg. In Europe, colour ringing programmes must be harmonised and registered internationally (https://cr-birding.org/) to prevent overlapping markings and misidentification.

For nestlings already being handled during ringing, it is worthwhile to measure a few important biometric parameters and take additional samples for research projects, provided it does not cause injury or significantly increase handling time. Recommended measurements include weight, tarsus length, tarsus diameter, hind claw length and tail feather vane length *(Figure 4)*.

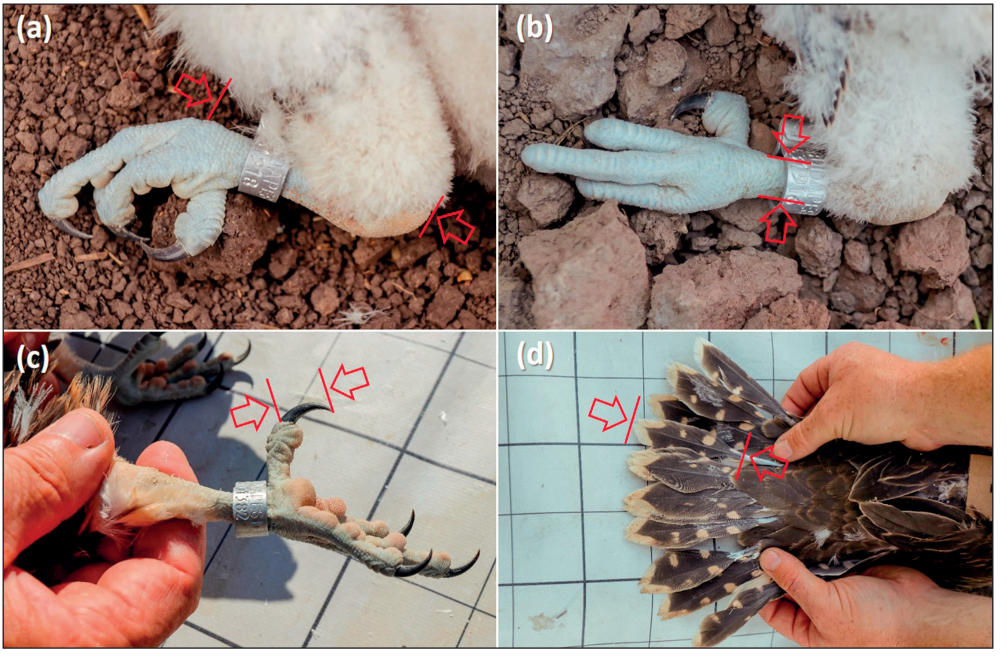

Figure 4. Recommended measurements of Saker Falcon nestlings: (a) *tarsus* length; (b) *tarsus* diameter; (c) hind claw length; (d) tail feather vane length (Photo: Márton Horváth)

4. ábra Javasolt mérések kerecsensólyom-fiókákon: *tarsus* hossz; (b) *tarsus* átmérő; (c) hátsó karom hossz; (d) faroktoll-zászló hossz (Fotó: Horváth Márton)

Mounting telemetry device on nestlings

The ideal time to attach a tracking device to young Saker Falcons is as close to fledging as possible, as the body parameters (especially the girth in front of and behind the wings) will closely match those of free-flying juveniles. However, accidentally forcing premature fledging during the mounting procedure (when climbing the nest) can result in a lengthy search for the fledged individual or even losing the bird altogether, which decreases the survival chances of the nestlings. Therefore, it is recommended to time the attachment when the nestlings are 36–40 days old, which in Hungary generally occurs between 21 May and 20 June. In Hungary, most nestlings are within this age range between 25 May and 5 June, so most tagging activities should be planned during this period.

The ideal age for tagging is a very narrow window when the body is fully covered by contour feathers, the remiges and rectrices are well developed but still in sheath at the base, and a few downy feathers are visible on the otherwise feathered head (see 36–40 days category in *Figure 2*). Once the downy feathers disappear completely from the head, the likelihood of involuntary fledging due to disturbance becomes very high (see 41–45 and 46–55 days categories in *Figure 2*). Accidentally forced premature fledging can increase mortality due to a higher risk of injuries (to bones, joints, or sensitive growing feather pulps) or because the fledglings may land in high vegetation, making it difficult for them to return to the nest or maintain visual contact with the parents. Therefore, the surrounding vegetation and wind direction (as first-time flying juveniles will glide downwind after jumping from the nest) should be considered before approaching large young to ensure they can be located and returned if accidental fledging occurs. For example, avoid risking fledging in nests surrounded by large contiguous fields of sunflower or rape, as it would be particularly difficult to find the fledgling, and they may not be able to escape such vegetation on their own.

It is recommended that more than two people participate in the tagging process. While one person climbs to the nest and another waits directly beneath it, the rest of the team should stay 50–200 meters away in case a nestling jumps out. At least one person should position themselves downwind, as this is the most likely direction for a fledgling to glide. First-time flyers cannot actively fly far, but if the wind is strong, they may glide up to 800–1,000 metres from a nest box situated 30–40 metres high on a pylon.

Any premature fledging accidentally caused by climbing the nest may result in injury or death of the fledglings, and even without such incidents, it increases their risk of predation. Therefore, all fledglings that have jumped must be collected and returned to the nest. If a nestling leaves the nest, its flight must be visually tracked until it lands, and the landing site should be approached without losing visual contact. The immediate landing area must be approached carefully, especially if the vegetation is dense, as personnel could accidentally step on the fledgling. If the vegetation is less dense at ground level (e.g. sunflower fields) or the fledgling lands on a dirt road, it may move relatively far on foot, leaving the initial landing area. A trained dog or a drone may assist in locating the fledgling if it is not found through a standard search. If the fledgling is not found by nightfall, the search must be repeated the following day. In some cases, a 'lost' fledgling may find its way back to the pylon with the nest – repeated visits after such incidents can confirm the fledgling's fate.

The collected fledglings that have jumped must be checked for injuries before being placed back in the nest box. It should be noted that these individuals may have undetectable internal injuries from the forced fledging, therefore later inspections are especially needed to assess their health condition and fledging success. If weather conditions allow, it is advisable to water the fledglings before returning them to the nest. Soaking their feathers makes them less likely to jump out immediately after being returned, a situation that has occurred on a few occasions in Hungary.

The attachment of telemetry devices should only be undertaken by a licensed expert with the necessary experience and research permits. Marking nestlings with transmitters requires more precise timing and can have a more significant impact on survival than ringing, necessitating extensive experience and careful planning. It is advisable to select the brood proposed for transmitter attachment early in the breeding season, with a drone inspection 1–2 weeks before the planned tagging to accurately determine the age and number of nestlings.

Transmitters can negatively affect breeding behaviour or even the survival of birds (Barron *et al.* 2010). It is generally recommended that the weight of backpack transmitters should not exceed 3% of the bird's weight (Kenward 2001). Given that any artificial 'accessories' – regardless of their weight – on birds, especially on actively hunting raptors, are unlikely to support survival, tracking should be applied only if the expected new information provided by the tracking devices clearly offers greater overall benefits for the population (e.g. by enhancing the effectiveness of conservation measures) than the potential negative effects on the tagged individuals. Moreover, sample sizes should be kept to the minimum necessary to answer the specific conservation-related research questions. In addition, special caution should be taken in the selection of transmitter type and its attachment method.

We recommend a maximum transmitter weight of 1.5% of body mass for this species. However, it is important to note that the possible negative effects of harness-mounted transmitters may still be present even with very small devices. The average weight of Saker Falcons in Hungary was measured at 1,240 g for adult females (n=14) and 880 g for males (n=15), with the smallest male weighing only 790 g (Bagyura *et al.* 2022). Therefore, transmitters under 12 g are recommended for this population. Solar-powered devices of this size (10–12 g) are available on the market, but significantly smaller devices may face charging issues as feathers could completely cover the solar panels.

Significant sexual dimorphism and minor individual differences among Saker Falcons must be considered when attaching satellite transmitters. Generally, we recommend using the "backpack" method with special Teflon tape, usually provided with the transmitter. The commonly used "leg-loop" method has not yet been sufficiently tested on large falcons, although it has been suggested to be better for larger vultures and eagles (Longarini *et al.* 2023), and less effective for smaller *Falco* species (Biles *et al.* 2023).

We suggest using 6 mm wide Teflon tape for both male and female birds, typically requiring an 80 cm length per bird. The method of attaching the tape to the transmitter depends on the transmitter type and preference of the tagging expert. The tape must be securely fixed to the front of the transmitter, and we suggest sewing the two tapes together diagonally, forming

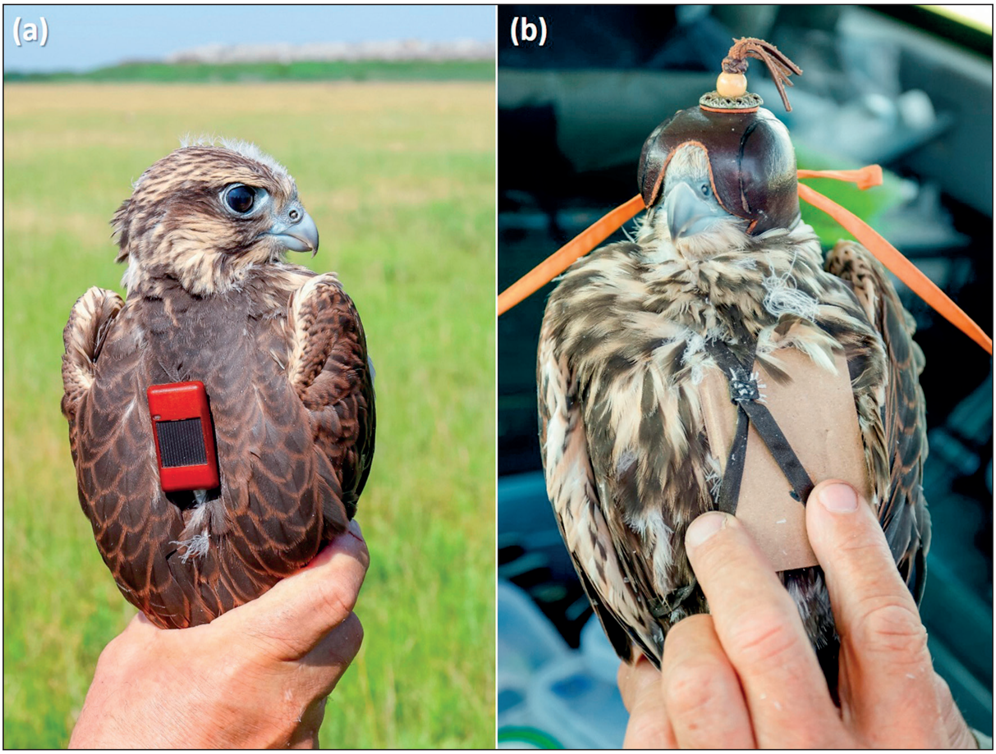

Figure 5 Telemetry device mounted on Saker Falcon nestling: (a) dorsal view; (b) ventral view (piece of cardboard is used temporarily to avoid accidental gluing of feathers) (Photo: Márton Horváth)

5. ábra Kerecsensólyom-fiókára szerelt jeladó: (a) hátoldali nézet; (b) hasoldali nézet (a kartonlap ideiglenesen, a tollak véletlen ragasztása elkerülésére kerül felhasználásra) (Fotó: Horváth Márton)

an 'X' above the sternum of the bird. The length of the two sides of this neck-loop must be equal and each sides should be approximately 10–13 cm long (10.5 cm for males and 12.5 cm for females on average), but it should always be fitted to the size of the individual bird, with the seam positioned at the sternum's tip. The tape should run behind the falcon's wings, be thoroughly adjusted under the feathers, and reach back toward the transmitter's caudal end, ensuring that the ribbons are not twisted. Temporarily secure the tape ends to the transmitter's end (e.g. with a surgical clamp), position the transmitter symmetrically between the bird's shoulders, ensuring it is neither too tight nor too loose *(Figure 5)*. When the tag is lifted at the back of the bird, there should be a gap of approximately 10–20 mm for fully developed (i.e. juvenile or adult) birds to allow the necessary space for natural movements. In the case of nestlings or fledglings, when pectoral muscles are still developing, this gap should be larger (i.e. 15–30 mm) and should be carefully determined by the tagging experts based on the size, development, and condition of the individual nestling. If the length of the tapes has been carefully determined, they should be sewn, and the seams reinforced with adhesive to prevent them coming undone.

Optionally, metal (aluminium or copper) crimps can be used instead of sewing the harness. Applying that method can save a significant amount of time during the process, but it should be used with caution, as metal structures can easily cause injuries (such as scratches or inflammation) if they contact the skin. Additionally, improperly positioned crimps with sharp edges may damage and eventually cut through the harness.

Collecting biological samples from the nestlings

Genetic methods can be employed for sex determination, individual identification, or population-level genetic analyses. The least invasive way to collect genetic samples from nestlings is by pulling out small, growing feathers along with their *calamus* when handling the birds for ringing. Generally, underwing covert feathers with a vane of 0.5–2 cm are the most suitable, ensuring that their feather shafts do not break into the skin. Larger feathers, particularly flight or tail feathers (remiges and rectrices), should not be plucked under any circumstances, as they can bleed significantly, and their absence can impair flying performance. A maximum of three samples per bird should be collected in three different Eppendorf tubes containing silica gel – or alternatively, 96% ethyl alcohol – allowing for at least three different analyses.

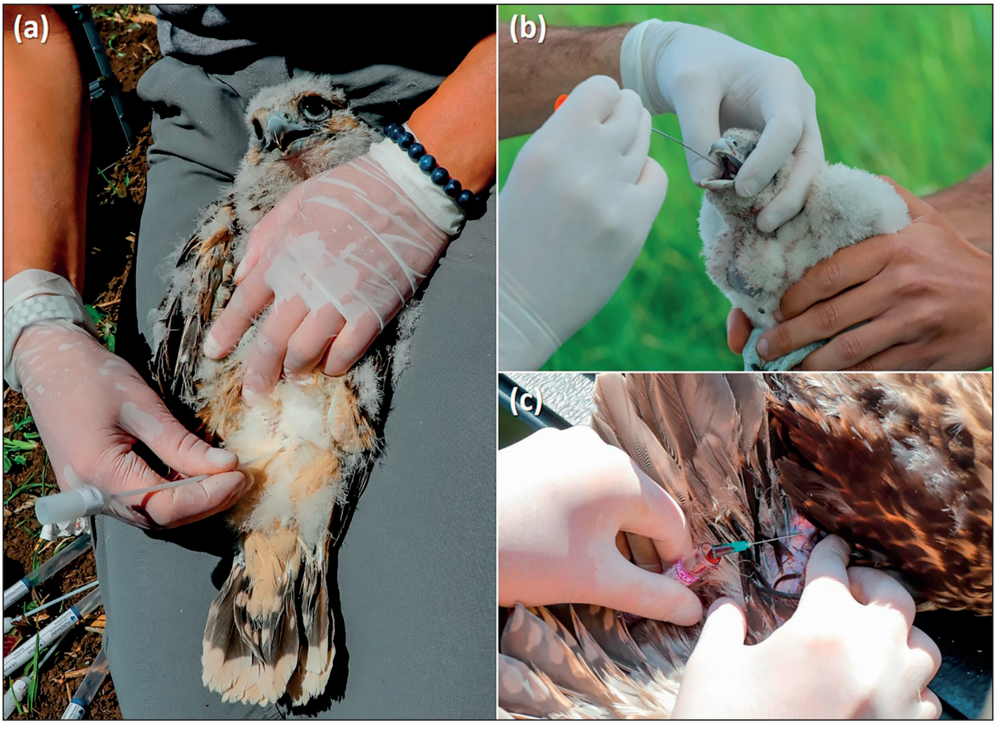

Figure 6 Veterinarian sampling of Saker Falcon nestlings: (a) cloacal swab; (b) tracheal swab; (c) blood sample taken from the nestling's wing vein (Photo: Márton Horváth)

6. ábra Állatorvosi mintavétel kerecsensólyom-fiókákon: (a) kloáka tampon; (b) *trachea* tampon; (c) vérvétel a fióka szárny vénájából (Fotó: Horváth Márton)

Veterinary sampling from nestlings may be warranted to address animal health concerns. This may involve collecting bacteriological, virological, or parasitological samples quickly and with minimal intervention. Monitoring for avian influenza virus is particularly important, as it has been detected in Saker Falcons, with cases of entire brood mortality confirmed in 2022 (Bagyura *pers. comm.*). For this purpose, cloacal or tracheal swabs are commonly used, and qualified personnel may also collect blood samples from the nestlings' wing veins *(Figure 6)*.

Camera traps

Camera traps may be placed at nests to identify prey brought in for feeding nestlings, identify parent birds, observe behaviour patterns of parents and nestlings, or study nestling mortality. The ideal time to place cameras is before the breeding season (i.e. by 1 February), provided the nest location remains stable, the camera can store or transmit all footage throughout the breeding season, and the batteries can be kept charged continuously until fledging (e.g. by using solar-powered devices). Alternatively, a simpler and more cost-effective solution is to install the camera during ringing activities (typically between 15 and 25 May), as this allows for additional data collection without extra disturbance or logistical challenges.

A camera with a commonly used focal length lens (e.g. 60−80 mm) should be positioned 50–60 cm above and 100–150 cm to the side of the nest to provide an optimal view of the nest and its surroundings. Depending on the resolution of the camera trap, any greater distance may prevent the capture of photos or videos clear enough to read (colour) rings, while closer exposure of the camera to the nest could cause disturbance for the parents. The sensitivity of the motion sensor, the frequency of shots, and the number of photos taken in quick succession should be adjusted according to the needs. However, it should be noted that the continuous movement of young in the nest will likely trigger the camera trap frequently, resulting in a high volume of photos, with only a small portion capturing the adults. We typically set the camera trap to take batches of three photos at 30-second intervals. As there are a wide variety of cameras on the market with numerous setting options, the most important recommendation is to check the settings before and immediately after placement by taking test shots.

The camera should be retrieved a few weeks after the nestlings have fledged and are no longer regularly around the nest or have developed sufficient flight skills (typically between 1 and 30 July). This timing helps avoid disturbing the juveniles, but it is advisable not to wait too long, as leaving the batteries in the camera for several months could lead to battery leakage and potential damage.

While the previous section focused on traditional camera traps without telecommunication capabilities and using conventional batteries, there are now camera traps equipped with solar panels and capable of communicating through GSM, Wi-Fi, or Bluetooth. These advanced traps can operate 'indefinitely' without the need for retrieval. Although these camera traps likely represent the future of wildlife monitoring, they are relatively new to the market, and there is still limited experience in using them at nests, and they come with additional costs (e.g. GSM service, virtual storage place, etc.).

Collecting addled eggs, carcasses and prey remains

During monitoring activities, remains of Saker Falcons, such as addled eggs, eggshell fragments, and dead nestlings or adults, may be found. These remains can be valuable for determining causes of death or for genetic sampling, so they should be collected and sent for laboratory analysis.

Similarly, you may find moulted feathers of adults, which are also valuable as they typically contain sufficient DNA for genetic analyses (Horváth *et al.* 2005), or potentially can be used also for other analyses (e.g. heavy metal contamination). Feathers should be collected in separate zip-lock bags for each nest. They must be stored in dry, dark, room-temperature conditions, free from contamination, as humidity, UV light, and heat can significantly degrade DNA quality (Vili *et al.* 2013). Including a silica gel packet in the bags is recommended to absorb moisture.

Additionally, prey remains are often found in or under Saker Falcon nests. These remains can provide valuable insights into the species' feeding habits and should be collected and examined (e.g. Horváth *et al.* 2018). Before leaving the nest site, it is advisable to collect all identifiable remains in one place, categorize them by species, and photograph them with a scale reference. Record the number of identifiable species/taxa on a data sheet, and collect unidentifiable remains (pellets, bone fragments, etc.) if you have the capacity for later identification.

All collected materials should be properly labelled and delivered to the relevant laboratory as soon as possible. Always consult with the responsible laboratory personnel beforehand to ensure proper storage and handling of the samples until they are analysed.

The labelling principles outlined in the Documentation section should be followed for all collected samples. Additionally, the guidelines detailed under Human Health Considerations should be strictly adhered to when handling and collecting biological remains.

Human health considerations

Handling nestlings and working in nests involves risks to human health, including the potential for physical injury and infection. Although rare, there is a risk of physical injury, particularly when dealing with larger nestlings. Saker Falcons can occasionally cause injuries with their beaks, and their talons may cause accidental (usually superficial) scratches. It should be noted, however, that unlike large raptors, this species cannot cause serious injury to humans. Additionally, when nestlings are handled properly, as described in the previous section, injuries are uncommon. If a bleeding injury occurs, allow the wound to bleed, disinfect it thoroughly, apply a medical bandage, and seek medical attention promptly to prevent infection.

Prey remains and faeces in nests, as well as nestlings infected with zoonotic pathogens (which can be transmitted from animals to humans), can pose infection risks to handlers. To minimize these risks, adhere to the following hygiene practices:

– Wear disposable masks (minimum FFP2 standard) and change them after handling each nest.
– Avoid touching your face (especially eyes, mouth, nose and ears) and refrain from eating during work.

- Use disposable gloves and disinfected "bird bags" (breathable canvas drawstring bags) when handling birds, replacing them after each nest.
- After placing nestlings back in the nest, always disinfect your hands with an alcohol-based disinfectant (at least 50%) and clean any clothing or equipment that may have had physical contact with the nestlings (e.g. carrier bags, tongs, measuring and sampling equipment).
- Dispose of used masks, gloves, and paper towels in hazardous waste bags before leaving the site and ensure proper disposal.
- Place collected samples or remains in separate, sealable plastic bags and store them properly until analysis to avoid contamination with biological samples.

Documentation

Finally, and importantly, it is crucial to strive for the most complete written and photographic documentation during nest inspections. Many years of experience show that inconsistencies or unclear information on breeding success in long-term national datasets often result from inadequate field documentation.

The following data are minimally required in written or online documentation (preferably on specially designed data sheets) during fieldwork:

- Date and time;
- Settlement/area name;
- Territory and nest ID;
- Coordinates;
- Nest base: tree species or power line section (including section ID and the ID number of pylon);
- Nest type (natural nest/platform/box);
- Activity (active breeding/failed/unknown) and breeding stage (nesting pair, incubation, rearing, fledging);
- Breeding success (number of nestlings/eggs) and estimated age of nestlings (if relevant);
- Ring number(s), sex and measurements of nestlings (if relevant);
- Tracking device ID(s), parameters (type, size), and attachment method (if relevant);
- Collected sample types and numbers (prey, feather, DNA, veterinary, etc.) (if relevant);
- Identified prey species and the minimum number of specimens (if relevant);
- Details of other remains and collected materials (if relevant);
- Names of participants in the nest inspection, including separately the drone pilot, climber, ringer, or the person mounting the tracking device.

Additionally, it is strongly recommended to create detailed photographic documentation of the nest inspections, including:

- Habitat with the nest;
- Brood in the nest (in case of drone inspection or climbing);
- Rings (with readable ring number), full-body and head photos showing development/age and any observed abnormalities (in case of ringing);
- Tracking device on the bird (with readable ID);
- Biological samples (Saker Falcon or prey remains, moulted feathers).

A small data slip (separately enclosed or attached to the bag) must accompany and be fixed to all collected materials, including the following minimal information:
- Date;
- Area/territory name;
- Coordinates;
- Collector’s name and contact information.

It is important to mention that the locations of nesting sites of strictly protected bird species are usually considered confidential information. This confidentiality helps prevent intentional disturbance or destruction of breeding sites by certain interest groups (e.g. destruction of broods and/or nests, illegal harvesting of nestlings). Additionally, inexperienced observers could unintentionally disturb the breeding process, causing harm. Therefore, efforts should be made to ensure that nesting sites are not disclosed to the public, involving only the necessary number of appropriately trained personnel in nest inspections. Participants must accept and follow the basic rules suggested in this guide, understanding that the exact locations of nests can only be shared with third parties with prior consent from the relevant conservation authorities/managers (National Park Directorate in Hungary) or the relevant conservation experts (the Saker Falcon conservation coordinator in Hungary).

Discussion

While political borders do not fragment the Saker Falcon population biologically, they do affect the design and implementation of monitoring programmes. This complicates data collection and harmonisation, making it difficult to assess conservation status and plan and implement conservation measures at a European level (Prommer *et al.* 2025). Although ongoing monitoring programmes exist in each European countries of the species’ breeding range, this article represents the first attempt to propose a standard for terminology in data collection and for the methods applied. It summarises decades of experience gathered through Saker Falcon monitoring in Hungary, and the suggested standards can be applied across the European population.

However, we emphasise that we do not intend to suggest that these are the only effective and final standards or that others cannot be accepted and used. Our intention here is merely to draw attention to the lack of and need for agreed terminology and harmonisation in monitoring methods at the European level for this endangered species. Additionally, we propose a starting point for discussion about harmonising and improving monitoring efforts among Saker Falcon experts across the species’ European range.

Acknowledgements

We are thankful to all the volunteers and professional staff of MME BirdLife Hungary, the Hungarian National Park directorates and MAVIR Zrt., who have collected monitoring data and contributed to the improvement of monitoring methods over the past decades.

We are especially grateful to István Balázs, Gábor Deák, Miklós Dudás, Imre Fatér, József Fidlóczky, László Haraszthy, Tibor Juhász, Róbert Kazi, Antal Klébert, Ádám Pongrácz, István Sándor, József Serfőző, Gábor Tihanyi, Imre Tóth, Miklós Váczi, Levente Viszló and Tamás Zalai.

The protocol was developed as part of the LIFE SakerRoads project (LIFE21-NAT-HU-LIFE-SakerRoads / 101074704), which has been supported by the European Commission and the Hungarian Government and managed by Márton Árvay and Kata Gócs.

The monitoring and research of Saker Falcons in Hungary are conducted under the permits of the MME Birds of Prey Protection Section (OKTF-KP/56-25/2015, PE-KTFO/1867-9/2018, PE-KTFO/1867-10/2018, PE-KTFO/1867-11/2018, PE-KTFO/507-16/2019, PE-KTFO/1466-3/2023, PE-KTFO/1951-17/2024) and the research permits of the MME Bird Ringing and Migration Research Section (PE-KTF/97-13/2017).

We are grateful to Volen Arkumarev, Jozef Chavko, Gábor Tihanyi, Tibor Juhász, Gábor Deák and Tibor Csörgő for their comments on the earlier versions of the manuscript.

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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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Received: November 12, 2023 – Revised: October 18, 2024. – Accepted: November 04, 2024

Prommer, M., Bagyura, L., Chavko, J., Škorpíková, V., Milobog, Y., Zink, R., Kmetova-Biro, E., Ajder, V., Gavrilyuk, M., Nagy, A., Hegyeli, Zs., Klisurov, I., Pužović, S., Fântână, C., Veres-Szászka, J. & Karyakin, I. 2025. Beyond borders: A decade of change in Europe's Saker Falcon (*Falco cherrug* Gray, 1834) population (2012–2022). – Ornis Hungarica 33(1): 26–48. DOI: 10.2478/orhu-2025-0002

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.

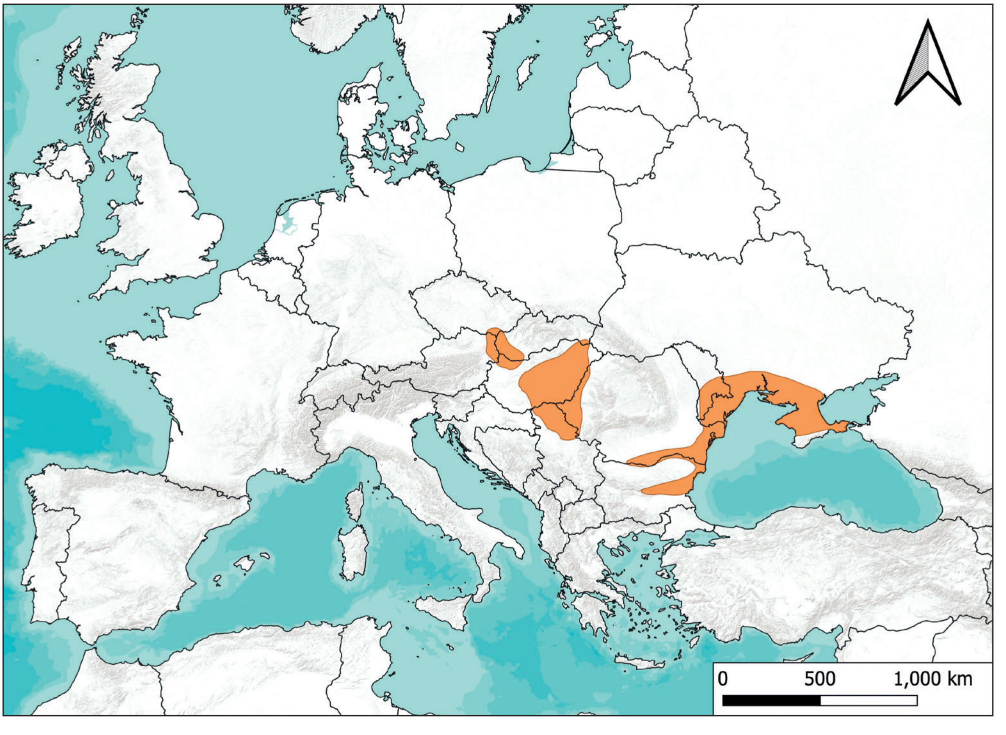


Figure 1. Approximate breeding distribution range of the Saker Falcon in Europe (highlighted in orange) in the study period (2012–2022)

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.

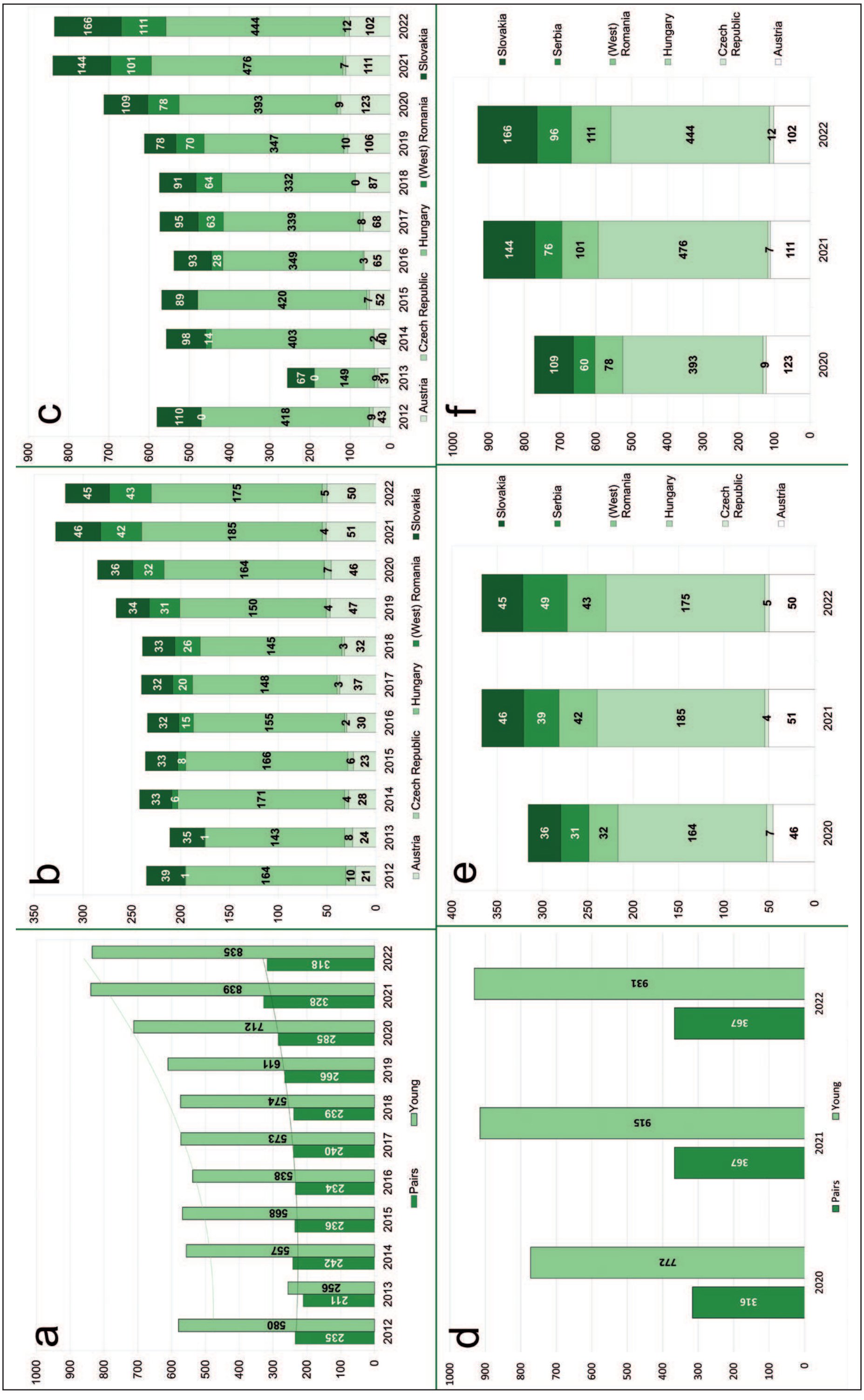
Results

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

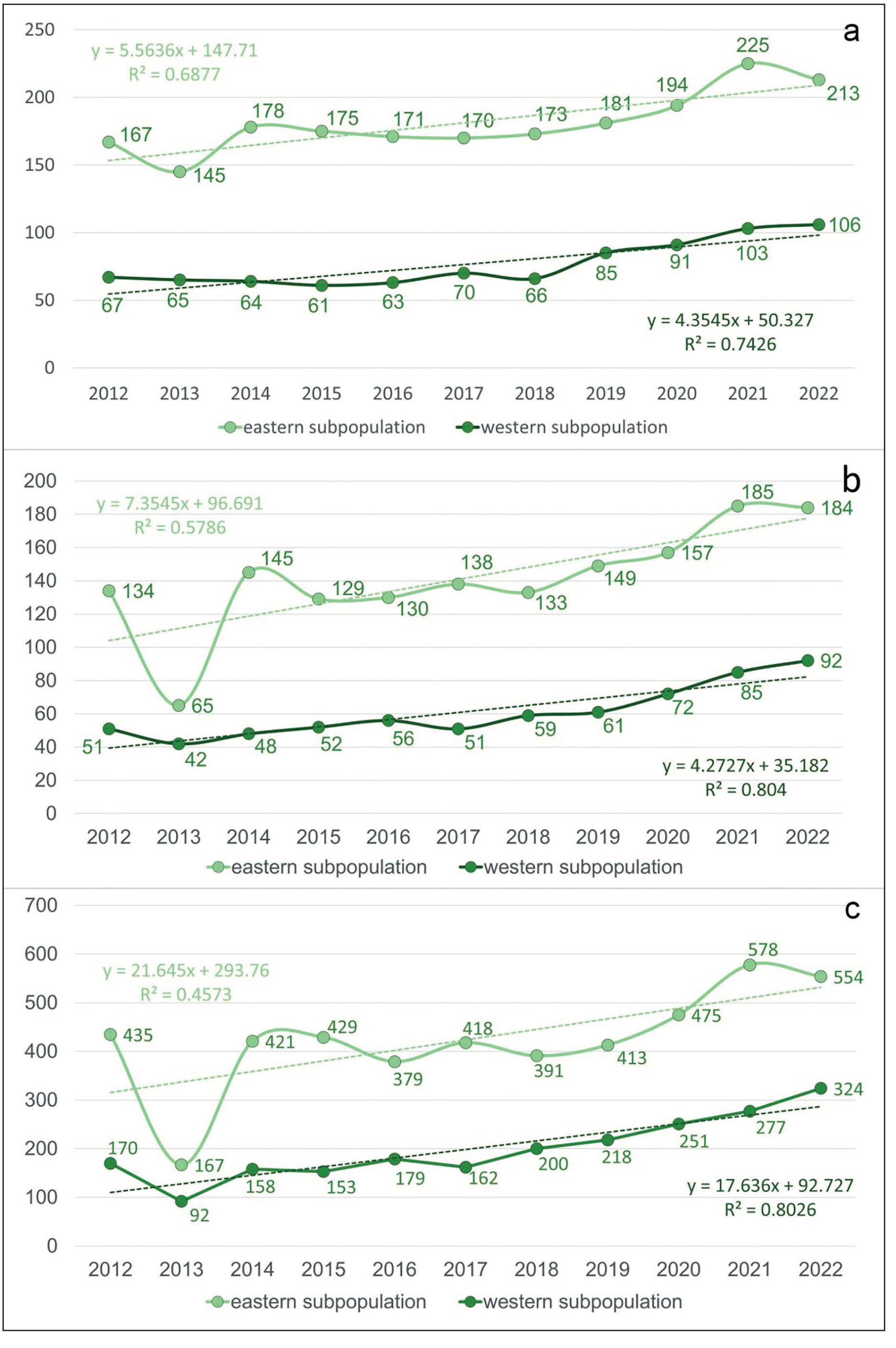


Figure 3. Trends of demographic data – number of breeding pairs (a), number of successful pairs (b), and number of young (c) – in the eastern and western subpopulations in Central Europe

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

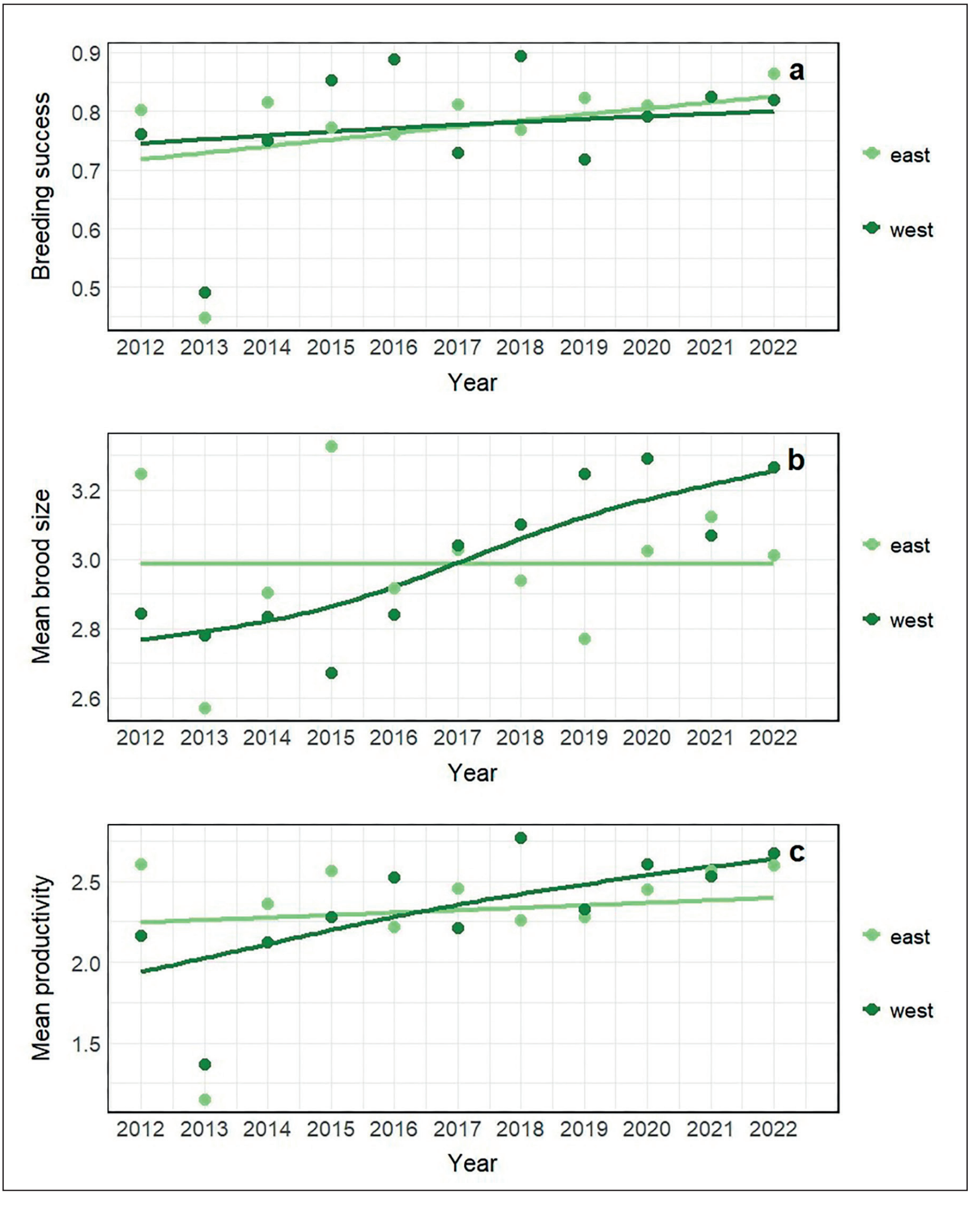


Figure 4. Trends of demographic parameters – probability of breeding success (a), mean brood size (b), and mean productivity (c) – in the eastern and western subpopulations in Central Europe. Means are weighted by country, and a smoothing function using Generalized Additive Models (GAM) was applied to 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 $\mu_{NS} = 0.78 \pm 0.032$ (n = 76), while the mean brood size (mean number of young per successful pairs) was $\mu_{BS} = 3.02 \pm 0.047$ (n = 76), and the mean productivity was $\mu_{P} = 2.35 \pm 0.116$ (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 $\mu_{NSeastern} = 0.781 \pm 0.033$ (n = 32) and $\mu_{NSwestern} = 0.777 \pm 0.049$ (n = 44), and there was no significant difference between them (t = 0.436, df = 4.610, p = 0.682). The mean brood size ($\mu_{BSeastern} = 3.01 \pm 0.131$, n = 32; $\mu_{BSwestern} = 3.04 \pm 0.364$, n = 44) did not differ significantly either (t = 1.277, df = 3.456, p = 0.281). Productivity of the eastern subpopulation ($\mu_{Peastern} = 2.35 \pm 0.191$, n = 32) was almost identical with that of the western subpopulation ($\mu_{Pwestern} = 2.36 \pm 0.338$, 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

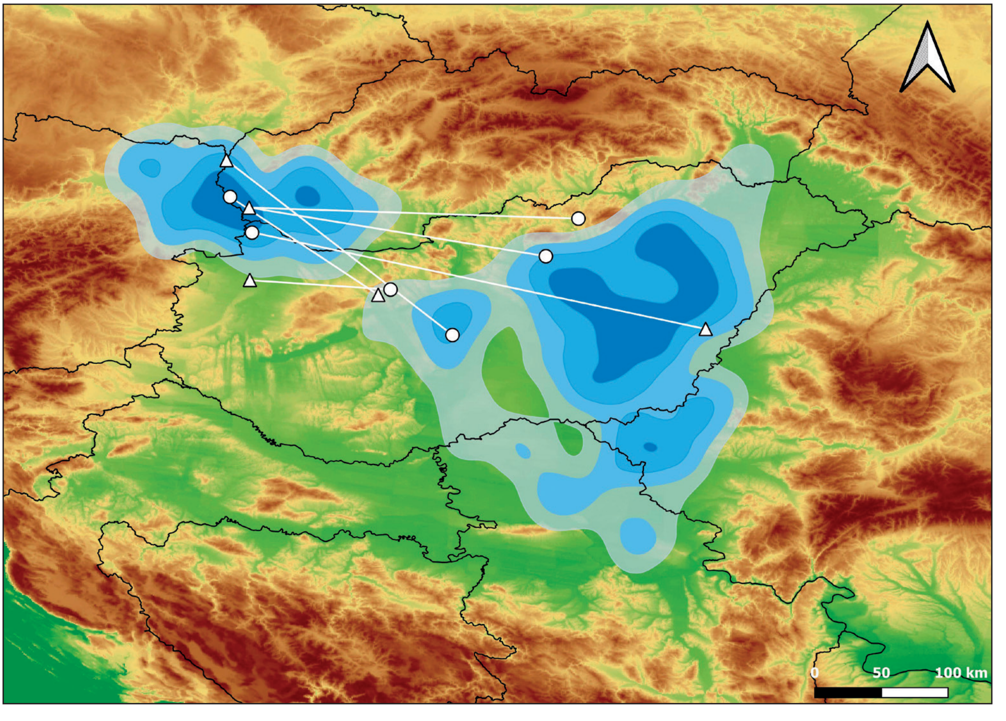


Figure 5. Ring recoveries indicating presumed natal dispersal connecting the two Central European subpopulations. The arrows indicate the direction of dispersal (○ = place of fledging, △ = place of assumed breeding). All recovered individuals on the map were adult, female and were ringed as nestlings

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.

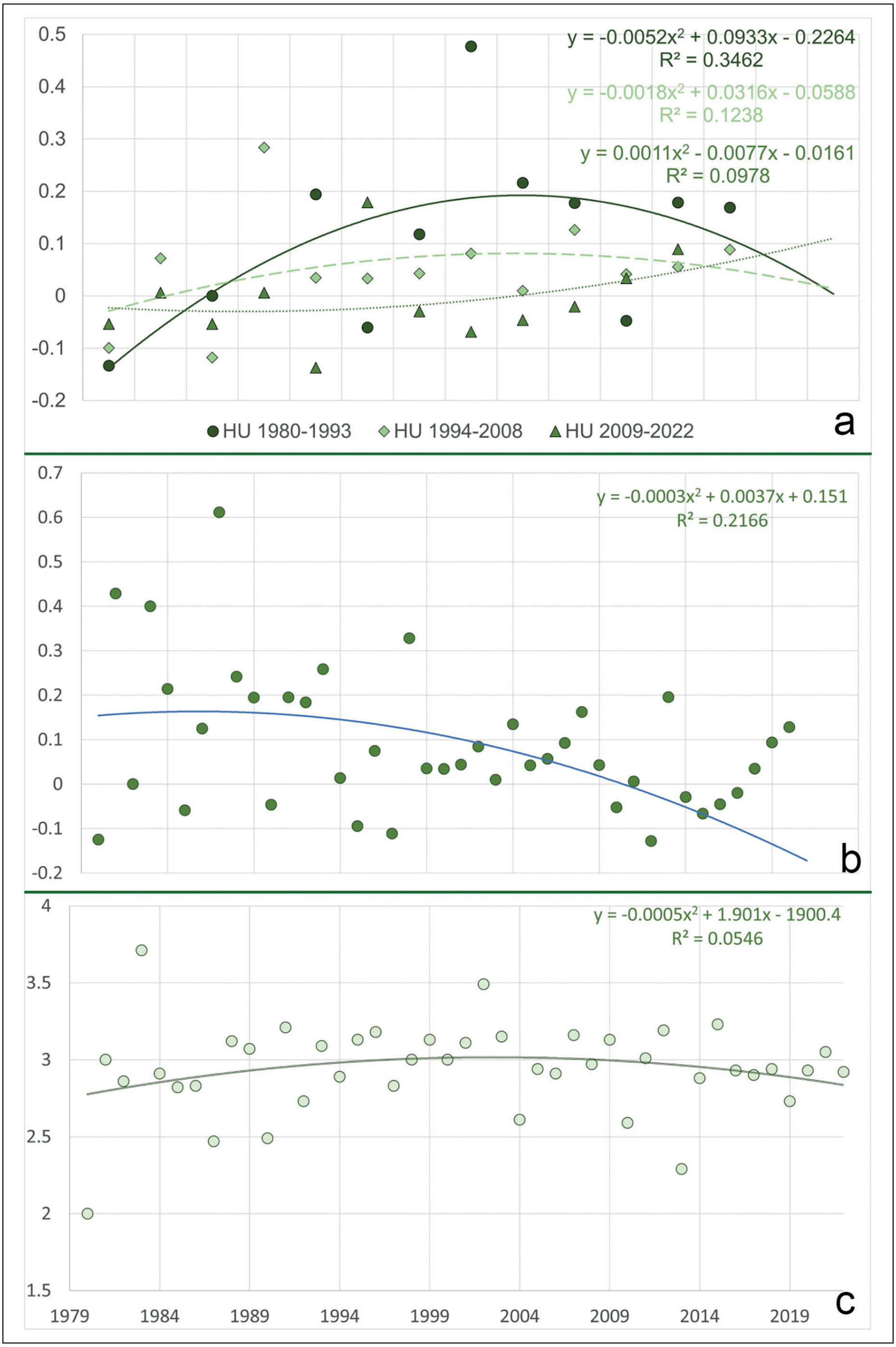

y = -0.0052x² + 0.0933x - 0.2264
R² = 0.3462
y = -0.0018x² + 0.0316x - 0.0588
R² = 0.1238
y = 0.0011x² - 0.0077x - 0.0161
R² = 0.0978
HU 1980-1993
HU 1994-2008
HU 2009-2022
a
y = -0.0003x² + 0.0037x + 0.151
R² = 0.2166
b
y = -0.0005x² + 1.901x - 1900.4
R² = 0.0546
1979
1984
1989
1994
1999
2004
2009
2014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

Acknowledgements

We extend our heartfelt thanks to colleagues from all range countries for their invaluable contributions to this study through their dedicated work and data provision. Our appreciation also goes to the supportive roles played by various governments, national park directorates, universities, and research institutes. Additionally, we acknowledge the vital contributions of national and international non-governmental organizations (NGOs) in facilitating this collaborative effort. A special mention is due to the European Commission's LIFE Fund, which has been instrumental in financially supporting the research and conservation of the Saker. This support has been channeled through several projects, including LIFE06 NAT/H/000096, LIFE07 NAT/BG/000068, LIFE09 NAT/HU/000384, LIFE13 NAT/HU/000183, LIFE20 NAT/BG/001162, and LIFE21-NAT-HU-LIFE-SakerRoads/101074704. In addition to the LIFE Fund, we are also grateful for the financial assistance provided by the Rufford Foundation, which has significantly contributed to the advancement of our work. The combined efforts and support of all these entities have been pivotal in driving forward our research and conservation initiatives for the Saker, and for this, we are immensely grateful.

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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

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Ornis Hungarica 2025. 33(1): 49–69.
DOI: 10.2478/orhu-2025-0003

Population trend and conservation of Saker Falcon *(Falco cherrug)* in Austria (2012–2021)

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Received: March 24, 2023 – Revised: October 24, 2024 – Accepted: October 28, 2024

Zink, R., Hohenegger, J. A., Berg, H-M. & Kmetova-Biro, E. 2025. Population trend and conservation of Saker Falcon *(Falco cherrug)* in Austria (2012–2021). – Ornis Hungarica 33(1): 49–69. DOI: 10.2478/orhu-2025-0003

Abstract We present data on the population trend and nesting success of Saker Falcon *(Falco cherrug)* in Austria in the period of 2012–2021. 339 active nests were recorded, 262 of them were successful, resulting in a total of 726 fledglings. The 10-year average breeding success is 2.14 fledglings per monitored active nest and 2.77 fledglings per successful nest. The average breeding success per successful nest is 3.1 fledglings for nest boxes, 2.7 fledglings for natural nests on trees, 2.4 fledglings for both stick nests and artificial platforms on pylons. Our most recent data shows that in 2021, a total of 53 territorial Saker pairs were reported in Austria, 41 of them successfully bred, resulting in a total of 111 fledglings (2.71 chicks/successful nest). The Saker Falcon population in Austria exhibits a marked increase (concerning the number of breeding pairs, fledged chicks, and breeding success) in the period studied. Furthermore, a positive correlation was found between the number of available artificial nesting structures and the number of successful nests. Since the population has shown a steady increase for the past years, as opposed to rather stable or more moderately increasing nearby populations in Central Europe, it is important to better understand the underlying causes and contemporary threats to keep the positive trend and ensure effective conservation.

Keywords: Saker Falcon, *Falco cherrug*, breeding success, nesting structures, mortality, contemporary threats

Összefoglalás Bemutatjuk az ausztriai kerecsensólyom *(Falco cherrug)* állomány alakulását és költési sikerét a 2012–2021-es időszakban. Összesen 339 aktív fészket jegyeztünk fel, 262 sikeres költéssel, amelynek eredményeként összesen 726 fiatal repült ki. A tíz év átlagát tekintve a költési siker 2,14 fiatal volt fészkenként, 2,77 fiatal sikeres költésenként. Az átlagos költési siker a fészekládákban 3,1, a fán lévő természetes fészkekben 2,7, a nagyfeszültségű távvezetékek oszlopain lévő gallyfészkekben és fészektálcákon egyaránt 2,4 fiatal volt. A legfrissebb adataink alapján 2021-ben 53 kerecsensólyom pár volt ismert Ausztriában, közülük 41 pár sikeresen költött, aminek eredményeképpen 111 fiatal repült ki (2,7 fiatal/sikeres költés). Az ausztriai kerecsensólyom-állomány jelentős növekedésen ment keresztül (a fészkelőpárok, a kirepült fiatalok és a költési siker tekintetében). Emellett pozitív összefüggést találtunk az elérhető mesterséges fészkek száma és a sikeres fészkelések száma között. Mivel ez az egyetlen folyamatosan növekedő állomány Közép-Európában, fontos megérteni a háttérben húzódó okokat és a veszélyeztető tényezőket, hogy fenn tudjuk tartani a pozitív trendet és biztosítsuk a hatékony védelmet.

Kulcsszavak: kerecsensólyom, *Falco cherrug,* költési siker, mesterséges fészek, mortalitás, jelenlegi veszélyforrások

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Introduction

Global distribution of Saker Falcon

Saker Falcon (*Falco cherrug* J. E. Gray, 1834) is found across the Palearctic from Central and South-East Europe, across Central Asia and all the way to Western China and Mongolia. Most recent global population estimates suggest a total population of 12,200–29,200 mature individuals. The status of the species was recently reassessed by the IUCN Red List Committee, yet retained its "endangered" global conservation status, due to an on-going very rapid decline, especially taking the unclear status and negative trends in the Asian strongholds of the species (China, Russia and Mongolia) into account (BirdLife International 2021a).

Compared to this, the European population of Saker Falcon is small and limited to some 430–630 breeding pairs in 2021. The species has been recently up-listed from "vulnerable" (2015) to "endangered" (2021) on a European scale, mostly due small population size, combined with a 48% population decline over three generations and an on-going decrease (BirdLife International 2021b). The worsening of the population trend is mostly attributed to land use changes, capture for falconry, pesticide exposure and electrocution (BirdLife International 2021a).

European population trends

The European population is split into two main distribution centres: Central European (Pannonian) population and Eastern European population (comprising Ukraine, Moldova and eastern Romania), geographically divided by the Carpathian Mountains (Prommer *et al.* 2014, Bauer 2020). The Pannonian population is estimated at 252–278 breeding pairs, more than half of it being concentrated in Hungary (145–165 breeding pairs) (Bagyura *et al.* 2017).

Despite significant evidence that the Pannonian population has been positively affected by well-targeted conservation measures and installation of supplementary nesting aid (Chavko 2010, Bagyura *et al.* 2012, Prommer *et al.* 2012, Fidlóczky *et al.* 2014, Trgalová & Chavko 2016), recent studies show that increase in the Hungarian and Slovak populations slowed down considerably (Bagyura *et al.* 2022, Prommer *et al.* 2025, Chavko *et al.* 2025), while the Czech breeding populations are undergoing a slight decrease (Škorpíková *et al.* 2019). At the same time, although the species is considered a former breeder in Germany, nowadays it is only a rare visitor with a single recorded breeding pair around 2000s (August 2000, Barthel 2011, Prommer *et al.* 2012). Hence, the species is considered extinct in Germany (BirdLife International 2021b).

This makes the status and population trend of Saker Falcon in Austria particularly interesting to study and consider as the species reaches the western limit of its global breeding distribution here.

Population trend in Austria

Saker Falcon was considered a widely spread species in the regions of Burgenland and Lower Austria, bordering Hungary until the end of the 19th century (Baumgart 1991).

Definite proof of a wide distribution is mostly missing, but as faunistic research on the species was hardly conducted at the time, only the few available written sources can serve as a reference. Later on, the population of the species experienced a supposed decrease, reaching approximately 10 pairs at the end of the Second World War (Bauer 1977), and further declined to almost extinction with barely two to four breeding pairs reported in 1970 (Bauer 1977, Senn 1980).

A slow recovery started in the 1980s (Gamauf 1992, Baumgart 1994), and the population was estimated to 15–20 breeding pairs at the end of the 1990s (Baumgart 1994, Berg 2000), which continued to increase to 25–30 breeding pairs by 2010 (Gamauf 2012).

The species was once included in the national priority list of the 50 most threatened species in Austria (Umweltdachverband 2008) and is currently on the Austrian Red List (Dvorak *et al.* 2017). Due to the reported positive population trend of 21–30%, it has been recently down-listed from “critically endangered” (2005) to “endangered” (2016) (Dvorak *et al.* 2017). Its legal status is characterized by a year-round protection in all nine Austrian provinces, regulated in the respective provincial hunting or nature protection laws (Lower Austria Hunting Law (NÖ Jagdgesetz) 1974; Burgenland Hunting Law (Bgld. JagdG), Wildlife Regulation Ordinance 2017). Furthermore, the species benefits from its protection in federal criminal law, as offences against Saker Falcons can be punished with up to two years in prison (BMJ 2022, Schmidt & Hohenegger 2022).

Contemporary threats

Some of the threats that previously caused the rapid decline of Saker Falcon populations in Central Europe have been largely reduced or eliminated through legislative measures. The following contemporary threats, however, still affect the species in Central Europe: shift to intensive agriculture, land use changes, direct persecution (poisoning and shooting), and trapping and egg collection for falconry (Nagy & Demeter 2006, Chavko 2010, Kovács *et al.* 2014). Newer threats that have been identified more recently include electrocution (Nagy & Demeter 2006, Prommer 2011, Kovács *et al.* 2014, Nemček *et al*. 2014, Bagyura *et al.* 2017), possible hybridization with escaped falconry birds (Nittinger *et al*. 2005, 2007, Kovács *et al.* 2014) and wind farm collisions (Dereliev & Ruskov 2005, Nagy & Demeter 2006). A potential risk that has not been studied in sufficient detail yet is secondary poisoning through rodenticides and other environmental pollutants (Kovács *et al.* 2014).

Conservation efforts

One of the measures, which has proven successful for increasing the Saker populations in Hungary, Slovakia and the Czech Republic, has been the installation of artificial nesting structures on high-voltage pylons (Chavko 2010, Beran *et al*. 2012, Chavko & Deutschová 2012, Chavko *et al.* 2014). This is explained by the fact that Sakers do not build nests themselves and can therefore be limited by nest site availability (Newton 1994). At the same time, natural breeding of Sakers on an electricity pylon has already been reported in Austria in 1999 (Straka 1999).

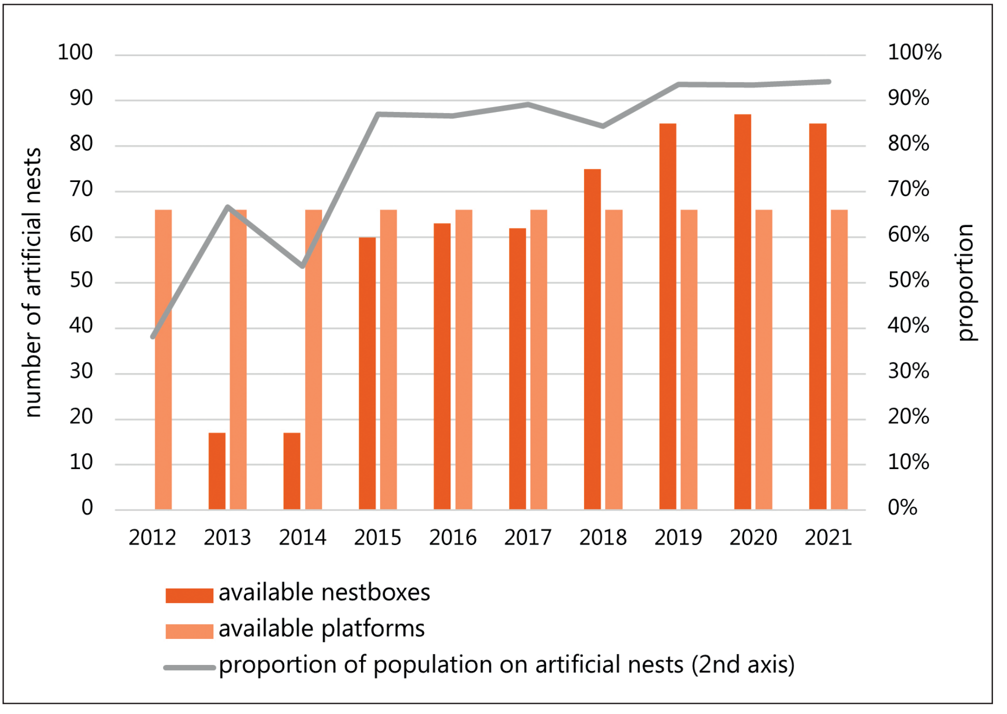


Figure 1. Temporal development of the number of available nesting aids in the period of 2012–2021
1. ábra A kihelyezett mesterséges fészkek számának alakulása 2012–2021 között

As a result, the Research Institute for Wildlife Ecology (FIWI) at VetMedUni Vienna and the Austrian Power Grid AG (APG) initiated a project to provide artificial nesting platforms on high-voltage electricity pylons in Lower Austria in 2004 (Zink & Sachser 2015). The project has continued in close cooperation with BirdLife Austria from 2010 onwards and in 2018 FIWI was replaced by the Austrian Ornithological Centre (AOC) at the VetMedUni Vienna. From 2012 onwards, also nesting boxes have been provided and the initiative has been joined by other electricity providers, such as NÖ Netz (formerly EVN), ÖBB Infra and Netz Burgenland (formerly BEWAG). As a result of all these efforts in the breeding season of 2021, there were a total of 151 nesting structures (platforms and nesting boxes) in Austria, offering suitable breeding sites, safe from human persecution and disturbance *(Figure 1, 2).*

Since the start of these conservation measures, the Austrian population of Saker has showed an even more rapid increase (Zink *et al.* 2016).

The current publication therefore aims to present the contemporary population trend and nesting success of Saker Falcon in Austria in the period of 2012–2021, following the conservation measures initiated and carried out by the Austrian Ornithological Centre at VetMedUni Vienna and BirdLife Austria.

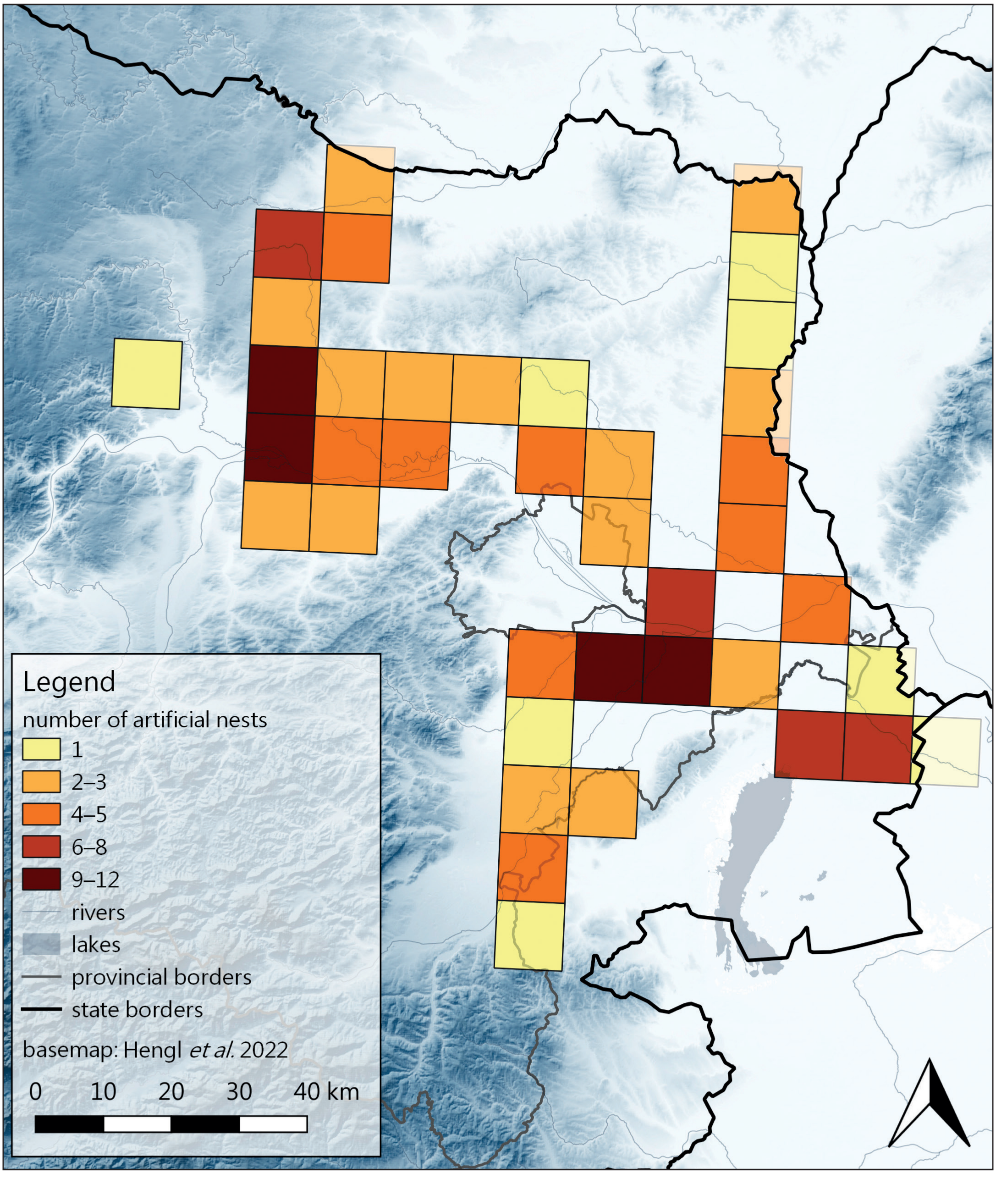


Figure 2. Total number of installed nesting aids available per grid cell in 2022
2. ábra A kihelyezett mesterséges fészkek száma négyzetenként 2022-ben

Material and Methods

Our study is an overall summary of a set of internal annual reports on the breeding success of Saker Falcon, developed together or separately by the Austrian Ornithological Centre (AOC) at VetMedUni Vienna and BirdLife Austria in the period of 2012–2021. The information from all annual reports, prepared in German, has been translated, merged, and processed

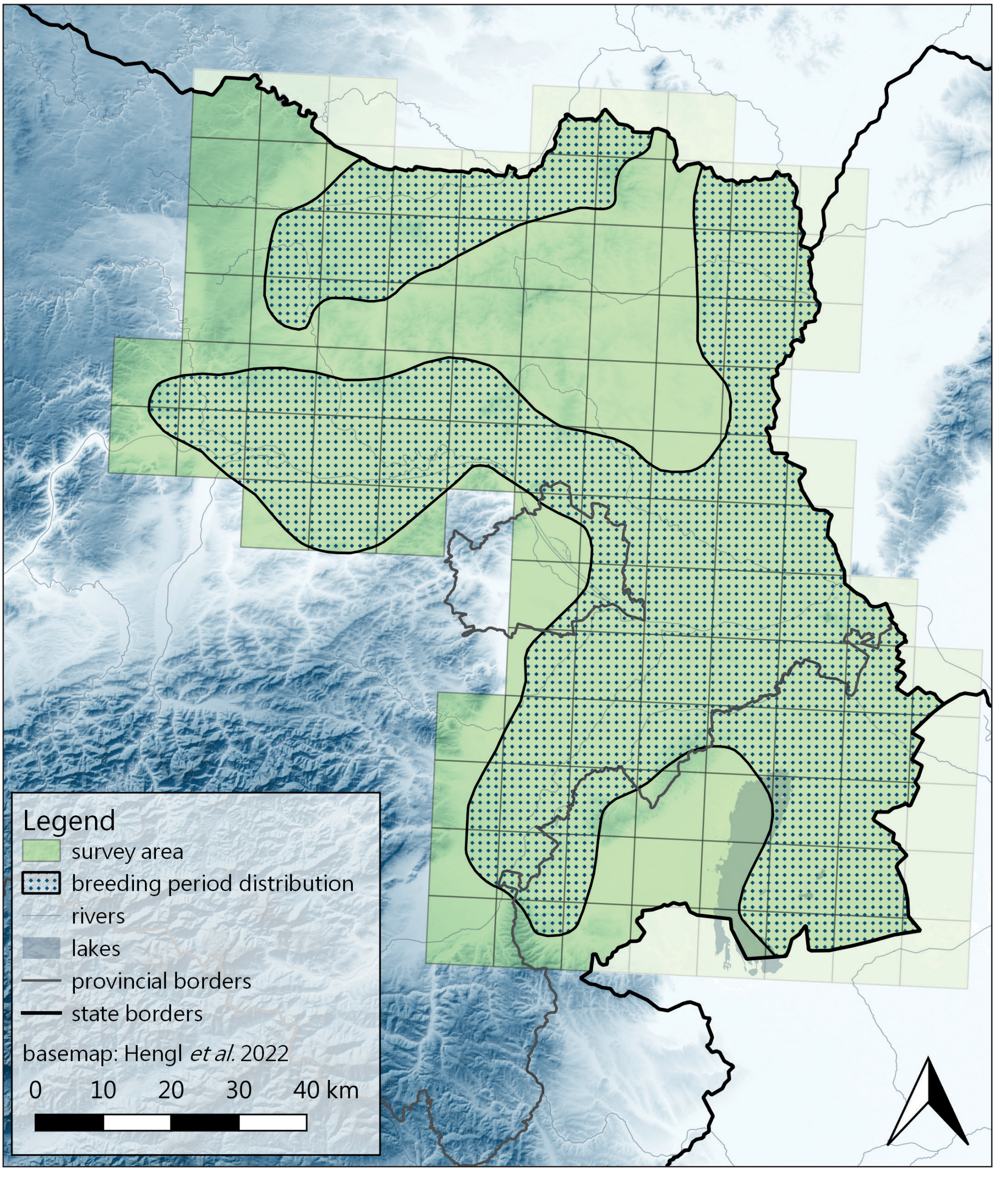


Figure 3. Survey area and breeding period distribution of Saker Falcon in 2012–2021
3. ábra A felmért terület és a kerecsensólymok elterjedése (költési időszakban) 2012–2021 között

together to produce summary results. Following the consolidation of the two datasets, population numbers published here marginally differ from the information published in the original internal reports.

The data presented below is based on the standardized monitoring of all known breeding pairs of Saker Falcon in Eastern Austria. The monitored area comprised parts of the state provinces of Burgenland, Lower Austria and Vienna *(Figure 3)*.

However, the detection of pairs breeding in natural stick nests in regions without artificial nesting structures can be difficult and it is possible that individual pairs have successfully bred without notice. In 2015, a total of 87% of all recorded breeding pairs in Austria were nesting on artificial structures (Rozsypalová *et al.* 2022), so the presented results can be considered quite comprehensive and thorough.

To optimize the monitoring effort and coordinate the teams of AOC and BirdLife, since 2014, the study area has been divided to regions, and staff, experts or volunteers of one of the two organizations have been assigned to single regions. The AOC expert team focused on monitoring the nesting structures installed and carried out individual ringing of non-fledged chicks, while BirdLife Austria staff members and volunteers additionally monitored natural broods in some of the areas. Known territories of tree-breeding Saker Falcons were also included in the surveys and unsystematic observation data collected by BirdLife Austria were used to identify additional possible territories (Hohenegger *et al.* 2020).

The survey areas primarily comprised areas known to have been occupied by Saker Falcon, regions with overhead power lines (with nesting structures), open/semi-open regions, and prospect "distribution gaps" between already established sites (Hohenegger *et al.* 2020).

Monitoring

The breeding sites were monitored using spotting scopes (such as Swarovski ATS 80 HD, 20-60 Zoom) as well as binoculars (ex. Swarovski 8×56 and 10×42) and documented with a digital camera.

When surveying pylons, the first viewing of a pylon was usually done from preliminarily agreed optimal observation points, at a minimal distance of 400-500 meters, but often way more to avoid disturbance, checking the nesting structures and the rest of the pylon for perching birds, stick nests, already present corvid nests or any other hints of possible occupation. The average time spent at each pylon varied between a few minutes and several hours depending on the conditions and the birds' behavior.

Each pylon with an artificial nesting structure was checked for the presence of Saker Falcons at least twice within the breeding season (starting from end of February). Between mid-March and end of April, a selected set of Saker Falcon nests was more frequently surveyed to guarantee that the newly hatched falcons could be marked with standard ornithological rings at an optimum age of approximately 20–30 days in the first half of May. Between mid-May and mid-June, all known nesting sites were additionally controlled to determine the number of "pre-fledged" chicks. This is, in our experience, the most effective method for assessing breeding success, since counting the freshly fledged Saker Falcons is time-consuming and often produces wrong numbers.

Nevertheless, the number of "pre-fledglings" in the nests can also be difficult to determine, due to the height of the nesting structures, poor viewing angle or big observation distance and these shortfalls must be considered when interpreting the breeding success data.

Data reporting and consolidation

In the first years of the project, the monitoring data was reported in paper monitoring forms, which were then transferred to a MS Excel table and location data was processed with open-source software, such as QGIS (https://www.qgis.org/en/site/). In the following years, a SQL online database was set up at the AOC to collect all relevant data: Saker Falcon observations, breeding status data, power line and pylon locations (with or without nesting structures) and all other nest locations.

At the same time, the staff members of BirdLife Austria used the online observation platform www.ornitho.at, set up in spring 2013 (Berg & Wichmann 2014). An extra input code was activated later to separate the breeding data from the non-standardized observations collected by other observers and hide it from public use.

The following data was collected by all field observers (AOC and BirdLife Austria) within the project: date and time of observation, nest site location, breeding status (possible, breeding, aborted, no breeding), number of birds, age, sex (if identifiable), observation content and any other information worth mentioning (e.g. suspected hybrid); photos.

At the end of the survey period each year, the results of BirdLife Austria were compared with those of AOC and jointly discussed after the young birds had fledged (Berg *et al.* 2017, Hohenegger *et al*. 2020). Observation data on breeding success was cross-checked through the chick ringing carried out by the first author of the current publication.

Finally, the summarized breeding status data of each pair was entered into the online database at www.saker-info.at, where a summary of the results is also publicly accessible (Berg *et al.* 2017, Zink *et al.* 2018).

Breeding parameters

The breeding parameters reported in this study should be read as follows:

- “territorial pairs” comprises all registered pairs, whether breeding successfully or unsuccessfully, and territorial, non-breeding pairs confirmed for the particular year, excluding sites with possible breeding attempts, where Saker Falcons were observed during the breeding season, but no territorial pair could be confirmed;
- “monitored active nests” comprises all active nests (whether successful or not) on artificial nesting sites, trees and electricity pylons (breeding behavior had to be observed for a possible nest site to qualify as “nest”); excluding non-breeding and possible territorial pairs as well as pairs with unknown nest site;
- “successful nests” comprises only pairs with confirmed breeding success from the known, monitored nests; excluding successful breeding, where the nest site could not be located precisely.

Breeding success is calculated as follows:

- “fledglings/successful nest” is based on the total number of fledged chicks from monitored nests, divided by the “successful nests”;
- “fledglings/nest” is based on the total number of fledged chicks from monitored nests observed for the season, divided by the “monitored active nests” identified for the year.

Correlations and trendlines are calculated as follows:
- Correlation is calculated using MS Excel by dividing the covariance by the product of the two variables' standard deviations;
- Trendlines are added using MS Excel suggesting a linear trend and a steady increase over time and the automatically calculated R-square value, measuring the trendline reliability is used.

Results

Current breeding area of Saker Falcon in Austria

Our summarized results show that the breeding range of Saker Falcon in Austria is restricted to the lowlands and hilly regions in the Pannonian part of Lower Austria and northern Burgenland *(Figure 3, 4)*. The strongholds for Saker Falcons in Austria are the Thaya-March region, the Marchfeld, the Feuchte Ebene and the Parndorf Plateau (Zink *et al.* 2016), the northern and western part of the Weinviertel, the Wagram-Tullnerfeld region and the southern Vienna Basin. As a result of the nesting structure installation programme, breeding occurrences are clustered mainly along large overhead power lines within agricultural areas. Yet, despite targeted searches, breeding occurrences in large forest areas, such as those known from the Danube and the March floodplains, the Ernstbrunn Forest, the Hochleithen Forest and the Leithagebirge, are currently very rare and probably under-reported. The most important area for Saker Falcons breeding in natural nests is the northern Weinviertel, where the species uses corvid and Common Buzzard *(Buteo buteo)* nests on trees or powerline pylons within an open agricultural area. It should be noted that in this area there are no artificial nests.

Our results clearly show that Saker Falcons in Austria readily take the artificial nesting structures provided on high-voltage electricity pylons. Furthermore, the number of pairs using artificial nesting structures has increased from less than 30% in 2012 to over 90% in 2021 *(Figure 4)*. Additionally, we have established a positive correlation between the number of provided artificial nesting sites and the number of breeding pairs (r=0.7912).

Breeding population and trend

The breeding population of Saker Falcon in Austria has nearly doubled (89% increase) in 10 years from 28 territorial pairs in 2012 to 53 territorial pairs in 2021 *(Figure 5)*. Furthermore, there is an even greater increase in the number of successful nests from 16 nests in 2012 to 41 in 2021 (156% increase) and a positive trend in the proportion of successful nests compared to the total number of territorial pairs reported for the same year (R^2 = 0.6248). The average proportion of successful nests for all monitored active nests is 77%, with a maximum of 96.9% (2018) and a minimum of 62.5% (2013).

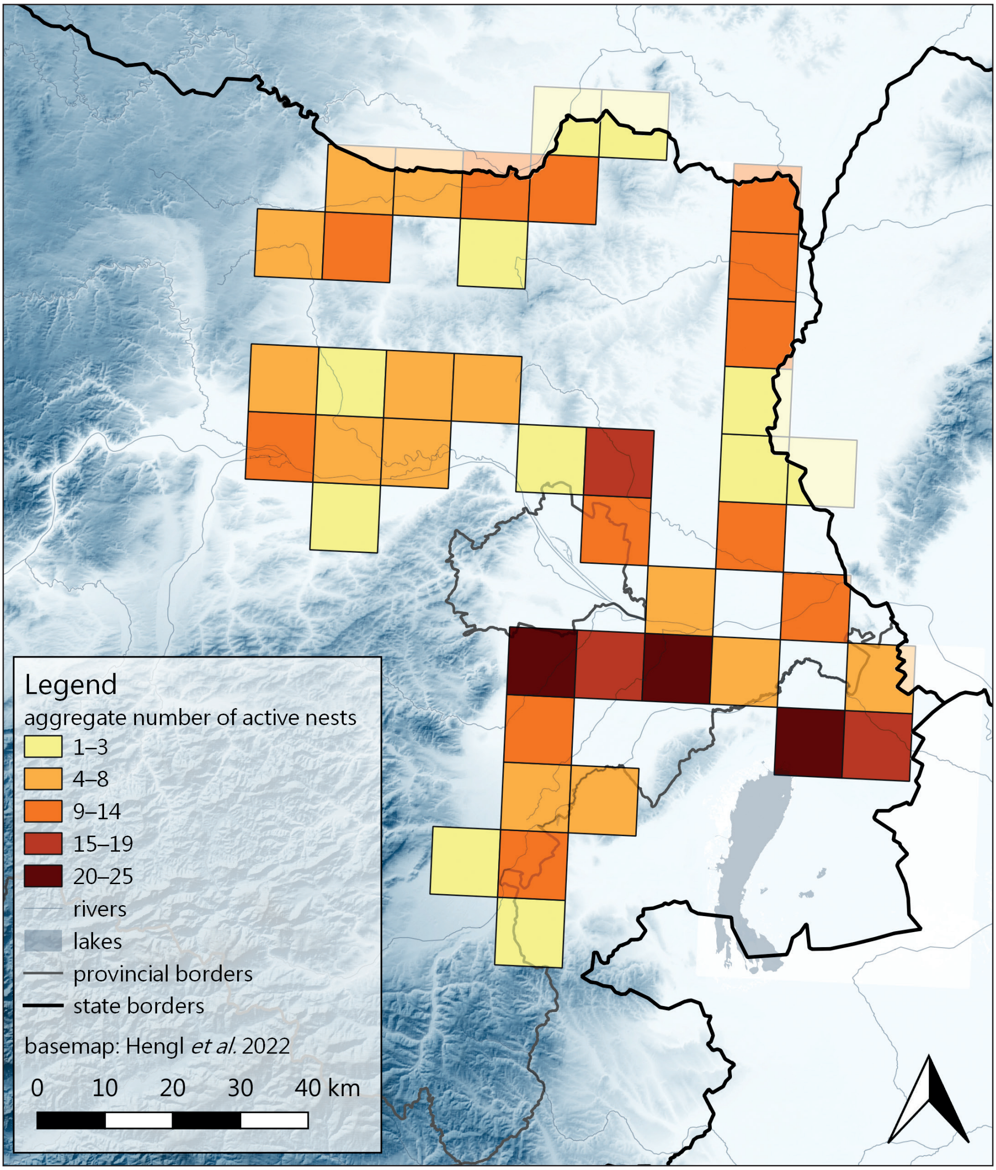


Figure 4. Total number of monitored active nests of Saker Falcon per raster cell (2012–2021)
4. ábra A felmért aktív kerecsensólyom-fészkek összesített száma cellánként (2012–2021)

Breeding parameters

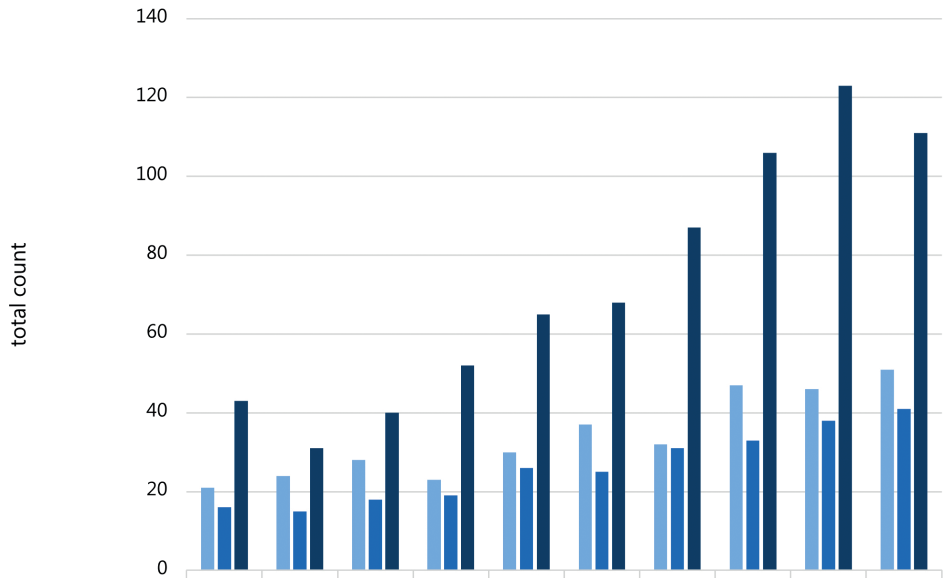
The ten-year average breeding success of Saker Falcon in Austria in the period of 2012–2021 is 2.14 fledglings/monitored active nest and 2.77 fledglings/successful nest *(Table 1)*. A total of 726 fledglings have been recorded from both artificial and natural Saker Falcon nests between 2012 and 2021 in all monitored nests in Austria *(Figure 5, 6)*.

Table 1. Breeding success parameters per nest type (aggregate numbers for 2012–2021)
1. táblázat Fészektípusonkénti költési siker (összesített adatok 2012–2021 között)

	Natural tree nests	Natural nests on pylons	Platforms	Nest boxes	All nests
Monitored active nests	26	33	118	155	339
Success rate (%)	65	76	62	90	77
Fledglings per nest	1,73	1,64	1,50	2,77	2,14
Fledglings per successful nest	2,65	2,16	2,42	3,09	2,77

While the population is growing over this ten-year period, there is also a slight positive trend in the number of juveniles per known breeding pair ($R^2 = 0.3993$), as well as number of juveniles per successful nest ($R^2 = 0.4649$) *(Figure 7)*. Strikingly, the average number of fledglings per nest grows by cca. 10% per year over the ten-year period. Furthermore, the proportion of pairs, which have abandoned their nests (failure rate), although fluctuating over the years (mostly due to the weather conditions or occasional disturbance that year), is generally decreasing.

The highest breeding success (fledglings per successful nest) was recorded in 2020 (3.24) and 2019 (3.21). Both 2019 and 2020 were characterized by dry and warm spring seasons



	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
monitored nests	21	24	28	23	30	37	32	47	46	51
successful nests	16	15	18	19	26	25	31	33	38	41
fledged young	43	31	40	52	65	68	87	106	123	111

monitored nests successful nests fledged young

Figure 5. Temporal development of the Saker Falcon breeding population in Austria, in 2012–2021
5. ábra A kerecsensólyom fészkelőállományának alakulása Ausztriában 2012–2021 között

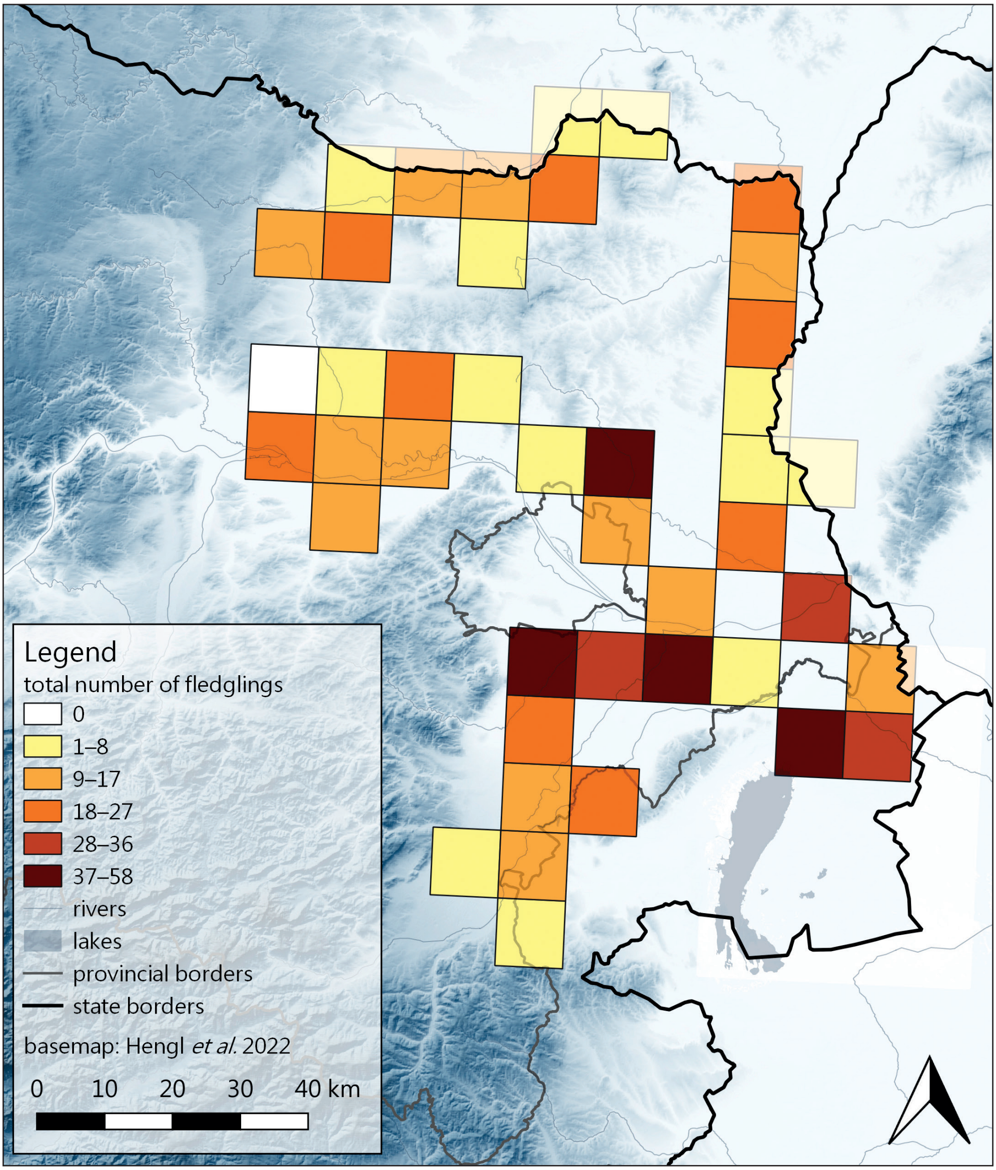


Figure 6. Aggregated number of fledglings of Saker Falcon per raster cell (2012–2021)
6. ábra A kirepült kerecsensólyom fiatalok összesített száma cellánként (2012–2021)

(February – April), providing excellent conditions until the hatching of the young birds. Despite several days of heavy rain and storms around the turn of the month April – May 2019 (ZAMG 2022a), the prolonged period of good weather in June 2019, providing good hunting conditions for the adults, likely had a positive effect on the survival rate of the young, especially combined with the extreme prevalence of voles that year (Hohenegger *et al.* 2020). On the contrary, June 2020 was characterized by relatively high precipitation

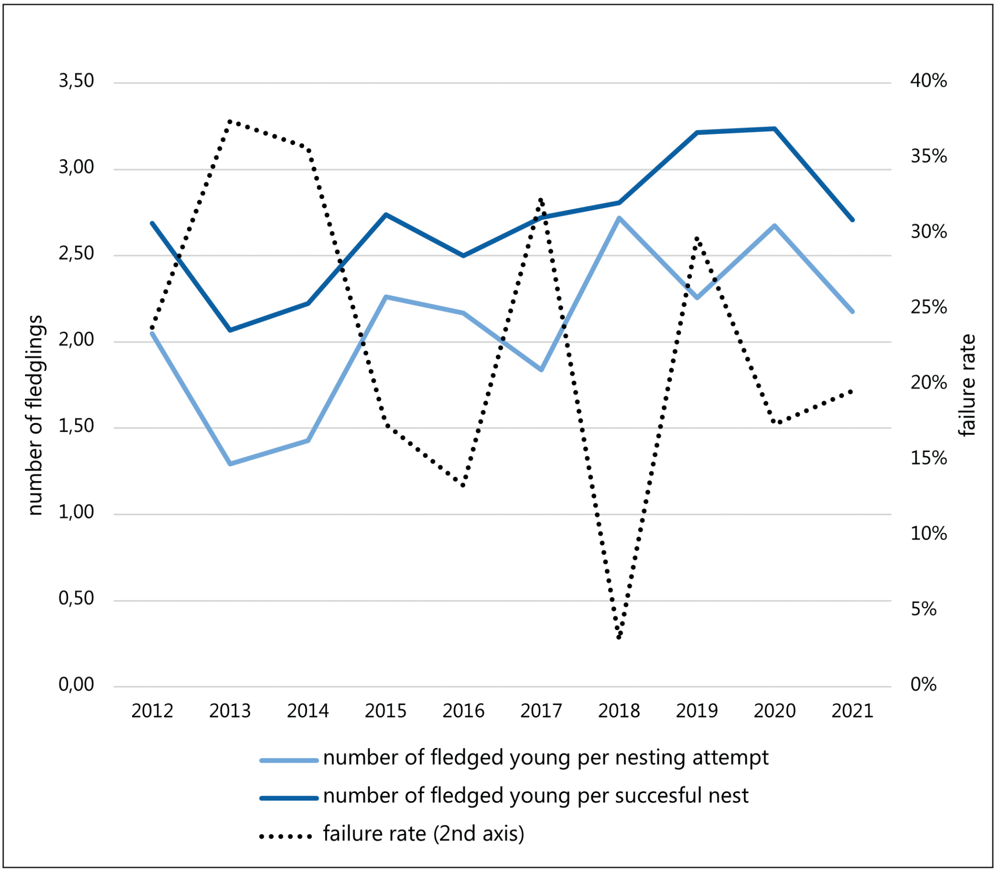


Figure 7. Temporal development of abortion rate and fledgling number of Saker Falcon in Austria (2012–2021)

7. ábra A meghiúsult költések arányának és a kirepült fiatal kerecsensólymok számának alakulása Ausztriában (2012–2021)

and mild weather (ZAMG 2022a), which obviously did not compromise the high breeding success.

The two years with lowest breeding success are 2013 (2.07 fledglings/successful nest) and 2014 (2.22 fledglings/successful nest). The weather in 2013 was characterized by relatively cold spring (March, start of April and May), as well as high precipitation in May (ZAMG 2022a), which also caused a high rate of breeding failures (more than 37% of all monitored active nests that year failed). The nearby Slovakian population was also affected by the poor weather in 2013, with a record-low breeding success of 1.79 chicks/nest (Chavko *et al.* 2014). The respective number for Austria (1.29) is also the lowest recorded in the reporting period.

In 2014, despite a warm and dry March, high precipitation was recorded all through April-July (ZAMG 2022b).

In terms of nest substrate and breeding success, it should be noted that the average breeding success of Sakers breeding on artificial nesting structures (nesting boxes or nesting platforms

Table 2. Total number of ringed Saker Falcons in Austria (2015–2021)
2. táblázat Az Ausztriában összesen gyűrűzött kerecsensólymok száma (2015–2021)

Year	*All nests*	*Platforms*	*Nestboxes*	*Recoveries* (year in brackets)*
2015	24		24	1 x Czech Republic (2015)
2016	30	9	21	1 x Poland (2016) 1 x Algeria (2017) 1 x Austria (2021)
2017	22	1	21	
2018	37	14	23	[2 x recently fledged iuv.] 1 x Austria (2018) 1 x Serbia (2018) 1 x Slovakia (2018)
2019	31	3	28	
2020	51	7	44	1 x recently fledged iuv.
2021	26	7	19	
Total	**221**	**41**	**180**	

on high-voltage power lines) of 2.86 fledglings/successful nest (2012–2021) is higher than the average success of the total Saker pairs using natural stick nests on power lines or trees (average of 2.37 fledglings/successful nest for the period 2012–2021) *(Table 1).* It should however be noted that breeding success on natural stick nests on trees (2.65 fledglings/successful nest) exceeds the breeding success of stick nests on pylons (2.16 fledglings/successful nest) and artificial platforms (2.2 fledglings/successful nest) *(Table 1)*. At the same time the combined breeding success for all three nest types (artificial nesting structure; natural nests on power lines and natural nests on trees) shows a positive trend between 2012 and 2021. When testing for different artificial nest types, both platforms and nest boxes show an increasing nesting success in recent years. However, the average number of fledged chicks per successful nest is clearly higher in nest boxes (3.09) than on platforms (2.42). Furthermore, the breeding success trend of platforms exhibits higher fluctuations than in nest boxes. We consider that further research is needed to determine the environmental factors influencing this difference.

Ringing and ring recoveries

Between 2015 and 2021, a total of 221 chicks (30.3% of all fledged young) hatched in artificial nesting structures (platforms and nesting boxes) were marked by AOC with Austrian standard ornithological rings. A total of 10 of the AOC-ringed birds (4.5%) have been recovered injured or dead in Austria or abroad *(Table 2)*.

Information about the recovery of Saker Falcons in Austria is kept separately by the Austrian Ornithological Centre, BirdLife Austria, and the Owl & Birds of Prey Rescue Station, Haringsee. These databases comprise information about a total of 14 birds found dead or injured in Austria *(Table 3)* and a total of 5 Austrian-ringed birds found abroad between 2012 and 2022 *(Table 2)*. It should be noted that there are no data entries from 2012 till 2014, while there are two data entries in 2022 alone.

Table 3. Inland recoveries of Saker Falcons, found on the territory of Austria in the period 2012–2022
3. táblázat Ausztriában 2012–2022 között megkerült kerecsensólymok száma

Ring origin	Total number of birds	Tagged with transmitters
AOC-ringed	4	
Hungarian-ringed	2	1
Slovakian-ringed	5	4
Non-marked	3	
Total:	**14**	**5**

The most distant recovery of an Austrian-ringed bird was reported in Algeria in 2017 of a Saker trapped for falconry. Other foreign recoveries of Austrian-ringed birds were reported in the Czech Republic in 2015, Poland in 2016 (115 days post-release and 265 km from ringing site); Central Serbia in 2018 and Trnava district and Slovakia in 2019 and 2020. The bird found in Slovakia (AUW G000327) was once found in 2019 near Opoj, Trnava injured by suggested collision with wires (70 days post-ringing and 76 km from the ringing site). A year later, in 2020, the same bird was found freshly dead from electrocution with a total of 286 days post-ringing and 89 km from ringing site *(Table 2)*.

Causes of death and current threats

Between 2015 and 2022 a total of 14 dead or injured Saker Falcons were found in Austria.

Our recovery data shows that the main reason for these findings is collision with man-made objects (a total of 57% of reported fatalities): wires and power line structures (36%), wind turbines (14%) and vehicles (7%); followed by territorial fights (22%), and electrocution

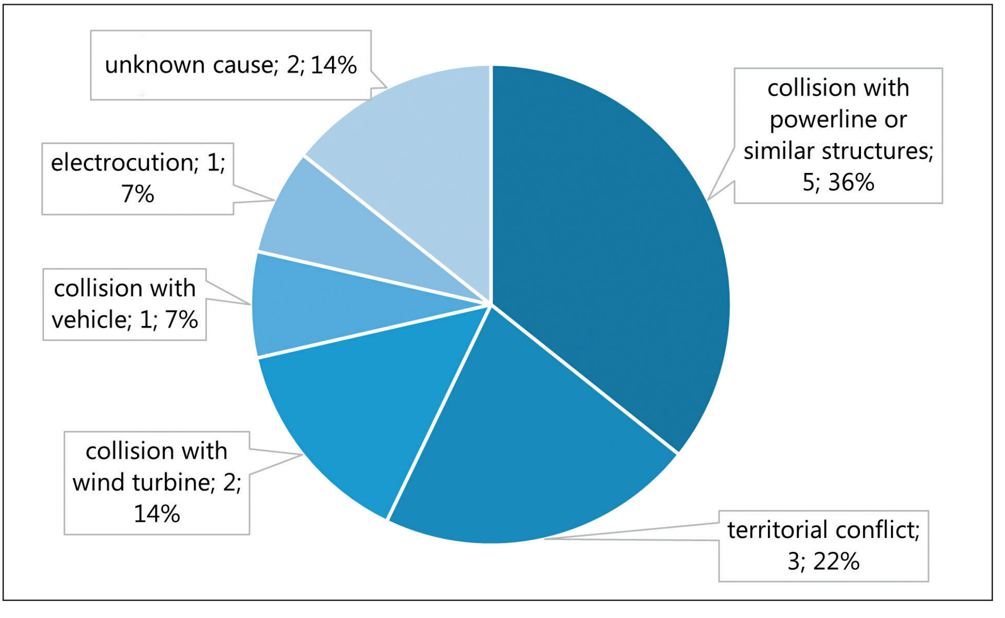


Figure 8. Reasons of injury/death of Saker Falcons found injured/dead in Austria from 2015 to 2022
8. ábra A kerecsensólyom sérülések/pusztulások okai Ausztriában 2015 és 2022 között

(7%) *(Figure 8)*. It should be noted that in 2022 alone, a total of two Saker Falcons have been irrecoverably injured by wind turbines.

Another documented threat is collision with vehicles (one confirmed case and a second possible one, excluded from the upper analysis). Two further unclear causes concern possible electrocution and botulism, while electrocution on medium-voltage power lines (< 20 KV) has been proven to be a relevant threat in many parts of the range, including the Pannonian basin (Rozsypalová *et al.* 2022).

It should be also noted that five of the dead birds recovered were carrying transmitters and the finding of the carcasses was not necessarily facilitated by the presence of the devices. In one of the cases in 2018, a collision was heard, and the bird was observed falling directly under the cable. The Saker died immediately, and the postmortem performed at VetMedUni Vienna showed an approximately six-year-old female with signs of attack from another bird, but also severe transmitter-induced trauma (subcutaneous chest muscle rupture exactly under the harness). The injuries clearly suggested direct contact between the backpack-mounted transmitter and the power line cable, which most probably happened when the bird tried to fly under the cable, yet the transmitter hit it, causing an abrupt stop and chest muscle rupture.

In addition to that, a total of 5 birds ringed in Austria have been recovered dead or injured abroad between 2015 and 2022. Main causes of finding were collision with power lines and electrocution (one case in Poland and two cases in Slovakia) and trapping and keeping for falconry (Algeria and Serbia). The bird (AUW G000267) kept in Serbia was reported as found exhausted after being harassed by Ravens and maintained in captivity (Milan Ruzic, BirdLife Serbia via Matthias Schmidt; Daliborka Stankovic, *pers. comm.*).

Other direct threats possibly affecting the species in Austria are illegal persecution and deliberately poisoned homing pigeons. Despite of the lack of recent evidence that Saker Falcons have been directly affected, findings regarding other birds of prey clearly suggest that these practices are still in place and represent a potential threat (WWF Österreich & BirdLife Österreich *in prep*.). Pesticides, especially persistent rodenticides, and lead, which have been recovered from different birds of prey in Austria in relevant concentrations, are also likely to affect the fitness and survival probability at least indirectly (Hauzenberger *et al.* 2020, Umweltbundesamt 2020).

Discussion

The population of Saker Falcon in Austria is currently the one of the very few exhibiting such a clear and stable increase in Central Europe.

The species quickly and positively responds to the provision of safe artificial nesting structures, as already confirmed in Hungary, Slovakia and the Czech Republic (Chavko 2010, Bagyura *et al.* 2012, Beran *et al*. 2012, Chavko *et al.* 2014). Considering the established correlation between the availability of supplementary nesting sites and the breeding population increase (r=0.7912), we also consider nesting site shortage as a contemporary limiting factor in Austria, which can be easily handled by targeted conservation measures. At the same time, the population trends in the countries mentioned above are either stable or decreasing, so the provision of sufficient number of safe nesting structures is obviously not the only factor determining the abundance and breeding success of Saker Falcon in Central Europe.

Looking at the average breeding success per successful nest of 2.69 fledglings for the period of 2012–2021 in Austria, the value remains lower than the most recent reports for Slovakia – 3.10 fledglings/successful breeding (2011–2014) (Chavko *et al.* 2014); Hungary – 3 chicks per nest (2014–2015) (Bagyura *et al.* 2014, 2015). It should, however, be noted that these are average values covering non-matching periods, when weather conditions, prey availability, etc. could have impacted the breeding success. Additionally, the installation of artificial nesting structures in Hungary started as early as 1991, with more consistent effort already in 2007, so that between 2009 and 2013, nearly 70% of Saker pairs already nested in artificially supplied nesting structures (Fidlóczky *et al.* 2014). In comparison, similar efforts in Austria only started in 2004, and by 2013, still less than 50% of the population occupied the aids provided *(Table 1)*. At the same time, several authors (Bagyura *et al.* 2014, 2015), similarly to us, reported a difference in the breeding success and failure rate on different nesting structures.

Considering the overall positive trend of the population in Austria, the average breeding success reported for only the past three years of our study (2019 and 2021) accounts for 3.05 fledglings/successful nest, which is comparable to the maximum values reported for Hungary, at the time where a steady increase of the Hungarian population was recorded (Bagyura *et al.* 2004, 2014, 2015).

The most recent breeding success in Austria significantly exceeds the comparable data for the Czech Republic, where only 2 chicks/successful pair were recorded between 2011 and 2018 (Škorpíková *et al.* 2019). The same authors observed a shift of the breeding pairs to Austria since 2013, suggesting that land use changes and intensive agriculture have led to a decrease in abundance of prey in the Czech Republic (Škorpíková *et al.* 2019).

We therefore consider that the breeding success of Saker Falcon in the past years in Austria is catching up with or, in some cases, is even higher than the breeding success of the species in the nearby countries.

In the case of Austria, we have provided an increasing number of safe supplementary breeding sites and apparently the prey sources are sufficient to maintain a growing population. A limiting factor gaining significance is securing the survival of the birds, especially the breeding adults, potentially threatened by the expansion of wind farm areas. Wind power use seems to be among the most important direct threats to Saker Falcons in Austria and increased conflicts are expected to emerge with the planned expansion of wind power plants in eastern Austria. In any case, the further development of wind parks should be carefully considered and coordinated with the existing breeding and hunting territories of the species.

As an additional measure to decrease mortality, considering our results as well as the evidence presented by Dixon *et al.* (2016), the potential negative effects of backpack-mounted transmitters on Saker Falcon fitness and survival should also be carefully considered.

It is particularly difficult to compare the success rate of Saker Falcon pairs in Central Europe, since the available datasets cover different time periods and there is a clear shift to nesting on artificial nesting structures, which could also impact the percentage of successful pairs. On overall, the reported values vary between 58.4% (Horák 2000) and 81.1% (Chavko 2010) with a median of 77%, which is exactly the average number of successful nests reported for Austria between 2012 and 2021 *(Table 1)*.

It should also be noted that the Austrian population is at the westernmost edge of the global distribution of the species, so there must be a factor affecting the further expansion of this highly mobile species. Climatic features might be among the factors determining the distribution or breeding success and we recommend further studies to establish the potential correlation.

When considering breeding success, we suggest that rain and lower temperatures potentially impact the chicks shortly after hatching, as well as the availability of prey and the hunting success of the adult birds, and therefore impede the provision of food, resulting in overall decrease of the breeding success and higher failure rates (such as above 35% in 2013–2014). Yet more focused research is needed to explain this potential causality.

In this sense, it becomes crucial to better study the underlying causes determining the development of Saker Falcon population in Austria, as well as to preserve the on-going positive trends, limiting potential anthropogenic threats, particularly wind farm development, poaching, collision and electrocution.

Conflict of interests

The Austrian Saker Falcon protection programme and the respective monitoring in the covered period were co-financed by the Austrian Power Grid AG, ÖBB Infrastruktur, AG Netz Niederösterreich GmbH and Netz Burgenland GmbH. However, project design, data collection and analysis were not influenced by the relevant financiers.

Acknowledgements

The installation of supplementary nesting boxes and the monitoring and ringing of Saker Falcons has been financially supported by Austrian Power Grid AG, ÖBB Infrastruktur, EVN and Energie Burgenland, Sven Aberle, project coordinator at APG. We are also very grateful to all staff members and volunteers of BirdLife Austria and AOC, VetMedUni Vienna as well as all other data providers, who have contributed to this work (in alphab. order): Mildren Adam, Stefan Agnezy, Michael Bierbaumer, Manuel Denner, Michael Dvorak, Konrad Edelbacher (†), Johannes Feichtinger, Hans Frey, Marie-Theres Furch, Markus Furch, Rupert Hafner, Jennifer Hatlauf, David Horal, Walter Hovorka, Helmut Jaklitsch, Richard Katzinger, Hans Kemle, Günther Kloner, Bettina Klöpzig, Felix Knauer, Stefan Knöpfer, Mathias Kürsten, Johannes Laber, Beatrix Leitold, Gerhard Loupal, Katharina Loupal, Barbara McAllister, Johanna Petrus, Rainer Raab, Andreas Ranner, Christoph Roland, Tobias Schernhammer, Marion Schindlauer, Rudolf Schmid, Matthias Schmidt, Alexander Schmied, Susanne Schreiner, Hans Senn, Vlasta Skorpikova, Lukas Strobl, Bernadette Strohmaier, Daniel Szücs, Norbert Teufelbauer, Wolfgang Vogl, Theresa Walter, Benjamin Watzl, Stefan Wegleitner, Beate Wendelin, Gábor Wichmann, Sabine Zelz, Thomas Zuna-Kratky.

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Ornis Hungarica 2025. 33(1): 70–97.
DOI: 10.2478/orhu-2025-0004

Population trend, breeding performance and diet of Saker Falcons *(Falco cherrug)* in Hungary between 1980 and 2024

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Received: February 07, 2025 – Revised: February 27, 2025 – Accepted: February 28, 2025

Bagyura, J., Haraszthy, L., Szitta, T., Solti, B., Jánossy, D., Prommer, M., Fidlóczky, J. & Horváth, M. 2024. Population trend and diet of Saker Falcons *(Falco cherrug)* in Hungary between 1980 and 2024. – Ornis Hungarica 33(1): 70–97. DOI: 10.2478/orhu-2025-0004

Abstract The Saker Falcon *(Falco cherrug)* is a globally threatened bird species, and Hungary hosts the second-largest population in Europe. The Hungarian population most likely reached its historical minimum by the 1970s, with an estimated number of 15–30 breeding pairs. Intensive monitoring and conservation efforts began in 1980 through the cooperation of MME BirdLife Hungary and the national park directorates. In this paper, we present the long-term natural history of the Hungarian Saker Falcon population from 1980 to 2024. Throughout the study period, both range expansion and breeding population size exhibited an increasing trend. The number of known territorial pairs grew at an average annual rate of approximately 8%. The population reached its historical maximum in 2024, when 200 territorial pairs were recorded, of which 177 successfully bred, producing 530 fledglings. A total of 4,429 breeding attempts were monitored in Hungary over 45 years, of which 3,467 were successful, yielding 10,319 nestlings. The breeding performance parameters of the population showed a generally stable trend with slight fluctuations throughout the study period. The annual mean (±SD) success rate was 0.76 (±0.14), and the mean brood size was 2.94 (±0.29), resulting in an overall productivity of 2.26 (±0.49). Following the socio-economic changes in Hungary in the 1990s, the breeding population of Saker Falcons shifted its range from the mountains to the lowlands. This shift was driven by decreased persecution of raptors, habitat changes and the subsequent decline in the availability of key prey species in the foothills. Between 1986 and 2015, 24,882 identifiable prey items of Saker Falcons were recorded, belonging to 164 different taxa. Diet analysis revealed that four species played a particularly significant role in the diet of Saker Falcons in Hungary: Feral Pigeon *(Columba livia* f. *domestica)*, European Ground Squirrel *(Spermophilus citellus)*, Common Starling *(Sturnus vulgaris)*, and Common Vole *(Microtus arvalis)*. Although Columbiformes remained the most common prey group, their abundance did not show a significant trend. In contrast, the proportion of Passeriformes increased significantly. A more pronounced change was observed among mammals in the diet. The previously common European Ground Squirrel declined dramatically, while the proportion of other Rodentia and Lagomorpha species increased significantly. The growth of the Hungarian Saker Falcon population halted after 2010. However, a slight increase has been observed in recent years (2018–2024), raising the hope that a gradual recovery may still be possible in the coming decades.

Keywords: endangered species, raptor, monitoring, conservation, prey composition

Összefoglalás A kerecsensólyom *(Falco cherrug)* egy globálisan veszélyeztetett madárfaj, és Magyarország ad otthont Európa második legnagyobb nemzeti állományának. Az állomány történelmi mélypontját valószínűleg az 1970-es évekre érte el, amikor a becslések szerint mindössze 15–30 pár élt az ország területén. Az intenzív állományfelmérési és természetvédelmi erőfeszítések 1980-ban kezdődtek a Magyar Madártani és Természetvédelmi Egyesület, valamint a nemzeti park igazgatóságok együttműködésével. Jelen tanulmányban a magyarországi kerecsensólyom-populáció helyzetét mutatjuk be 1980 és 2024 között. Az elterjedési terület terjedésével párhuzamosan a populáció mérete is növekedett, és az ismert territóriumok száma évente átlagosan 8%-kal emelkedett. Az ismert populáció történelmi csúcsát 2024-ben érte el, amikor 200 territóriumot fedeztünk fel, és 177 sikeres pár összesen

530 fiókát nevelt fel. Összesen 4429 költési próbálkozást követtünk nyomon Magyarországon a 45 év alatt, amelyek közül 3467 sikeres költés során 10319 fiókát regisztráltunk. A populáció költési sikerességi mutatói általában stabilak maradtak, kisebb ingadozásokkal. Az éves átlagos (±SD) sikerességi arány 0,76 (±0.14), míg az átlagos fészekaljméret 2,94 (±0.29) volt, ami összességében 2,26 (±0.49) produktivitást eredményezett. Az 1990-es években bekövetkezett társadalmi-gazdasági változásokat követően a kerecsensólymok költőállománya a hegyvidékekről az alföldi területekre helyeződött át. Ezt az elmozdulást a ragadozómadarak üldözésének csökkenése, az élőhely-változások, valamint a hegylábi területeken a kulcsfontosságú zsákmányfajok elérhetőségének visszaesése idézte elő. 1986 és 2015 között összesen 24882 zsákmányállatot sikerült azonosítani, amelyek 164 különböző taxonba tartoztak. A táplálkozási vizsgálatok eredményei alapján négy faj kiemelkedő szerepet játszott a kerecsensólymok étrendjében Magyarországon: a házigalamb *(Columba livia* f. *domestica)*, az ürge *(Spermophilus citellus)*, a seregély *(Sturnus vulgaris)* és a mezei pocok *(Microtus arvalis)*. A leggyakoribb zsákmánycsoportot alkotó galambfélék állománya nem mutatott jelentős változást, azonban az énekesmadarak aránya szignifikánsan növekedett. Még jelentősebb változás volt megfigyelhető az emlősök között, ahol az egykor gyakori ürgeállomány drámaian visszaesett, miközben más rágcsálók és nyúlalakúak aránya növekedett. A magyarországi kerecsensólyom-populáció növekedése 2010 után megállt, de az utóbbi években (2018–2024) ismét enyhe növekedésnek indult, ami reményre ad okot, hogy a következő évtized(ek)ben a populáció még további lassú erősödése lehetséges.

Kulcsszavak: veszélyeztetett faj, ragadozómadár, monitoring, természetvédelem, zsákmányösszetétel

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Introduction

The Saker Falcon *(Falco cherrug)* (hereinafter 'Saker') is a globally threatened bird species, of which Hungary hosts the second-largest population in Europe (BirdLife International 2021). The breeding pairs in Hungary form a common population within the Pannonian ecoregion, along with pairs in Austria (Zink *et al*. 2025), the Czech Republic (Škorpíková *et al.* 2025), Slovakia (Chavko *et al*. 2025), western Romania (Prommer *et al.* 2025), and Serbia (Puzović 2025).

The Saker is the national bird of Hungary and is widely considered the most probable origin of the "Turul," the mythical bird in Hungarian legends (Bagyura 2022). Probably, it was a relatively rare but regular breeding species in Hungary at the end of the 19th and the beginning of the 20th century. However, very few precise data are available from this early period. Based on the limited historical records (including published observations, hunting statistics, and falconry archives), it is estimated that the national population may have reached 300–400 pairs at the beginning of the 20th century (Bagyura *et al.* 2019b). However, the widespread persecution of raptors and carnivores, particularly through poisoning and shooting during the first half of the 20th century, led to the near disappearance of the Saker from the lowland open habitats of Hungary.

The first national survey of rare raptor species was conducted in Hungary by the Forestry and Hunting Authorities in 1949 and 1950. This extensive survey documented 28 nesting pairs of Sakers, almost exclusively in the mountainous and forested northern regions of the country (Pátkai 1954). These findings contributed to the strict legal protection of most falcon and eagle species in Hungary in 1954. However, no further national surveys were undertaken until the 1980s. The widespread use of DDT during the 1950s and 1960s likely had additional negative effects on raptor populations in Hungary, as was observed in many other regions worldwide (Peakall & Kiff 1979).

The population most likely reached its historical minimum by the 1970s, with an estimated number of 15–30 breeding pairs (Bagyura *et al.* 2022). Intensive monitoring and conservation efforts began in 1980 through the collaboration of MME BirdLife Hungary and national park directorates (Haraszthy & Bagyura 1993). This comprehensive conservation programme included nest guarding (Bagyura *et al.* 1994a), the installation of artificial nests on trees and high-voltage pylons (Fidlóczky *et al.* 2014), the reintroduction of European Ground Squirrels *(Spermophilus citellus)* (Szitta *et al.* 2021), the retrofitting of medium-voltage electric poles (Demeter *et al.* 2018), and anti-poisoning measures (Deák *et al.* 2021). The annual results of national Saker monitoring between 2004 and 2022 were published in population status reports (Bagyura *et al.* 2006, 2007, 2008a, 2009, 2010a, 2010b, 2012a, 2014, 2015a, 2015b, 2016, 2017, 2018, 2019a, 2023). In addition, various aspects of conservation efforts, population trends, and breeding biology have been documented (Bagyura *et al.* 1994a, 2004a, 2008b, 2012b, 2019b, 2022, Fidlóczky *et al.* 2014), alongside preliminary data on diet composition (Bagyura *et al.* 1994b, 2004b). However, these reports and periodical summaries were presented in different formats and used slightly varied definitions for breeding parameters, complicating direct comparisons and dataset integration.

In this paper, we harmonise a unique 45-year database to provide a comprehensive analysis of the Hungarian Saker population. Based on this dataset, we examine the development and geographical distribution of the population, as well as its diet composition. By applying standardised definitions, we present the long-term natural history of the Saker population in Hungary from 1980 to 2024.

Material and Methods

Population size and breeding performance

Over the last five decades, the methodology of the national Saker monitoring and conservation programme in Hungary has continuously improved (Bagyura *et al.* 2022). However, its primary aim has remained unchanged: to locate as many territorial pairs as possible and determine various parameters of their breeding performance.

In the beginning of the surveys in the early 1980s, monitoring the species required significant effort due to the low density of breeding pairs, the limited number of active raptor experts, the lack of reliable information, and the potential presence of Sakers across most of Hungary (~93,000 km^2). The initial surveys were based on published records (1890–1979) and anecdotal information (1945–1979) from ornithologists, falconers, hunters and foresters regarding known nesting sites and the potential distribution of the species. Intensive field surveys conducted between 1980 and 1984 likely identified most of the nesting pairs within the country. As the population expanded, the geographical coverage and intensity of population surveys also increased. Since the early 2000s, when the distribution area reached its present extent, the number of regular data providers within the *Saker Falcon Working Group* of MME and the national park directorates has exceeded 100 people annually.

Active territories were typically visited between three and six times to collect data, preferably from each breeding stage. The data analysis focused on three main breeding parameters, which were available for the entire study period: the *number of territorial pairs (TP)*, the *number of successful pairs (SP)*, and the *number of fledglings (NF)*. The exact field protocol, methodology, and definitions used for Saker population monitoring in Hungary are described in Bagyura *et al.* (2025), therefore, they are not detailed here.

TP were usually surveyed between mid-March and early April by investigating all previously known and potential nesting sites by traditional field surveys (i.e. by 4×4 cars, binoculars and field scopes), with a special emphasis on the surroundings of artificial nests and large stick nests. *SP* and *NF* were surveyed between mid-May and early June, in the frame of ringing activities (i.e. by climbing to the active nests), drone surveys (2020–2024) or by distant (500–1,000 m) observations with field scopes. Beside these two crucial surveys, an additional 1–4 surveys were also undertaken between February and July to collect more precise information on breeding performance, adult birds and potential threats, depending on the local capacity of observers. If no precise nest survey was undertaken to determine the number of large nestlings or fledglings (nestlings older than ca. 27 days), than *NF* was estimated by using the latest number of observed alive nestlings, or indirectly by extracting the detected number of dead large nestlings from the number of middle-aged nestlings (the later were surveyed usually for all detected breeding attempts). Similarly, in such cases *SP* was estimated by extracting the detected number of late breeding failures (i.e. mortality of the total brood of large nestlings) from rearing pairs (Bagyura *et al.* 2025).

Territorial pairs were defined as unsuccessful if: (1) they did not start breeding (i.e. did not lay eggs and started the incubation); (2) the breeding attempt failed during incubation (mortality of all laid eggs); or (3) the breeding attempt failed during rearing (mortality of the total brood of nestlings).

According to Bagyura *et al.* (2025), we used the following three parameters to assess breeding performance for long-term population monitoring: (1) *success rate* (*SP/TP*); (2) *brood size* (*NF/SP*); and (3) *productivity* (*NF/TP*).

Despite the maximised field effort of the Working Group, the dataset may be subject to slight biases due to the following scenarios:

- territorial pairs remained undetected by the national Working Group, leading to an underestimation of *TP*, *SP*, and *NF*;
- successful breeding attempts of known territorial pairs were missed due to changes in nesting sites or the absence of proper nest surveys later in the breeding season, resulting in an underestimation of *SP* and *NF*;
- the number of chicks was underestimated when assessed through distant observations, particularly when nests were not climbed for nestling ringing or inspected by drone, leading to an underestimation of *NF*;
- late nestling mortality or breeding failure went undetected if no precise nest survey was conducted to determine the number of large nestlings, potentially leading to an overestimation of *SP* and *NF*.

To assess the potential bias in the dataset, an expert opinion poll was conducted between March and October 2023, involving most of the experienced members of the *Saker Falcon Working Group* – i.e. those who had played a significant role in field surveys and data management over the past decades. The results of the poll indicated that the majority (93%) of experts estimated that 76–100% of the national breeding population (i.e. *TP*) of Sakers had been located and monitored annually in Hungary over the past decades (n=42). Similarly, 83% of experts estimated that breeding success (i.e. *SP* and *NF*) had been accurately surveyed for 76–100% of the national breeding population. Most of the remaining experts (5% and 17%, respectively) estimated survey coverage at 51–75%, while only a single person (2%) estimated that the national coverage for *TP* could be 50% or lower for some years.

In large-scale and long-term field surveys, it is important to acknowledge that such studies can rarely, if ever, achieve 100% coverage of the entire studied population. In case of the Saker population in Hungary, expert opinion suggests that annual monitoring effort likely covered more than 75% of the estimated population in all years after 1985. This level of coverage enabled accurate monitoring of long-term changes in breeding distribution, population trends, and breeding success. Nevertheless, it should be noted that during the first five years of the study (1980–1984), when the monitoring methodology was first developed and the network of experienced observers was established, surveys may have missed as much as 25–50% of the population.

Monitoring the diet composition

Prey remains found in or beneath active nest sites were collected during nest surveys, typically once or twice per year between 1986 and 2015. Sporadic data gathered outside this period were excluded from the present analysis due to their low annual sample size. The most comprehensive surveys were conducted in mid-May, when most known nesting sites in Hungary were visited, and many were climbed to ring the nestlings. Therefore, the presented data primarily represents the diet of rearing Sakers within the breeding season, while it cannot be applied for the non-breeding period or non-breeding specimens.

For the collection, identification, and management of prey remains, we followed the protocol detailed in Horváth *et al.* (2018). Prey remains found around a nest site were collected in the field, and items that could be unambiguously identified on-site were recorded on field datasheets. To minimise bias from indirect sampling, the following types of remains were excluded from the dataset, even if found beneath nest sites: (1) single feathers, which may have been shed by live birds; (2) full carcasses of large animals that could not have been physically transported by the falcons; and (3) old or deteriorated samples that may have originated from previous years.

Fresh prey items that still contained edible parts for the chicks were photographed but not removed from the nests. Food remains containing a significant amount of soft tissue and/or those that could be unambiguously identified in the field were left in place to prevent contamination and putrefaction before analysis. Pellets, bones, feathers, hairs, and dried skins of prey animals were collected and stored in plastic bags with ID labels until further analysis.

The collected samples were identified by comparison with museum reference materials, typically within one year of collection. Remains from the same nest site and year were categorised by species, sex (for species with clear sexual dimorphism), body size, and body part. A remain was classified as a separate prey specimen if it: (1) belonged to a different species or sex; (2) had a clearly different body size from the already listed specimens; or (3) included the same body part as another remain.

The same minimum estimation methodology was applied when merging field data (including both datasheets and photographs) with laboratory data. Consequently, in some cases, remains from different prey specimens may have been grouped as one, but the risk of multiple counting of the same specimen was eliminated.

Camera traps were introduced as an alternative method for collecting data on the diet composition of Sakers in 2011 and became the primary method from 2016 onwards (Bagyura *et al.* 2025). Due to the fundamentally different methodology, which could bias comparisons between annual datasets, data obtained from camera traps were not included in the present analysis.

Visualization and trend analyses

Distribution maps of Saker breeding pairs and collected prey items was elaborated in QGIS 3.16.8. To analyse long-term trends in the population size, breeding performance, and diet composition of the Saker in Hungary, linear regression models were applied. The models were constructed to assess changes in key demographic parameters, as well as shifts in diet composition over the study period. Each parameter was regressed against time (year) using the ordinary least squares (OLS) method to determine the direction and rate of change. The coefficient of determination (R^2) was calculated for each model to quantify the proportion of variance explained by the linear trend. All statistical analyses were performed using Microsoft Excel (Microsoft Office Professional Plus 2016), ensuring consistency in data handling and visualization. The regression analyses assumed a linear relationship between the variables and time, with model fit assessed through R^2 values. While linear regression provided a general representation of trends, additional exploratory analyses were conducted to evaluate potential deviations from linearity.

Results

Population trend

The population grew significantly over the 45-year study period, with *TP* increasing by approximately 8% on average per year *(Figure 1a)*. The known population size reached its historical maximum in 2024, with 200 territorial pairs recorded, of which 177 successfully bred, producing 530 fledglings.

The long-term trends in the population parameters and diet composition of the Saker in Hungary were analysed using a linear regression model *(Figure 1a)*. The linear regression equations derived for key population parameters demonstrated a strong positive trend,

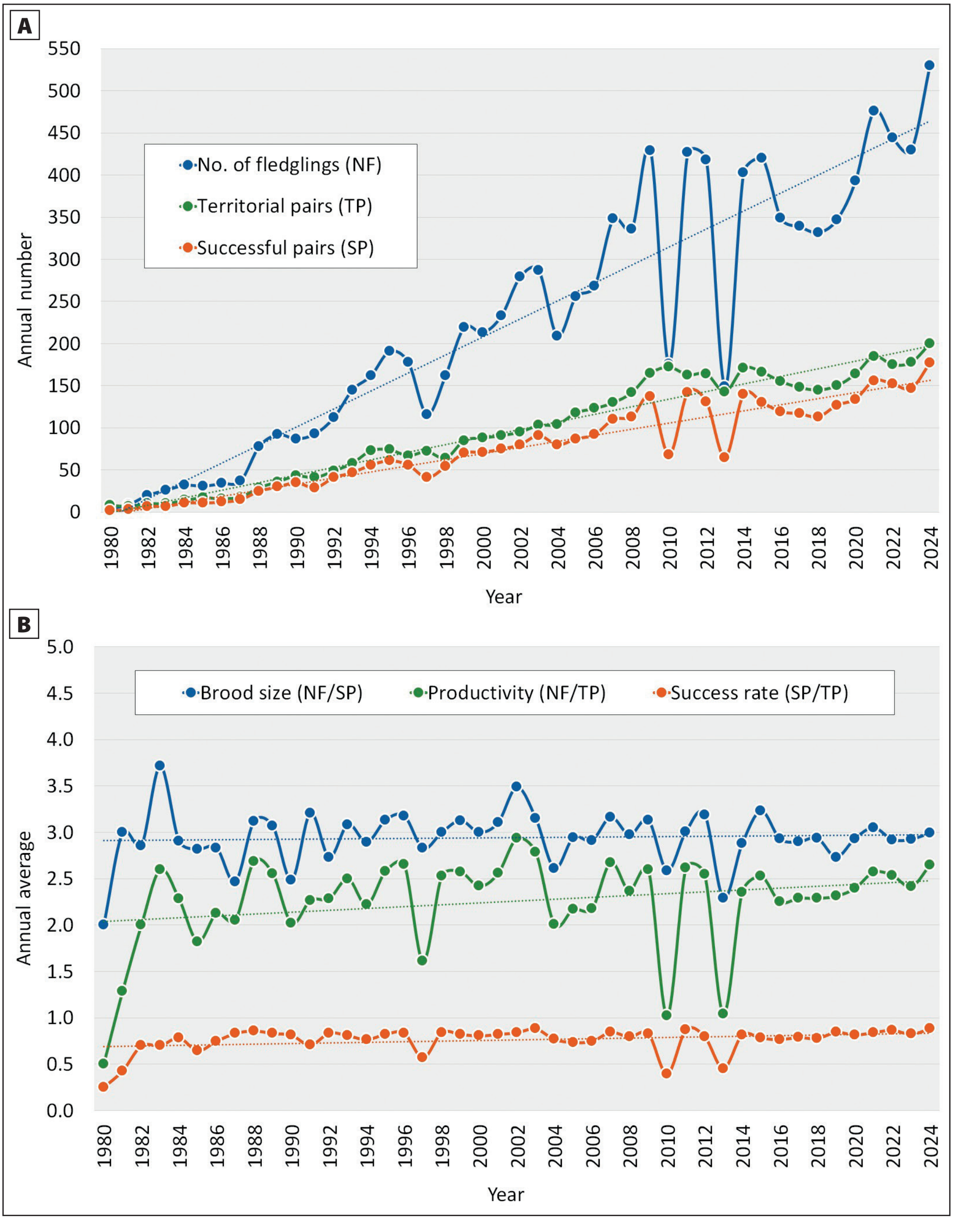


Figure 1. Trends in the demographic parameters of the Saker Falcon population in Hungary from 1980 to 2024. (a) Population size and number of fledglings, (b) Breeding performance parameters, Dotted lines: linear regression

1. ábra A kerecsensólyom költő populáció alakulása Magyarországon 1980 és 2024 között. (a) Költő populáció mérete. Kék: kirepült fiókák száma (NF); Zöld: territoriális párok száma (TP); Piros: sikeres párok száma (SP). (b) Költési siker paraméterek: Kék: fészekaljméret (NF/SP); Zöld: produktivitás (NF/TP); Piros: sikerességi arány (SP/TP). Pöttyözött egyenesek: lineáris regresszió with *TP* increasing at an annual rate of ca. 4.50 pairs (y=4.502x–5.123; R^2=0.951), *SP* at 3.65 pairs per year (y=3.653x–6.337; R^2=0.909), and *NF* at 10.69 fledglings per year (y=10.691x–16.574; R^2=0.863). These high R^2 values indicate that the linear models effectively capture the overall trend in population growth. However, it is important to note that while the R^2 statistic quantifies the proportion of variation explained by the model, it does not validate the appropriateness of the linear assumption itself. Given the fluctuations observed in the population trend – such as the plateau between 2010 and 2018 and subsequent resurgence from 2018 to 2024 – the model provides a useful but simplified representation of the broader trend rather than an exact predictive tool.

Breeding performance

A total of 4,429 breeding attempts were monitored in Hungary over the 45-year study period, of which 3,467 were successful, resulting in 10,319 recorded nestlings. The breeding performance parameters of the population exhibited a generally stable trend with slight fluctuations throughout the study period *(Figure 1b)*. Neither productivity (*NF/TP*; n=45; y=0.010x+2.029; R^2=0.072), brood size (*NF/SP*; n=45; y=0.001x+2.912; R^2=0.004), nor success rate (*SP/TP*; n=45; y=0.003x+0.685; R^2=0.102) showed any clear trend.

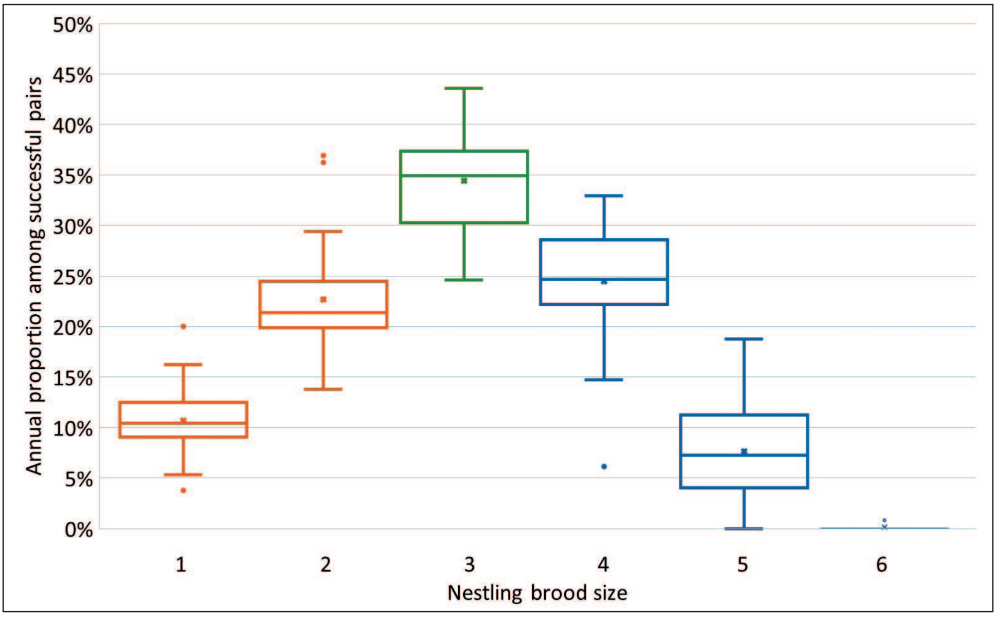


Figure 2. Distribution of nestling brood size among successful Saker Falcon breeding attempts in Hungary based on their annual proportions between 2001 and 2024 (n=24). Colours indicate if breeding performance was below (red), at (green) or above (blue) the most common (three-nestling) brood size

2. ábra Fiókás fészekalj-méret eloszlása a sikeres kerecsensólyom költések esetében Magyarországon az éves arányaik alapján 2001 és 2024 között (n=24). A színek azt mutatják, hogy a költések sikeressége a leggyakoribb (háromfiókás) fészekaljméret alatt (piros), azzal megegyező (zöld) vagy afeletti (kék) volt

The annual average (±SD) success rate was 0.76 (±0.14), and the average brood size was 2.94 (±0.29), resulting in an overall productivity of 2.26 (±0.49) (n=45). Productivity was low during the first two years of the study, when sample sizes were small, and monitoring activities were still being developed. In later years, when the population was much larger and well monitored, exceptionally low productivity was recorded in three specific years (1997, 2010, and 2013), when extreme spring weather conditions caused widespread breeding failure.

The distribution of nestling brood size was investigated for 2,783 successful breeding attempts between 2001 and 2024 based on their annual proportions *(Figure 2)*. Three-nestling broods were the most common (34.44±5.20%), followed by four-nestling (24.50±6.10%), two-nestling (22.69±5.77%), one-nestling (10.70±3.36%), and five-nestling broods (7.60±4.58%) (n=24). A natural six-nestling brood was recorded only once (in 2015), while in another instance (in 2008), an artificially raised chick was successfully adopted as a sixth nestling in a naturally occurring five-nestling brood.

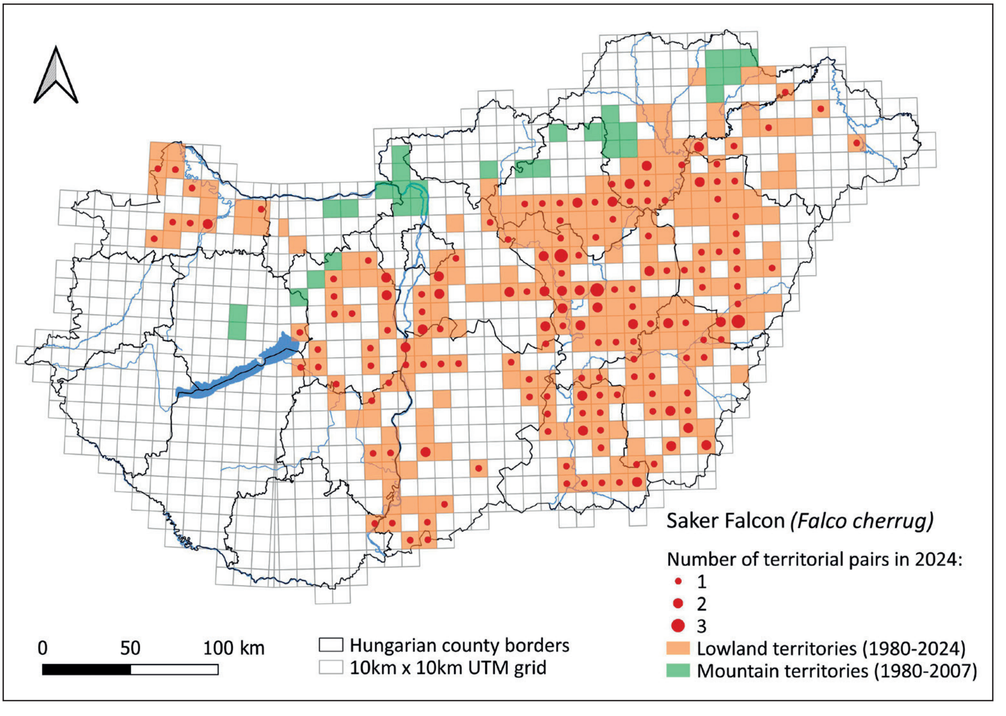


Figure 3. Breeding distribution of the Saker Falcon in Hungary from 1980 to 2024 and the number of surveyed territorial pairs in 2024

3. ábra A kerecsensólyom elterjedési területe Magyarországon 1980 és 2024 között, valamint a felmért territóriumok száma 2024-ben. Piros körök: territoriális párok száma 2024-ben; Narancs négyzetek: síkvidéki territóriumok (1980–2024); Zöld négyzetek: hegyvidéki territóriumok (1980–2007)

Distribution area

In the 1980s, the distribution of Sakers was primarily restricted to medium-elevation mountains (300–800 m a.s.l.) in the northern part of Hungary *(Figure 3)*. However, a few (<5) pairs also nested sporadically in lowland habitats, mainly along the Danube and Tisza rivers.

Sakers naturally bred primarily on cliffs, using ledges, cavities, or nests of Common Ravens *(Corvus corax)*. They also occupied abandoned tree nests of raptors, including Northern Goshawk *(Accipiter gentilis)*, Eastern Imperial Eagle *(Aquila heliaca)*, Golden Eagle *(Aquila chrysaetos)*, Common Buzzard *(Buteo buteo)*, Long-legged Buzzard *(Buteo rufinus)*, White-tailed Eagle *(Haliaeetus albicilla)*, and European Honey Buzzard *(Pernis apivorus)*, as well as nests built by corvids such as Raven and Hooded Crow *(Corvus cornix)*. In rarer cases, they nested in the abandoned nests of Great Cormorants *(Phalacrocorax carbo)* and White Storks *(Ciconia ciconia)* (Bagyura *et al*. 2022).

The population began expanding southward and northwestward towards open lowland habitats during the 1990s and 2000s. In these areas, Sakers initially occupied natural tree nests built by the aforementioned species, but later, most of the population preferred the meanwhile constructed artificial nests on trees and high-voltage transmission pylons (see notes in the Discussion). By the 2010s, the distribution range of Sakers had expanded across most of the Hungarian Plain, reaching the Serbian and Romanian borders in the east and south, and Austria in the northwest. Meanwhile, the Hungarian mountain population began to decline and had completely disappeared by 2007, when the last recorded breeding attempt was observed in the Gerecse Mountains (Bagyura *et al.* 2022).

Diet composition

A total of 24,882 prey items of Sakers were identified between 1986 and 2015. Of these, the year of collection was known for 24,776 items (99.57%), while the location (settlement) was recorded for 21,264 samples (85.46%). The missing data were primarily due to the deterioration of ID labels. The identified prey items belonged to 164 different taxa, including 124 species and an additional 40 taxa where identification was limited to a higher taxonomic level: Genus (22), Family (8), Order (7), or Class (3). The complete list of identified species and taxa is provided in *Appendix 1*.

The annual number of collected and identified prey items varied throughout the study period, however, in most years, it ranged between 200 and 2,000 *(Figure 4)*. This dataset was therefore suitable for detecting long-term trends among the most common taxa. Prey items were collected from 169 settlements, and their geographical distribution closely reflected the distribution of Sakers in Hungary *(Figure 5).*

The relative frequency of the most common taxa among the collected and identified prey items is presented in *Figure 6*. The Feral Pigeon *(Columba livia* f. *domestica)* accounted for 53.63% of all identified prey items. However, it is important to note that this species has significantly higher detectability than smaller prey species (e.g. rodents and Passeriformes). Consequently, its relative frequency among identified items is likely to be significantly overestimated compared to its actual proportion in the diet (see notes in the Discussion).

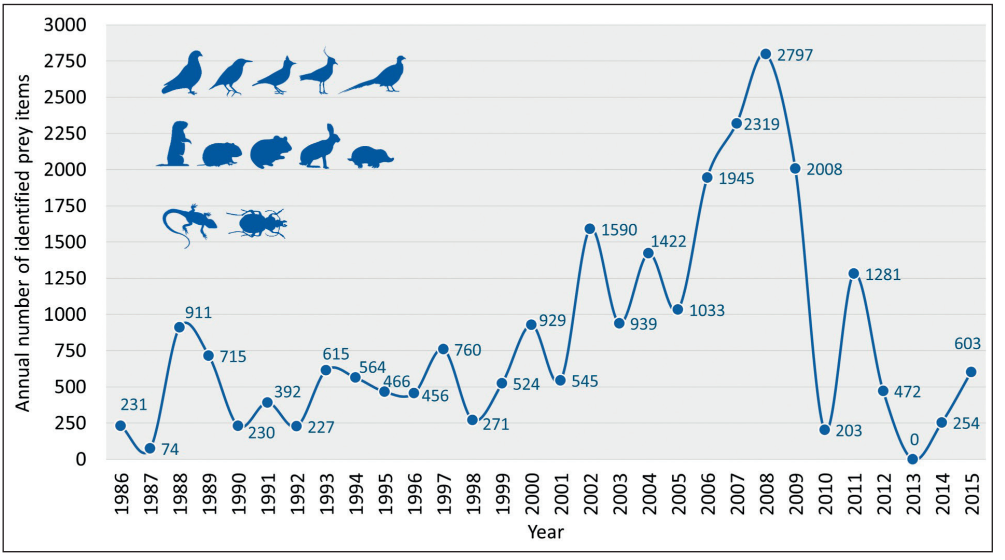


Figure 4. Number of collected and identified prey items of Saker Falcons in Hungary from 1986 to 2015 (n=24,776)

4. ábra Évente begyűjtött és meghatározásra került kerecsensólyom zsákmányállatok száma Magyarországon 1986 és 2015 között (n=24776)

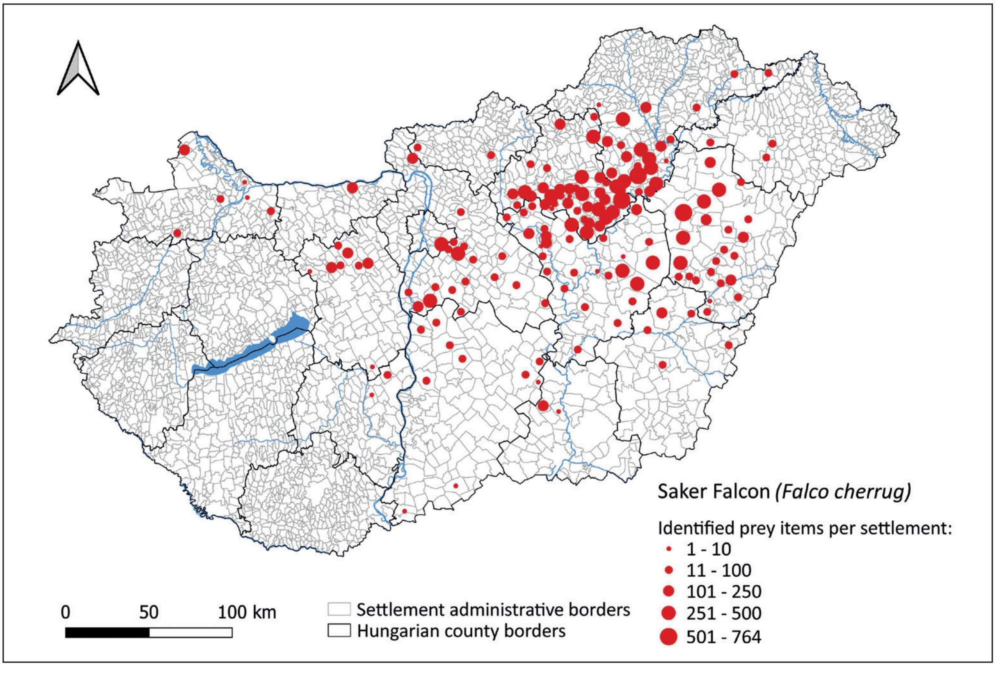


Figure 5. Geographical distribution of collected and identified prey items of Saker Falcons by the administrative borders of settlements in Hungary from 1986 to 2015 (n=21,264)

5. ábra Begyűjtött és meghatározásra került kerecsensólyom zsákmányállatok térbeli eloszlása településhatáronként Magyarországon 1986 és 2015 között (n=21264)

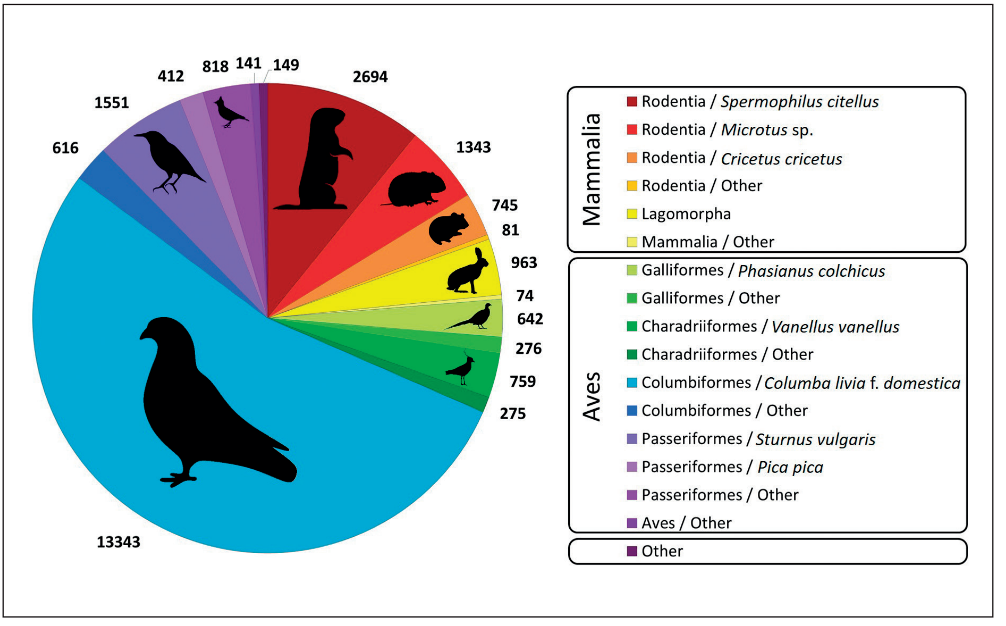


Figure 6. Distribution of the most common taxa among the collected and identified prey items of Saker Falcons in Hungary from 1986 to 2015 (n=24,882). The proportion of different taxa found among prey remains may significantly differ from their actual proportion among prey items delivered to the nest (see text)

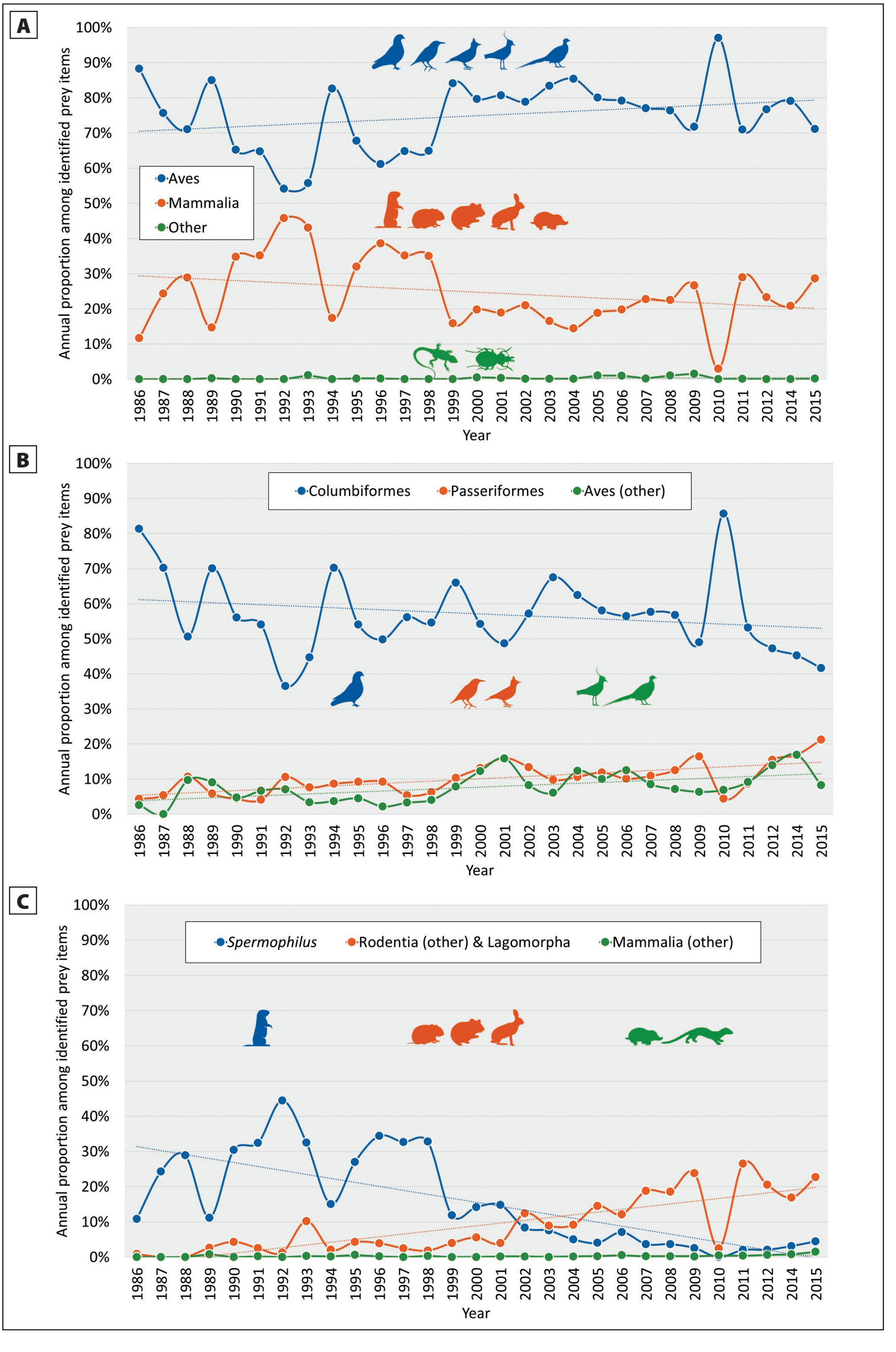
6. ábra Begyűjtött és meghatározásra került kerecsensólyom zsákmányállatok eloszlása a leggyakoribb taxonok között Magyarországon 1986 és 2015 között (n=24882). Az egyes taxonok maradványokból kimutatott gyakorisága jelentősen eltérhet a fészekbe hordott zsákmányok valódi arányától (ld. szöveg)

Three additional species exceeded 5% of the identified prey items: the European Ground Squirrel (10.83%), the Common Starling *(Sturnus vulgaris)* (6.23%), and the Common Vole *(Microtus arvalis)* (5.25%). Additionally, five further species accounted for more than 1% of the identified prey items: the Brown Hare *(Lepus europaeus)* (3.87%), the Northern Lapwing *(Vanellus vanellus)* (3.05%), the Common Hamster *(Cricetus cricetus)* (2.99%), the Common Pheasant *(Phasianus colchicus)* (2.58%), and the Eurasian Magpie *(Pica pica)* (1.66%).

The annual proportion of the most common taxa among the collected and identified prey items of Sakers is shown in *Figure 7*. The overall proportion of birds (n=30; y=0.003x+0.702; R^2=0.075), mammals (n=30; y=-0.003x+0.297; R^2=0.082), and other species (n=30; y=0.000x+0.001; R^2=0.067) did not show clear trends *(Figure 7a)*.

Columbiformes also did not exhibited any clear trend (n=30; y=-0.003x+0.615; R^2=0.050). However, the proportion of Passeriformes increased (n=30; y=0.003x+0.051; R^2=0.438), while a slight increase was observed among other non-Passeriformes (n=30; y=0.003x+0.036; R^2=0.313) *(Figure 7b)*.

A more pronounced change was detected among mammal species. The initially common European Ground Squirrel showed a dramatic decline (n=30; y=-0.011x+0.325; R^2=0.539),


A
Annual proportion among identified prey items
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Aves
Mammalia
Other
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2014 2015
Year
B
Annual proportion among identified prey items
Columbiformes
Passeriformes
Aves (other)
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Year
C
Annual proportion among identified prey items
Spermophilus
Rodentia (other) & Lagomorpha
Mammalia (other)
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2014 2015
Year

Figure 7. Proportion of the most common taxa among the collected and identified prey items of Saker Falcons in Hungary from 1986 to 2015 (n=24,765): (a) proportion of bird (Aves) and mammal (Mammalia) species; (b) proportion of the most common mammal taxa; (c) proportion of the most common bird taxa. The proportion of different taxa found among prey remains may significantly differ from their actual proportion among prey items delivered to the nest (see text for details). Dotted lines: linear regression

7. ábra Begyűjtött és meghatározásra került kerecsensólyom zsákmányállatok arányának éves alakulása a leggyakoribb taxonok között Magyarországon 1986 és 2015 között (n=24765): (a) madarak (Aves) és emlősök (Mammalia) aránya; (b) leggyakoribb emlős taxonok aránya; (c) leggyakoribb madár taxonok aránya. Az egyes taxonok maradványokból kimutatott gyakorisága jelentősen eltérhet a zsákmányolás valódi arányától (ld. szöveg). Pöttyözött egyenesek: lineáris regresszió

whereas the proportion of other Rodentia and Lagomorpha species increased (n=30; y=0.008x–0.028; R^2=0.668). The proportion of other mammal species within the diet remained low and showed no significant change (n=30; y=0.000x+0.000; R^2=0.249) *(Figure 7c)*.

Discussion

The well-known collapse of Peregrine Falcon *(Falco peregrinus)* populations across the Northern Hemisphere by the 1960s (Cade *et al.* 1968, Newton 1979, 2017), along with the significant decline of other raptor populations, prompted governments and non-governmental organisations worldwide to initiate conservation programmes focused on raptors. Hungary was no exception. As the largest westernmost European outpost of eastern steppe habitats, species associated with these habitats received special attention. The Saker Falcon, Red-footed Falcon *(Falco vespertinus)*, and Eastern Imperial Eagle have served as flagship species for nature conservation in Hungary since then. Several decades of targeted conservation efforts, carried out through the collaboration of governmental, non-governmental, and for-profit organisations, as well as private individuals, have led to tangible results for raptor populations in Hungary.

In the case of the Saker, the official ban on DDT, introduced in Hungary in 1968 (the first such ban in the world) (Bagyura *et al.* 2004a, Fidlóczky *et al.* 2014, Bagyura *et al.* 2019b), followed by comprehensive conservation efforts – including nest guarding, the installation of artificial nests, insulation of mid-voltage power line poles, and combating raptor persecution – has contributed to the remarkable recovery of the population over the past 45 years. In addition, a standardised monitoring methodology was established, along with a well-organised network of more than 100 field experts and ornithologists, enabling the effective monitoring of population size and breeding success (Bagyura *et al.* 2025). These efforts have likely resulted in the most comprehensive long-term dataset on the species globally, encompassing data on more than 4,000 breeding attempts and 10,000 nestlings.

The lowest point of the Saker population in Hungary occurred in the 1980s when the species was on the brink of extinction. In the first year of the study only four nestlings were detected from eight known nesting pairs, with an estimated total population of no more than 15–30 pairs. After more than four decades of dedicated conservation efforts, the population reached 200 nesting pairs in 2024, producing over 500 nestlings, making it one of the largest national populations in Europe. As of 2012, the only larger population on the continent was in Ukraine, estimated at 285–312 pairs. However, as this population has not been systematically monitored, it may have declined significantly over the past decade, similarly to the nearest Russian populations (Prommer *et al.* 2025). Consequently, the conservation of the Saker population in Hungary is of critical importance for the species' preservation in Europe. The central role of the Hungarian population is further supported by population trends in neighbouring countries. Before the 2000s, breeding Sakers were either absent or recorded only sporadically in most neighbouring countries, with the exception of Slovakia. By 2024, however, Austria, western Romania, Serbia, and Slovakia had established considerable populations (Chavko *et al.* 2025, Prommer *et al.* 2025, Pužović 2025, Zink *et al.* 2025), likely influenced by the growth and expansion of the Hungarian population.

The demographic parameters of the Hungarian pairs were generally stable and similar to other parts of the Pannonian population in the neighbouring countries (Chavko *et al.* 2025, Prommer *et al.* 2025, Puzović 2025, Škorpíková *et al.* 2025, Zink *et al.* 2025), which indicates that there are probably no significant recent problems in nesting or foraging possibilities for the species. There were three breeding seasons in which the proportion of successful breeding pairs, and consequently the number of fledglings, was considerably lower than average. In each case, the poor breeding outcomes could be attributed to an unusually wet and cold spring and could also contribute to the halt of the population increase between 2010 and 2018. However, mean brood size in Hungary was lower than in Mongolia, which may not be independent from the higher proportion of mammals in the diet of the Mongolian Saker population (Zhang *et al.* 2024).

The Saker inhabits open areas, which are essential for hunting. However, this does not mean that the species is restricted solely to lowland habitats, as observed in Hungary today. For example, in Central Asia, Sakers also breed at high elevations (>3,000 m a.s.l.) in mountain ranges such as the Altai-Sayan region and the Tibetan-Qinghai Plateau. Although the species is absent from the alpine regions of Europe (e.g. the Alps and the Carpathians), and satellite-tracked individuals have consistently avoided high mountains (Prommer *et al.* 2012), historical records indicate that Sakers bred in lower mountain ranges and plateaus, provided that suitable open habitats and a stable prey base were present.

The breeding distribution of the Saker in Hungary has shifted dramatically over the past 45 years. As the population expanded, breeding pairs moved from mountainous and hilly areas to the lowlands. They first occupied foothills before spreading further, while mountain populations gradually disappeared, culminating in the last (failed) breeding attempt in 2007 (Bagyura *et al.* 2022), interestingly in the same year when the last mountain breeding pair bred in western Slovakia (Chavko 2010).

This range shift was driven by political and economic changes following the collapse of communism. The transition reshaped agriculture, making traditional free-ranging grazing unviable (Biro *et al.* 2013). As pastures – critical habitats for the European Ground Squirrel, the Saker's primary mammalian prey – were abandoned, scrub encroachment and afforestation followed, particularly in mountainous regions where no alternative prey base was available.

This marked the culmination of a 150-year-long process, during which Hungary's grassland area – within its current borders – shrank from over 2.5 million hectares to approximately 800,000 hectares. The decline accelerated between 1985 and 2000, with an annual loss rate of 1.13% (Biró *et al.* 2011). Although national park directorates later reintroduced grazing, European Ground Squirrel populations did not recover. Meanwhile, cliffs abandoned by Sakers were recolonised by the recovering Peregrine Falcon (Prommer & Bagyura 2022), further limiting the chances of reoccupation due to potential interspecific competition.

In contrast, the lowlands offered abundant prey, and conservation efforts boosted corvid and raptor populations, providing ample nesting sites. A similar range shift was observed in Slovakia (Chavko *et al.* 2025). The significant decrease in the previously widespread persecution (poisoning and shooting) of predators and the ban of DDT were also essential factors, which enabled several raptor species to recolonise the Pannonian lowlands (Haraszthy & Bagyura 1993). Moreover, MME BirdLife Hungary and its partner organisations began installing artificial nests (stick nests and nest platforms) on trees in the late 1980s to facilitate the species' colonisation. This conservation measure proved highly effective, and artificial nests soon became more frequently used by the falcons than natural nests (Bagyura *et al.* 1994a).

Probably the most significant step in the colonisation process occurred in the late 1980s when Sakers began occupying natural stick nests built by corvids on high-voltage transmission pylons. However, as Sakers – like other falcon species – do not build or maintain nests, it was not uncommon for overused Corvid nests to deteriorate and eventually collapse, often resulting in the loss of eggs or nestlings. These incidents prompted MME BirdLife Hungary and national park directorates to collaborate with transmission and distribution system operators. As part of this effort, they developed a specialised nest box prototype and established an extensive network of more than 300 nest boxes along the high-voltage (120–700 kV) power grid between 1991 and 2010 (Fidlóczky *et al.* 2014, Bagyura *et al.* 2022). These nest boxes on pylons proved highly attractive to Sakers, and they had a fundamental importance in the recovery of the species, since the 2010s more than 80% of the national population has been breeding in them.

The shift of the breeding habitats also affected directly and indirectly the diet composition of Sakers. The results of the diet analysis indicated that four species played a dominant role in the diet of Sakers in Hungary during the study period: the Feral Pigeon, European Ground Squirrel, Common Starling, and Common Vole. The most striking finding from the trend analysis was the dramatic decline in the proportion of European Ground Squirrels within the diet, while the proportion of Rodentia (particularly the Common Vole), Lagomorpha (notably the Brown Hare), and Passeriformes (especially the Common Starling) increased significantly. A similar and concerning decline in European Ground Squirrels has also been observed in the diet of sympatric Eastern Imperial Eagles in Hungary (Horváth *et al.* 2018). These dietary shifts were primarily driven by two parallel and interrelated processes.

- *Decline of European Ground Squirrel colonies*: European Ground Squirrel populations in Hungary experienced a sharp decline between 1964 and 2012, affecting both foothill and open lowland habitats (Cserkész *et al.* 2025).

- *Regional variation in prey availability*: In contrast to the foothills and mountains, lowland habitats supported a greater abundance of alternative prey species, such as Brown Hares and Common Voles. Consequently, while the decline of Ground Squirrel colonies in mountainous regions was a key driver of the Saker's shift to lowland habitats, this habitat shift also resulted in significant changes to the population's diet.

Although the expanding distribution and stable productivity of Saker Falcons suggest that they have been able to compensate for the loss of Ground Squirrels in the short term by utilising alternative prey species, it remains unclear whether this dietary shift will have long-term consequences for population viability. The relationship between diet and demography is a potential subject for further investigation, especially given that a recent study demonstrated the impact of diet composition on the demographic parameters of Sakers (Zhang *et al.* 2024). A few other examples of potential future research topics:

- *Effects of fluctuating population dynamics of Common Voles on Sakers' productivity*: The population size of Common Voles fluctuates drastically in 3–5-year cycles, and their body mass (30–40 g) is significantly smaller than that of European Ground Squirrels (150–300 g). These differences influence their reliability and energetic value as a food source for predators, particularly during years of low vole abundance.
- *Possibility of secondary poisoning due to increased predation on Common Voles:* Farmers widely use pesticides in the lowlands to control vole populations, and their misuse (especially the illegal use of brodifacoum) is frequently causing secondary poisoning of raptors in Hungary (Deák *et al.* 2024), and a similar alarming trend of rodenticide poisoning has been reported for Sakers from Slovakia as well (J. Chavko *pers. comm.*).
- *Sakers' predation on young Brown Hares and potential persecution*: Increased predation on young Brown Hares may lead to greater persecution of raptors by game managers, as has been documented in the case of the Eastern Imperial Eagle (Kovács *et al.* 2016, Deák *et al.* 2018).
- *Increased avian prey and disease risk*: A rising proportion of avian prey in the diet may elevate the risk of infectious diseases, as avian pathogens are more easily transmitted to raptors than mammalian pathogens (van den Brand *et al.* 2015).

Although our diet analysis provides valuable insights into the prey base of Sakers in Hungary, it has certain limitations. The detectability of larger prey species (e.g. Feral Pigeon) *versus* smaller ones (e.g. Common Vole) differs significantly when using prey remains and/or pellets as a data source (Redpath *et al.* 2001, Sánchez *et al.* 2008). As a result, such studies tend to underestimate the proportion of smaller prey species relative to larger ones, leading to potential inaccuracies when comparing the relative proportions of different-sized prey taxa. Therefore, the frequency data presented should be interpreted with this limitation in mind.

Despite their limitations, large datasets remain highly effective in identifying the overall importance of key prey species within a region. Common prey species are consistently detected, whereas rare species appear only occasionally (Katzner *et al.* 2005, Bedrosian *et al.* 2017). Additionally, since the detectability of individual species or taxa does not change significantly over time, temporal trends in prey frequency can be considered reliable indicators of actual dietary shifts (Horváth *et al.* 2018).

In the case of Feral Pigeons, it is important to note that homing pigeon races coincide with the nestling period of Sakers. During this time, many pigeons are regularly present in addition to the resident pigeon and other prey populations that are available throughout the year (J. Bagyura *pers. comm.*). As a result, while Feral Pigeon remains provide a reliable estimate of their trend within the diet in the breeding season, these results should not be interpreted as representing the species' frequency in the annual diet. Moreover, e.g. Stock Doves *(Columba oenas)* are rarely reported from prey remains during the rearing period of Sakers, while they are frequently predated in wintertime, when the large flocks of wintering Stock Doves provide a significant prey source for falcons in the Pannonian lowlands (J. Chavko *pers. com.*).

Conservation implications

The growth of the Saker population in Hungary halted after 2010 and experienced a slight decline in some years. However, since 2018, the population has shown a modest increase again (2018–2024), raising hopes that further gradual population strengthening may still be possible in the coming decades. Nevertheless, the species remains highly dependent on direct conservation measures, including the installation and maintenance of artificial nests (Fidlóczky *et al.* 2014), the retrofitting of dangerous medium-voltage power line poles (Demeter *et al.* 2018), and efforts to mitigate raptor persecution (Deák *et al.* 2018).

Moreover, habitat loss due to urban expansion, infrastructure development, and the intensification of agriculture poses a significant threat to the entire ecosystem, including top predators of the Pannonian Plains. Therefore, the long-term future of the Saker depends not only on the continuation of direct conservation efforts but also on the capacity to advocate for the preservation and potential expansion of natural and semi-natural habitats within the agricultural landscape. Additionally, the transformation of agricultural policies to support biodiversity – both within and beyond protected areas – will be essential for maintaining a suitable prey base for Sakers and, consequently, ensuring the species' long-term survival.

Acknowledgements

We are grateful to all volunteers and professional staff of MME BirdLife Hungary, as well as the relevant Hungarian National Park Directorates (Bükk, Hortobágy, Körös-Maros, Kiskunság, Duna-Ipoly, Fertő-Hanság, Aggtelek, Duna-Dráva, and Balaton-felvidék), who have contributed to monitoring efforts and conservation activities over the past decades.

We extend our special thanks to MAVIR Zrt. (Hungarian Transmission System Operator) and the Hungarian Distribution System Operators (E.ON ELMŰ, E.ON ÉMÁSZ, E.ON DÉDÁSZ, OPUS TITÁSZ, and MVM DÉMÁSZ) for their cooperation in the installation and monitoring of artificial nest boxes on high-voltage transmission pylons.

We are especially grateful to Péter Agócs, István Balázs, Gábor Balogh, János Balogh, István Bártol, András Békefi, Attila Bereczky, István Béres, László Bence Besenyei, György Bíró, Sándor Boldogh, Péter Borbáth, Gábor Czifrák, László Csihar, Péter Csonka, Gábor

Deák, Iván Demeter, Miklós Dudás, Tibor Ézsöl, Imre Fatér, Gábor Firmánszky, Csaba Fitala, István Fodor, Balázs Forgách, Sándor Gróf, Béla Habarics, István Harangi, Krisztián Harmos, István Homoki Nagy, Róbert Horváth, Tibor Horváth, Zoltán Ilonczai, Tibor Juhász, György Kállay†, Béla Kalocsa, Zsolt Kalotás, Balázs Kármán, Róbert Kazi, Antal Klébert, András Kleszó, Zsolt Kosina, László Kotymán, László Kováts, László Kozma, Ferenc Kundráth, Miklós Lóránt, László Losonczi, Bertalan Majercsák, Pál Marik, Géza Molnár, Ákos Monoki, Attila Mórocz, Lajos Nagy, Péter Őze, Zoltán Petrovics, Csaba Pigniczki, Ádám Pongrácz, László Puskás, István Sándor, János Sasvári, Nándor Seres, József Serföző, Szabolcs Solt, István Staudinger, Fruzsina Szegedi, Antal Szél, Balázs Szelényi, Attila Szilágyi, Péter Szinai, László Tajti, Ádám Tamás, János Tar, Gábor Tihanyi, Imre Tóth, László Tóth, Péter Tóth, Hunor Attila Török, Miklós Váczi, Róbert Ványi†, András Vasas, Tibor Vince, Levente Viszló, Tamás Zalai, Attila Zelenák.

The conservation actions and population monitoring efforts were significantly supported by four consecutive LIFE projects, funded by the European Commission and the Hungarian Government: LIFE06NAT/H/000096 (2007–2010), LIFE09NAT/HU/000384 (2011–2014), LIFE13NAT/HU/000183 (2015–2018), and LIFE21-NAT-HU-LIFE-SakerRoads / 101074704 (2023–2024). The database was developed, and the analyses for this paper were conducted within the framework of the LIFE SakerRoads project (LIFE21-NAT-HU-LIFE-SakerRoads / 101074704).

The monitoring and research of Saker Falcons in Hungary was conducted under the permits of the MME Raptor Conservation Group (OKTF-KP/56-25/2015, PE-KTFO/1867-9/2018, PE-KTFO/1867-10/2018, PE-KTFO/1867-11/2018, PE-KTFO/507-16/2019, PE-KTFO/1466-3/2023, PE-KTFO/1951-17/2024), and the research permits of the MME Bird Ringing and Migration Research Centre (PE-KTF/97-13/2017). We are grateful to Volen Arkumarev, Jozef Chavko, Giovanni Leonardi and Tibor Csörgő for their valuable comments on the earlier versions of the manuscript.

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Appendix

Appendix Proportion of all identified prey taxa of Saker Falcons in Hungary in the study period
Melléklet Valamennyi meghatározott taxon eloszlása a kerecsensólymok magyarországi táplálékában a vizsgálati időszakban

Class	Order	Species	Number	% *N*
Amphibia			**13**	0.05%
	Anura		**13**	0.05%
		Anura indet.	3	0.01%
		Pelobates fuscus	1	0.00%
		Pelophylax sp.	9	0.04%
Aves			**18833**	75.69%
	Accipitriformes		**7**	0.03%
		Circus cyaneus	4	0.02%
		Circus pygargus	3	0.01%
	Anseriformes		**31**	0.12%
		Anas crecca	1	0.00%
		Anas platyrhynchos	13	0.05%
		Anas querquedula	15	0.06%
		Anas sp.	1	0.00%
		Anser anser f. *domestica*	1	0.00%
	Bucerotiformes		**2**	0.01%
		Upupa epops	2	0.01%
	Charadriiformes		**1034**	4.16%
		Actitis hypoleucos	1	0.00%
		Charadriiformes indet.	3	0.01%
		Charadrius hiaticula	1	0.00%
		Chroicocephalus ridibundus	195	0.78%
		Gallinago gallinago	1	0.00%
		Himantopus himantopus	1	0.00%
		Ichthyaetus melanocephalus	1	0.00%
		Larus cachinnans	1	0.00%
		Limosa limosa	8	0.03%
		Numenius arquata	5	0.02%
		Numenius phaeopus	3	0.01%
		Philomachus pugnax	19	0.08%
		Sterna hirundo	1	0.00%
		Tringa erythropus	1	0.00%
		Tringa glareola	6	0.02%
		Tringa sp.	6	0.02%

Class	Order	Species	Number	% N
		Tringa totanus	22	0.09%
		Vanellus vanellus	759	3.05%
	Columbiformes		**13959**	56.10%
		Columba livia f. *domestica*	13343	53.63%
		Columba oenas	39	0.16%
		Columba palumbus	239	0.96%
		Streptopelia decaocto	50	0.20%
		Streptopelia sp.	246	0.99%
		Streptopelia turtur	42	0.17%
	Coraciiformes		**4**	0.02%
		Coracias garrulus	3	0.01%
		Merops apiaster	1	0.00%
	Falconiformes		**17**	0.07%
		Falco tinnunculus	16	0.06%
		Falco vespertinus	1	0.00%
	Galliformes		**918**	3.69%
		Coturnix coturnix	140	0.56%
		Galliformes indet.	1	0.00%
		Gallus gallus f. *domesticus*	8	0.03%
		Perdix perdix	127	0.51%
		Phasianus colchicus	642	2.58%
	Gruiformes		**24**	0.10%
		Crex crex	4	0.02%
		Fulica atra	10	0.04%
		Gallinula chloropus	3	0.01%
		Porzana porzana	1	0.00%
		Rallus aquaticus	6	0.02%
	Passeriformes		**2781**	11.18%
		Acrocephalus sp.	1	0.00%
		Aegithalos caudatus	1	0.00%
		Alauda arvensis	196	0.79%
		Alaudidae indet. *(Alauda arvensis/Galerida cristata)*	33	0.13%
		Anthus campestris	1	0.00%
		Anthus sp.	2	0.01%
		Carduelis carduelis	5	0.02%
		Carduelis chloris	9	0.04%
		Coccothraustes coccothraustes	5	0.02%

Class	Order	Species	Number	% N
		Coloeus monedula	8	0.03%
		Corvus cornix	40	0.16%
		Corvus frugilegus	199	0.80%
		Corvus sp. *(cornix/frugilegus)*	120	0.48%
		Cuculus canorus	1	0.00%
		Emberiza calandra	8	0.03%
		Emberiza citrinella	1	0.00%
		Emberiza schoeniclus	2	0.01%
		Erithacus rubecula	1	0.00%
		Galerida cristata	4	0.02%
		Garrulus glandarius	13	0.05%
		Hirundo rustica	2	0.01%
		Lanius collurio	7	0.03%
		Lanius minor	21	0.08%
		Linaria cannabina	1	0.00%
		Motacilla alba	5	0.02%
		Motacilla cinerea	1	0.00%
		Motacilla flava	5	0.02%
		Muscicapa striata	1	0.00%
		Oenanthe oenanthe	4	0.02%
		Oriolus oriolus	3	0.01%
		Panurus biarmicus	1	0.00%
		Parus major	3	0.01%
		Passer domesticus	4	0.02%
		Passer montanus	18	0.07%
		Passer sp. *(domesticus/montanus)*	7	0.03%
		Passeriformes indet.	45	0.18%
		Pastor roseus	1	0.00%
		Pica pica	412	1.66%
		Saxicola rubicola	2	0.01%
		Sturnus vulgaris	1551	6.23%
		Sylvia curruca	1	0.00%
		Sylvia sp.	2	0.01%
		Turdus merula	5	0.02%
		Turdus philomelos	9	0.04%
		Turdus sp.	18	0.07%
		Turdus viscivorus	2	0.01%

Class	Order	Species	Number	% N
	Pelecaniformes		**21**	0.08%
		Ardeola ralloides	1	0.00%
		Nycticorax nycticorax	20	0.08%
	Piciformes		**3**	0.01%
		Dendrocopos major	2	0.01%
		Dendrocopos sp.	1	0.00%
	Podicipediformes		**3**	0.01%
		Podiceps grisegena	1	0.00%
		Podiceps nigricollis	1	0.00%
		Tachybaptus ruficollis	1	0.00%
	Psittaciformes		**1**	0.00%
		Melopsittacus undulatus	1	0.00%
	Strigiformes		**28**	0.11%
		Asio flammeus	15	0.06%
		Asio otus	9	0.04%
		Strix aluco	4	0.02%
Gastropoda			**3**	0.01%
	Pulmonata		**3**	0.01%
		Zebrina detrita	3	0.01%
Insecta			**115**	0.46%
	Coleoptera		**74**	0.30%
		Carabidae indet.	3	0.01%
		Cassida sp.	1	0.00%
		Cerambycidae indet.	2	0.01%
		Cetonia aurata	1	0.00%
		Coccinellidae indet.	6	0.02%
		Coleoptera indet.	32	0.13%
		Elateridae indet.	2	0.01%
		Holochelus aequinoctialis	1	0.00%
		Hydrophilidae indet.	1	0.00%
		Lucanus cervus	3	0.01%
		Melolontha melolontha	14	0.06%
		Oryctes nasicornis	2	0.01%
		Scarabaeidae indet.	4	0.02%
		Zabrus tenebrionides	2	0.01%
	Hymenoptera		**1**	0.00%
		Hymenoptera indet.	1	0.00%

Class	Order	Species	Number	% N
	Mantodea		**2**	0.01%
		Mantis religiosa	2	0.01%
	na		**22**	0.09%
		Insecta indet.	22	0.09%
	Orthoptera		**16**	0.06%
		Acrididae indet.	1	0.00%
		Calliptamus italicus	2	0.01%
		Gryllotalpa gryllotalpa	12	0.05%
		Gryllus campestris	1	0.00%
Mammalia			**5900**	23.71%
	Artiodactyla		**8**	0.03%
		Capreolus capreolus	7	0.03%
		Sus scrofa	1	0.00%
	Carnivora		**18**	0.07%
		Felis catus	2	0.01%
		Mustela nivalis	12	0.05%
		Mustela sp. *(eversmanii/putorius)*	2	0.01%
		Vulpes vulpes	2	0.01%
	Chiroptera		**18**	0.07%
		Chiroptera indet.	2	0.01%
		Nyctalus noctula	16	0.06%
	Eulipotyphla		**29**	0.12%
		Crocidura leucodon	1	0.00%
		Erinaceus roumanicus	4	0.02%
		Sorex minutus	1	0.00%
		Talpa europaea	23	0.09%
	Lagomorpha		**963**	3.87%
		Lepus europaeus	962	3.87%
		Oryctolagus cuniculus	1	0.00%
	na		1	0.00%
		Mammalia indet.	1	0.00%
	Rodentia		**4863**	19.54%
		Apodemus agrarius	5	0.02%
		Apodemus sp.	10	0.04%
		Arvicola amphibius	36	0.14%
		Cricetus cricetus	745	2.99%
		Micromys minutus	4	0.02%
		Microtus arvalis	1307	5.25%

Class	Order	Species	Number	% *N*
		Microtus sp.	33	0.13%
		Microtus subterraneus	3	0.01%
		Mus musculus	4	0.02%
		Mus sp. *(musculus/spicilegus)*	3	0.01%
		Mus spicilegus	1	0.00%
		Ondatra zibethicus	2	0.01%
		Rattus norvegicus	12	0.05%
		Rattus sp.	1	0.00%
		Rodentia indet.	3	0.01%
		Spermophilus citellus	2694	10.83%
Pisces			**1**	0.00%
	Cypriniformes		**1**	0.00%
		Cyprinus carpio	1	0.00%
Reptilia			**17**	0.07%
	Squamata		**17**	0.07%
		Lacerta agilis	14	0.06%
		Lacerta sp.	2	0.01%
		Natrix natrix	1	0.00%
Total			**24 882**	100.00%

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Ornis Hungarica 2025. 33(1): 98–109.
DOI: 10.2478/orhu-2025-0005

The Saker Falcon *(Falco cherrug)* population in the Czech Republic in 2011–2022

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Received: February 20, 2023 – Revised:October 03, 2024 – Accepted: October 18, 2024

Škorpíková, V., Horal, D. & Beran, V. 2025. The Saker Falcon *(Falco cherrug)* population in the Czech Republic in 2011–2022. – Ornis Hungarica 33(1): 98–109. DOI: 10.2478/orhu-2025-0005

Abstract In 2011–2022, the Saker Falcon *(Falco cherrug)* population in the Czech Republic fluctuated between 2 and 10 breeding pairs. In total, 64 breeding events were recorded, 42 of them were successful and 105 young were reared. The average breeding productivity was 1.6 juveniles/nest and 2.5 juveniles/successful nest. Sakers concentrated to the Pannonian part of the country, breeding at the three known localities in Bohemia finished in 2013. In comparison with former periods, number of pairs was lower, but some pairs apparently moved to neighbouring Austrian areas.

Keywords: *Falco cherrug*, Saker Falcon, Czech Republic, population, trend

Összefoglalás 2011 és 2022 között a kerecsensólyom *(Falco cherrug)* populáció Csehországban 2 és 10 fészkelő pár között ingadozott. Összesen 64 pár költését jegyeztünk fel, ebből 42 volt sikeres, és 105 fióka repült ki. Az átlagos költési siker 1,6 fióka/fészek, az átlagos fiókaszám 2,5 fióka volt sikeres fészkenként. A kerecsensólymok az ország pannon részére koncentrálódtak, a három ismert bohémiai fészkelőhelyen 2013 óta nem volt költés. Az előző időszakokhoz képest a párok száma alacsonyabb volt, és néhány pár a szomszédos osztrák területekre költözött át.

Kulcsszavak: *Falco cherrug*, kerecsensólyom, Csehország, állomány, trend

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Introduction

The Saker Falcon *(Falco cherrug)* belongs to the rarest breeding birds of the Czech Republic, its nesting sites are form the northwesternmost limit of the species' European range (after breeding in Germany has ceased after 2001, see e.g. Steffens *et al.* 2013 for details). The core breeding area is in the SE part of the country (South Moravia), geographically belonging to the Pannonian biogeographical province. Systematic research of this population started in 1976. Data up to 1998 (23 years) was published by Horák (2000), from years 1999–2010 by Beran *et al.* (2012). In this article, data between 2011–2022 is summarized, even if some information between 2011–2018 was partly published (Škorpíková *et al*. 2017).

Material and Methods

The Saker Falcon population in South Moravia has been regularly monitored. Annually, at least four people are involved in field work. They concentrated on observing display and territory defence behaviour at the beginning of the breeding season. Later, they tried to find occupied nests and record the number of nestlings and fledglings. For this article, only data on confirmed breeding was used. More intensive monitoring was only carried out in 2015, when 15 people were involved and suitable regions of Bohemia were also included.

Results

The results of the Saker Falcon monitoring in 2011–2022 are summarized in *Table 1.* In total, 64 breeding pairs were confirmed (5.3 per year, 2–10 annually), 42 pairs (65.6%) were successful and 105 young were fledged. The average breeding productivity was 1.6 juveniles per nest and 2.5 juveniles per successful nest. The number of confirmed breeding pairs usually ranges between 4 and 7 except for 2011–2013, when 2–3 pairs also nested in Bohemia, and a noticeable decline in 2016–2018, when only 2–3 pairs were detected in total *(Figure 1)*. We estimate a maximum population size of 10 pairs for the period 2011–2022.

In 2011–2022, Sakers bred in 16 grid squares of the Czech Republic *(Figure 2)*, squares 10´ of longitude and 6´ of latitude were used, which means roughly 12 by 11.1 km, i.e. 133 km^2 (Šťastný *et al.* 2021). After more than 70 years, breeding in Bohemia was again

Table 1. Annual breeding success data of the Saker Falcon in the Czech Republic between 2011–2022

1. táblázat A kerecsensólyom éves költési eredményei Csehországban 2011–2022 között

Year	No. of confirmed breedings in Moravia	No. of confirmed breedings in Bohemia	Total no. of confirmed breedings in the Czech Republic	No. of successful breedings	No. of fledged juv.	Juv./nest	Juv./successful nest
2011	6	2	8	6	16	2.0	2.7
2012	8	2	10	8	24	2.4	3.0
2013	5	3	8	5	9	1.1	1.8
2014	4	0	4	2	2	0.5	1.0
2015	6	0	6	5	7	1.2	1.4
2016	2	0	2	1	3	1.5	3.0
2017	3	0	3	3	8	2.7	2.7
2018	3	0	3	0	0	0	0
2019	4	0	4	4	10	2.5	2.5
2020	7	0	7	3	9	1.3	3.0
2021	4	0	4	2	7	1.8	3.5
2022	5	0	5	3	10	2.0	3.3
Total	**57**	**7**	**64**	**42**	**105**	**1.6**	**2.5**

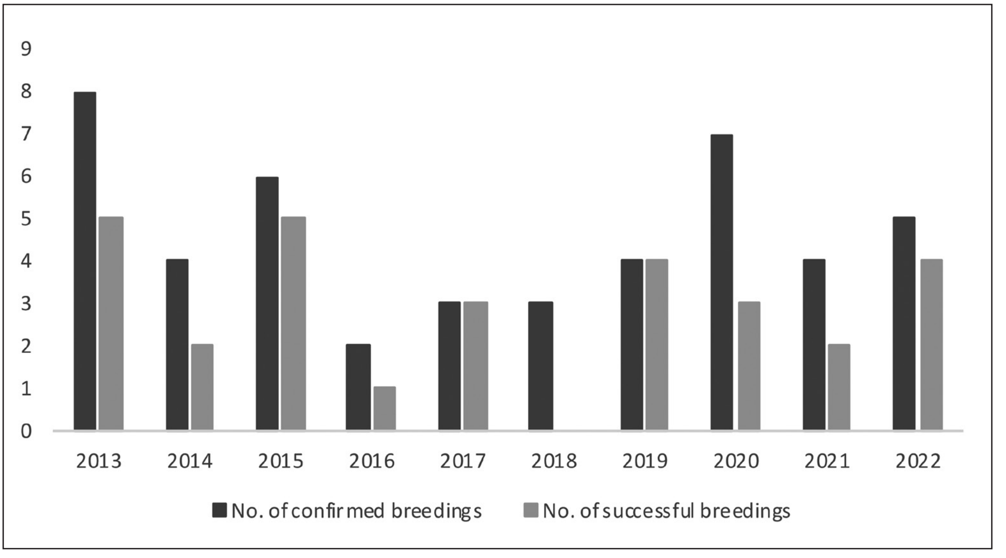

Figure 1. Development of the Saker Falcon breeding population in the Czech Republic between 2013 and 2022

1. ábra A kerecsensólyom fészkelőállományának alakulása Csehországban 2013 és 2022 között

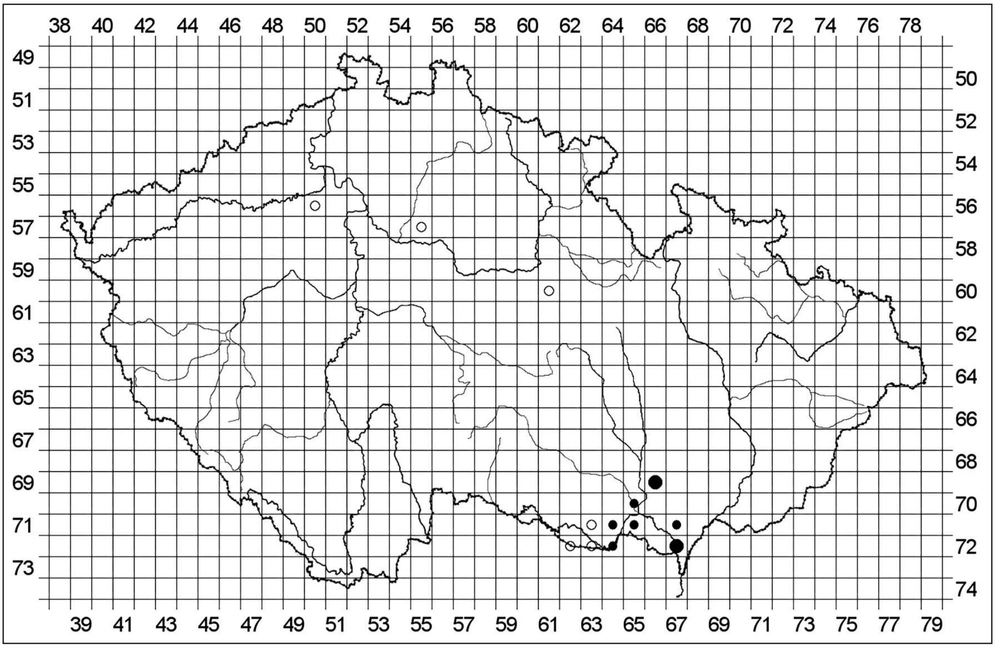

Figure 2. The number of Saker Falcon breeding pairs in the Czech Republic between 2011–2022 (n = 64). Big black dots: >7, small black dots: 4–6, white dots: 1–3

2. ábra A kerecsensólyom fészkelő párok száma Csehországban 2011 és 2022 között (n = 64). Nagy fekete pontok: >7, kis fekete pontok: 4–6, fehér pontok: 1–3 recorded, but just in a few localities. One pair was discovered thanks to the data from a satellite-tagged Hungarian male Barnabás, tagged as a chick near Hegyeshalom, Győr-Moson-Sopron county, in 2007 and regularly (six times) wintering in Sicily. He already stayed in Chrudim district (eastern Bohemia, cca. 120 km from a core breeding area) in 2010, breeding was confirmed in 2011. The birds used an old Common Buzzard´s *(Buteo buteo)* nest in a poplar windbreak, but the breeding was unsuccessful. After wintering in Sicily, the male returned in 2012 and bred with a female in the same nest as in the previous year. They reared four young. One of his chicks (male Tobias) was satellite-tagged (https://sakerlife2.mme.hu/en/content/barnab%c3%a1s%e2%80%99s-son-got-ptt/). Unfortunately this bird, after visiting Poland, Slovakia and Hungary, was shot in Austria (close to Hungarian border) on 9 November 2012. In 2013, Barnabás unsuccessfully bred at the same locality in a nestbox installed on a high-voltage pylon. He was observed for the last time there on 14 October 2013. The last data of this bird (autumn 2013) came from Mediterranean Sea near the southern coast of Italy, later the transmitter stopped working. The second Bohemian breeding was recorded in Mladá Boleslav district (Central Bohemia, cca. 200 km from a core breeding area). Sakers used Ravens´ *(Corvus corax)* nests and reared three young in 2011 and two young in 2012, when the Raven nest with chicks was probably robbed. In 2013, Sakers failed there. The breeding in all these cases started rather late, between 10 and 30 April, replacement clutches are very probable. Kladno district in Central Bohemia (cca 230 km from a core breeding area) was the third occupied Bohemian locality. Displaying Sakers were observed there in autumn 2012 and a family in summer 2013. But in following years, no nesting attempts were recorded outside of the traditional breeding area and all other breeding pairs were found in a region between the cities of Brno, Znojmo and Hodonín belonging to the Pannonian biogeographical province, most of them in 6966, 7164 and 7267 squares (13, 8 and 7 breeding attempts in 2011–2022). In 2012, Sakers abandoned floodplain forests along the lower Morava and Dyje rivers (Soutok-Tvrdonicko SPA), where up to four pairs used to breed for decades. They moved to breed on newly installed nest platforms on high-voltage pylons on the nearby Austrian territory. Along the Czech-Austrian border between the towns of Znojmo and Mikulov, 3–4 pairs alternated breeding localities on both sides, but they mostly bred in Austria since 2014.

In 2011–2022, 58 breedings were recorded at a stage of incubation or small chicks feeding, six times reared juveniles still dependent on parents were observed. In total, 25 pairs nested on high-voltage pylons (17, i.e. 68.0%, were successful), 16 of them on artificial platforms (12, i.e. 75.0%, successfully), 7 in Raven nests, 1 in a nestbox and 1 in a Hooded Crow *(Corvus corone)* nest. Another 33 pairs nested in tree nests (20, i.e. 60.6%, were successful). 23 of them were built by Common Buzzard, four by Imperial Eagle *(Aquila heliaca)*, three by Raven and once a nest of Goshawk *(Accipiter gentilis)*, Red Kite *(Milvus milvus)* and Black Kite *(Milvus migrans)* was used. Most of the used nests were situated in poplars (*Populus* sp.) – 19 and black locusts *(Robinia pseudacacia)* – 7, exceptionally nests in Scots pines *(Pinus sylvestris)*, European ashes *(Fraxinus excelsior)*, oaks (*Quercus* sp.) or elms (*Ulmus* sp.) were used. Repeated breeding in the same tree nest was rare. In 2011–2014, Sakers bred in a nest of the Imperial Eagle built in 2010. They were successful in the first two seasons, but after two following unsuccessful attempts, they abandoned the nest and bred in a Common Buzzard nest 1,495 m away in 2015. Two nests occupied in 2009 were re-used in 2011, another one from 2010 in 2012. In 2019, Sakers bred in a nest built by Common Buzzards in a black locust tree *(Figure 3)*, which was first occupied by a Saker pair in 2003 (the nest was multiple times re-built by buzzards). If successful breeding occurs in smaller nests (mostly originally built by buzzards), they are so disintegrated at the end of the breeding season that the chicks are in danger of falling out of the nest. This case was recorded in 2013, when one (probably the youngest) chick out of four was found on the ground. Only two young were reared, so it is probable that another chick fell out as well but disappeared between two controls. In another locality in the same year, the nest completely broke up approximately in the time of fledging, but fortunately all four chicks were successfully reared.

In total, 64 chicks were ringed, most of them also with colour rings. Four ringed birds produced the following recoveries:
– a female ringed as a nestling near Litobratřice (Znojmo district) on 11 May 2011 was found flightless near Hollabrunn (Austria) on 16 April 2014 (47 km, 1,071 days), after rehabilitation, she was released;
– a male ringed as a nestling near Hevlín (Znojmo district) on 10 May 2011 was captured near Székesfehérvár, Fejér county (Hungary) on 4 January 2013 (228 km, 605 days);
– a female ringed as a nestling near Otnice (Vyškov district) on 9 May 2012 was found injured near Újezd u Brna (Brno-venkov district) on 10 July 2012 (4 km, 62 days);
– a female ringed as a nestling near Měnín (Brno-venkov district) on 13 May 2019 was found injured (electrocuted) near Rebešovice (Brno-venkov district) on 9 June 2020 and delivered to a recovery station (5 km, 393 days).

In the Czech Republic, seven foreign ringing recoveries were obtained in 2011–2022:
– a female ringed as a nestling near Vadosfa, Győr-Moson-Sopron county, Hungary, on 18 May 2011 was found dead near the Lhovice village in the Plzeň region on 11 March 2019 (361 km, 2,854 days);
– a female ringed (and satellite-tagged) as a nestling near Kostolište, Malacky district, Slovakia, on 23 May 2011 was found electrocuted under medium-voltage pylon near Biskupice, Prostějov district on 25 August 2011 (116 km, 92 days);
– a bird ringed as a nestling in Mosonszolnok, Győr-Moson-Sopron county, Hungary, on 23 May 2012 was found dead (probably a victim of electrocution) near the Dolní Dunajovice village (Břeclav district) on 15 April 2014 (119 km, 692 days);
– a female ringed as a nestling in Kiskunlacháza, Pest county, Hungary, on 19 May 2014 was found injured (a broken wing) probably after collision with medium-voltage powerline near the Kozlany village (Vyškov district) on 8 September 2014 (268 km, 112 days);
– a female ringed as a nestling in Kiskunlacháza, Pest county, Hungary, on 18 May 2015 was found dead below a medium-voltage pylon near the Mšené-lázně town (Litoměřice district) on 25 August 2015 (500 km, 99 days);
– a male ringed as a nestling near Bánov, the Nové Zámky district, Slovakia, on 14 May 2021 was electrocuted by Žalkovice village (Kroměříž district) on 26 August 2021, it had to be euthanized due to severe injuries (156 km, 104 days);

Figure 3. Two juvenile Saker Falcons fledged from a nest in a black locust *(Robinia pseudoacacia)* tree. Nový Přerov. 5 June 2019. Photo: Vlasta Škorpíková

3. ábra Két fiatal, akácfán *(Robinia pseudoacacia)* lévő fészekből kirepült kerecsensólyom. Nový Přerov. 2019. június 5. Fotó: Vlasta Škorpíková

– a bird ringed as a nestling in Bernolákovo, Senec district, Slovakia, on 14 May 2022, was found electrocuted under a medium-voltage pylon near Hrubčice, Prostějov district, on 27 January 2023 (140 km, 258 days)

21 of the recorded breeding cases failed, twelve of them at the stage of incubation, four at the stage of advanced incubation or small chicks and five at the stage of chicks in the nest. We recorded or we suppose following reasons for failure in 14 cases:
– in one case, the *Liometopum microcephalum* aggressive ants, which had their colony in a hollow formed after a branch broke off just below a Saker nest, could be the reason (2011);
– a poor condition of a female resulted in laying low-quality eggs and insufficient care of them (2019);
– a nest with chicks fell down from an unknown reason (2012) or after a supporting branch was broken in a strong wind (2021);
– a pure nest quality (together with unsuitable weather conditions) could resulted in nest destruction (2013, 2018);
– severe conflicts with other birds of prey could cause Sakers to abandon their nests or could resulted in predation of a temporary abandoned clutch. In five cases, a competition for nests could be involved: three times with Common Kestrels *(Falco tinnunculus)* – 2012, 2013 and 2014, and twice with Common Buzzards – 2020 and 2022, once the breeding Sakers were disturbed by raptors (Common Buzzards, Red Kites, Common Kestrels, White-tailed Sea Eagles *(Haliaaetus albicilla)*, etc.) roosting nearby, when a field neighbouring the nest site was rich in voles – 2020;
– a predation without recorded disturbing could cause three cases of breeding failure (2014, 2015, 2016).

We did not find evidence of breeding failure caused by accidental or targeted human disturbance.

In total, the age of 63 breeding birds was determined. Interestingly, most of the breeding females were young, in 2cy or 3cy (67.7%, n = 31), most of the breeding males were adult (78.1%, n = 32).

From 152 food items *(Table 2)* recorded during observation of Sakers or checking nests, Feral Pigeons *(Columba livia* f. *domestica)* formed 54.6% of the diet. Obviously, pigeons are the most important source of food in our region, especially in the period of feeding young. Sometimes, a pair is really specialized on this food resource, as happened in the case of breeding near Drnholec in 2017, where any other food remnants were not found. Common Pheasants *(Phasianus colchicus)* and European Hares *(Lepus europaeus)*, both popular game species supported by local hunters' organizations, form an important proportion of the utilized food resources (11.8% and 5.3%, respectively). Young animals, in particular, were hunted or stolen (kleptoparasitism) from other avian predators.

During the monitoring in 2011–2022, we recorded several cases of interesting Saker breeding or behaviour:
– In 2012, a male from the breeding pair had a striking gap in his left wing. It was obviously not caused by moulting, because the missing feathers did not grow back during the

Table 2. Diet composition of Saker Falcon in the Czech Republic between 2011–2022 (n = 152 food items)

2. táblázat A kerecsensólyom táplálékösszetétele Csehországban 2011–2022 között (n = 152 táplálékmaradvány)

Species	**No. of recorded items**	**%**
Columba livia f. *domestica*	55	50.0
Phasianus colchicus	17	15.4
Lepus europaeus	8	7.3
Sturnus vulgaris	7	6.4
Vanellus vanellus	7	6.4
Microtus arvalis	7	6.4
Larus ridibundus	3	2.7
Anas platyrhynchos	1	0.9
Columba oenas	1	0.9
Columba palumbus	1	0.9
Asio otus	1	0.9
Garrulus glandarius	1	0.9
Nyctalus noctula	1	0.9
In total	**110**	**100**

breeding season. Despite this disadvantage, the male was very active and successful, the pair reared four young.

- Food caching was observed in two cases. In 2013, a pair breeding in a windbreak in Znojmo district repeatedly cached food items into three concrete cylinders of 1 m in diameter protecting an irrigation equipment 25–260 m apart from the nest (Škorpíková 2013). In 2021, food used by a male breeding near Měnín (Brno-venkov district) was cached in a pylon construction.
- Until the winter of 2013/2014 (typically from November to February), the regular wintering of the Saker Falcon, and in some years also the Peregrine Falcon *(F. peregrinus)*, was recorded on a grain silo in Chrlice, on the SSE edge of the city of Brno; later, the observations became very rare.
- Similarly, since the winter of 2012/2013, regular wintering of the Saker Falcon has been recorded on a grain silo (cca. 50 m high) near the village of Šakvice (Břeclav district), previously also well known as a regular wintering site of the Peregrine Falcon. On some occasions, both species were present (on different sides of the silo). From winter 2012/2013 onwards, Sakers have been found there every winter (typically between October and February) except for 2014/2015.
- In March and April 2016, a Saker Falcon female stayed in a nestbox installed on a chimney of Prunéřov Power Station (at the height of 125 m above the ground) and caused the breeding failure of a local Peregrine Falcon pair. She left the locality later, but she was observed in the surroundings several times during the winter. In spring 2017, she again occupied the Prunéřov nestbox, but no Saker male was recorded. Subsequently, the box was occupied by a Peregrine pair that reared two young from a rather late breeding.

Figure 4. A severe encounter of the Saker Falcon and Peregrine Falcon females. Dukovany power plant. Camera trap snapshot

4. ábra Heves összecsapás egy kerecsensólyom és egy vándorsólyom tojó között. Dukovany erőmű. Kameracsapda fotó

– On 27 September 2016, a severe attack of a young Saker female against a falconry Goshawk resting on the ground was recorded near Pravčice village (Kroměříž district). The Saker female was slightly injured, after recovery in a rehabilitation station it was released, tagged with GPS-GSM logger. The bird sent data for nearly ten months, visiting Slovakia, Hungary and Austria, and was finally found dead near Zurndorf, Burgenland, Austria on 3 September, 2017, for unknown reason (Rozsypalová *et al.* 2021).
– In 2017, a Saker pair bred in a nest only 103 m away from an occupied nest of Norther Goshawks and 110 m away from Common Buzzards. Surprisingly, only Sakers were successful and reared min. 3 juveniles.
– During ringing in a Sakers´ nest near Nový Přerov in 2019, one of the total of two chicks was freed from a string wrapped around its leg. It would not survive without this intervention.
– At least from 27 February to 6 April 2021, a Saker female was present around a nestbox for Peregrine Falcons at a ventilation chimney in the Dukovany nuclear power plant (Třebíč district), she repeatedly chased away a Peregrine pair *(Figure 4)*. She left after 18 May, and it might not be a coincidence that the Peregrine pair breeding failed in that year (only one egg was laid).

– On 22 May 2021, a Saker Falcon female incubating Peregrine chicks in a nestbox at a chimney of the Děčín heating plant was recorded. Later she disappeared and the Peregrine pair reared two chicks successfully (V. Šena *in litt*.).

Discussion

The presented data can be compared with the situation in the five-year periods since 1976, when the Saker Falcon population in the Czech Republic has been monitored *(Table 3)*. Until 2015, the situation was optimistic and the population increased up to 8.6 pairs per year in 2001–2005, later it stayed over a value of 7.0 pairs per year. But in the following five years, we only found 3.8 pairs per year, in 2018 all three breeding pairs failed *(Table 1)*. In the last two years, the situation seems to have improved, but still below the numbers from 1986–2015.

In total, 26 grid squares were occupied at least once in 1976–2018 in the Czech Republic. Breeding outside the main distribution range in the Pannonian part of the country was recorded in 1989–1999 and 2003–2007, when Sakers repeatedly occupied two grid squares in North Moravia near the Polish border, and in 2011–2013, when breeding in three different Bohemian localities was confirmed. However, none of these areas have been occupied continuously up so far. Recently, Sakers again concentrate to southeastern part of the country, they apparently find the best conditions in 6966, 7164 and 7267 squares *(Figure 2)*, which are occupied every year.

Using data from 2011, we attempted to estimate the theoretical recent population size of the Saker Falcon in the Czech Republic. In total, 16 grid sqaures were occupied (2,150 km^2), 13 of them (1,747 km^2) at least twice, 7 of them (941 km^2) more than fourtimes. According to studies by Prommer *et al.* (2018), the average home range size of a successfully breeding pair of Sakers is cca. 190.5 km^2 (51.3–529.7 km^2). Based on this data, 9–11 successful pairs can be expected in the Czech Republic in the best years, and around 5 pairs in years when conditions are worse.

Table 3. Comparison of basic breeding characteristics of the Saker Falcon population in the Czech Republic in 5-year periods between 2011 and 2022

3. táblázat A kerecsensólyom-állomány alapvető költési jellemzőinek összehasonlítása Csehország-ban 5 éves időszakokban, 2011 és 2022 között

Period	No. of years	No. of confirmed breedings	No. of breedings per year	No. of successful breedings (%)	No. of fledged juv.	Average no. of fledged juv. per successful nest
1976–1998	23	101	4.4	59 (58.4)	172	2.9
1999–2010	12	92	7.7	72 (78.3)	200	2.8
2011–2022	12	64	5.3	42 (65.6)	105	2.5
In total	**47**	**257**	**5.5**	**173 (67.3)**	**477**	**2.8**

In 2011–2012, only 5.3 breeding pairs were confirmed on average annually, 3.5 pairs / year bred successfully. This result could be caused by a fluctuation on the limit of the species range, but as the populations in important neighbouring countries (Slovakia, Austria, Hungary) have been stable or slightly increasing (Chavko *et al.* 2025, Prommer *et al.* 2025, Zink *et al.* 2025), we should look for other reasons. We can exclude the weather, because except for 2013 with a cold and rainy spring, the weather conditions were favourable. However, we have recorded a shift of breeding pairs to Austria since 2013. It was first observed in pairs from localities in the Soutok-Tvrdonicko SPA, where Sakers apparently took advantage of the offer of breeding possibilities on newly installed nest platforms on high-voltage pylons. Two other pairs regularly breeding on the Czech side of the border in Znojmo district have moved to Austria since 2016. All of these pairs obviously had transboundary territories and recently they have bred in Austria, so the total size of the Central European Saker population should not change. However, this is a very strong signal about the quality of our open landscape, where Sakers apparently have not found enough food or nesting sites. Similarly to Prommer *et al*. (2018), we think that agricultural practices that reduce prey abundance subsequently lead to fewer breeding pairs. From the biodiversity point of view, the current state of the Czech agricultural landscape is desperate and the decrease of population size in birds of the open landscape is proven (Reif *et al.* 2014). The main reasons such as large fields with few set-aside elements among them, low diversity of the crops grown and the high level of pesticides used have been discussed.

The recent (after 2012) disapperance of Sakers from the area of floodplain forests of the lower Morava and Dyje rivers, once a very imortant breeding ground, is clearly illustrated by the fact that in the period 2011–2022, no White Stork *(Ciconia ciconia)* nest was used for breeding of Sakers, while in 1999–2005, it was the second more common origin after Common Buzzard (10 out of a total 44, Beran *et al.* 2012).

A National Action Plan for the Saker Falcon was prepared in 2017. The proposed measures do not only include installation of new nesting platforms or boxes in regions where natural nests are obviously lacking, or applying proven equipment on dangerous types of medium-voltage pylons, but the pressure for changes to recent agricultural practices is also emphasized. However, the Action Plan has not yet been approved and its objectives are not being met.

Acknowledgements

We would like to thank to many friends and colleagues, who were or have been involved in the Saker Falcon monitoring in the Czech Republic: Petr Berka, Tomáš Bělka, Vladimír Gahura, Tomáš Koutný, Ján Svetlík, Pavel Štěpánek, Martin Valášek, Josef Vrána and Zdeněk Tunka, and who helped with their very valuable observations, especially to Jan Absolín, Jan Bína, Dušan Boucný, Josef Círl, Pavel Forejtek†, Johannes Laber, Ivan Literák, Hynek Matušík, Petr Navrátil, Marek Palička, Rainer Raab, Dušan Rak, Péter Spakovszky, Jaromír Šifta, Vladimír Teplý and Martin Tomešek. We also are grateful to all who put their observations of Sakers into the database of the Czech Society for Ornithology at http://

birds.cz/avif, we found much interesting information there. For data on ringing birds we are grateful to the Ringing Station of the National Museum in Prague.

Monitoring and protection of the Saker Falcon population in the Czech Republic has been supported by South Moravian Region and many activities carried out in 2015–2017 were financed thanks to the EEA grants.

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Ornis Hungarica 2025. 33(1): 110–126.
DOI: 10.2478/orhu-2025-0006

Distribution, abundance and reproductive success of the Saker Falcon in Slovakia in 1976–2022

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Received: March 27, 2023 – Revised: October 03, 2024 – Accepted: October 18, 2024

Chavko, J., Lipták, J., Gális, M., Slobodník, R. & Prommer, M. 2025. Distribution, abundance and breeding of the Saker Falcon in Slovakia in 1976–2022. – Ornis Hungarica 33(1): 110–126. DOI: 10.2478/orhu-2025-0006

Abstract Between 1976 and 2022, we monitored the distribution of nest sites across two habitats of the Saker Falcon *(Falco cherrug)*, nesting in both the mountains and lowlands of Western and Eastern Slovakia. In Western Slovakia, we observed nesting in 79 known nest sites, accounting for 703 nesting attempts, while in Eastern Slovakia, we monitored 281 nesting attempts in 32 nest sites. The brood size varied between these regions; pairs in Western Slovakia produced an average of 3.0 nestlings, whereas those in Eastern Slovakia produced an average of 2.5 nestlings per successful nest. Throughout the period from 1976 to 2022, a total of 2,468 young Saker Falcons fledged in Slovakia. During this period, the range of breeding population gradually shifted to the lowland from the mountains. In the new, predominantly agricultural environment, the nesting success significantly increased from 57.1% in the mountains to 81.1% in the lowland. In Western Slovakia, the benefits of shift in habitat were further justified by the observation that the mean brood size per all breeding attempts in the lowlands was consistently above two young per brood most of the time. In contrast, pairs breeding in the mountains frequently produced two or fewer young per all breeding attempts. Additionally, our findings indicate that electrocution on mid-voltage (22 kV) power lines is the primary cause of mortality among Sakers in Slovakia, with collisions being the second leading cause.

Keywords: *Falco cherrug*, habitat, reproductive success, conservation management, aluminium nest box, power lines

Összefoglalás 1976 és 2022 között figyelemmel kísértük a kerecsensólyom *(Falco cherrug)* fészkelőhelyeinek eloszlását két élőhelyen, a hegyekben és az alföldön, Nyugat- és Kelet-Szlovákiában. Nyugat-Szlovákiában 79 fészkelőhelyen 703 fészkelést figyeltünk meg, Kelet-Szlovákiában pedig 281 fészkelést ellenőriztünk 32 ismert fészkelőhelyen. A két régióban eltérő volt az átlagos fiókaszám; a nyugat-szlovákiai párok átlagosan 3,0 fiókát, míg a kelet-szlovákiaiak átlagosan 2,5 fiókát neveltek fel sikeres költésenként. Az 1976–2022-es időszakban összesen 2468 fiatal kerecsensólyom repült ki Szlovákiában. Ugyanebben az időszakban az állomány fészkelőterülete fokozatosan a hegyvidékről az alföldi területekre tevődött át. Az új környezetben – elsősorban az agrárterületeken – jelentősen megnőtt a fészkelési siker aránya (81,1% a hegyekben mért 57,1%-kal szemben). Nyugat-Szlovákiában az új élőhely választásának előnyeit igazolta továbbá, hogy az alföldön az összes költési kísérletre vonatkoztatott fiókaszám jellemzően két fióka / fészek érték felett maradt. Ezzel szemben a hegyvidéki pároknál ez az érték kettő, vagy annál kevesebb fióka volt. Az eredményeink megmutatták azt is, hogy az elsődleges pusztulási ok a kerecsensólymoknál Szlovákiában a középfeszültségű oszlopokon elszenvedett áramütés. Ezt követte másik fő okként az ütközés.

Kulcsszavak: *Falco cherrug*, élőhely, költési siker, természetvédelmi kezelés, alumínium fészekláda, távvezetékek

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Introduction

The Saker Falcon *(Falco cherrug)* inhabits a vast steppe zone from the Pannonian lowlands to the east through Moldova, Southern Ukraine, Russia, and Kazakhstan to the Asian steppe zone in Southern Siberia, Central Asia, and Western China. In non-nesting times, it occurs in Western and Southern Europe, the Middle East, the Indian subcontinent and East China (Baumgart 1994). According to the Saker Falcon Global Action Plan (Saker GAP), the Asian population reaches the level of ~5,400–14,000 pairs, with nests in 13 countries, while the European population (~640–730 pairs) makes only 7% of the world's population (Kovács *et al.* 2014). Within Pannonia it nests in the north in Slovakia, in the west in Southern Moravia (Beran *et al.* 2012) and in Lower Austria (Frey & Senn 1980, Zink *et al.* 2012) and in the south in Vojvodina, Serbia (Puzović 2008). The centre of the European population is in Ukraine and Hungary (Kovács *et al.* 2014, Bagyura *et al.* 2025, Prommer *et al.* 2025).

The original habitats of the Saker Falcon were grassland biotopes that have been turned to agricultural land use and gradually more or less disappeared in Slovakia, except for small areas of pastures, at the end of the 1950s–1960s (Chavko 2002a). As a result of the post-war change of the political orientation, there were also significant changes in the strategy of agricultural use of the country. The merge of smaller agricultural tables into large blocks of arable land has caused unfavourable changes in natural habitats, the impact of which persists even today. Recently, Saker Falcons in Slovakia nest and forage only in such secondary biotopes.

The mountains of south-western and south-eastern Slovakia are parts of the historically known nesting areas of the Saker Falcon, where the first findings of nests are dated back to the second half of the 19th century. The first documented nest in Western Slovakia was reported in 1885 and 1886 (the rock of Devín Castle near Bratislava in Devín). Further nests were found in lowland forests along the Danube in 1928, 1933 and 1934 (Kunszt 1929, Matoušek 1933, Csiba 1959). Also, between 1951 and 1959 up to two pairs of Saker Falcons nested in the floodplain of Šúr nature reserve at Svätý Jur near Bratislava, where active nests were found (Brtek 1956, Hell 1958a, 1958b, Ferianc 1964). In Western Slovakia, the core area was the Little Carpathians, where nesting was confirmed in 1931 (Janda 1932), and further evidence of nesting (observations of fledged young) were reported in the period of 1946–1954 (Brtek 1956, Matoušek 1956). Ferianc (1964) estimated the population of the Saker Falcon in the Little Carpathians in the 1950s and 1960s to six pairs. Later, nesting was also confirmed in the Považský Inovec mountains (Hell 1958a, 1958b, Soviš & Šindár 1964, Varga 1969), Strážov Mountains, White Carpathians and Pohronský Inovec Mountain range (Soviš & Šindár 1964).

The first data on nesting Saker Falcons in Eastern Slovakia (Slovak Karst) were recorded between 1860 and 1870 (Tschusi 1887). Other known nesting data from this mountain range are from 1931 (Lokcsánský 1931), 1951 and 1958 (Mošanský 1974). Nesting in Eastern Slovakia was comprehensively processed by Mošanský (1974). Based on the results of his work, we know that Saker Falcons nested in the Slovak Karst (on cliffs), Slanské and Volovské Hills (on both cliffs and trees).

Our work follows the two published articles for the period 1976–2010 (Chavko *et al.* 2010) and for the period 1976–2016 (Chavko *et al*. 2019) concerning the development of the Saker Falcon population in Slovakia. For this reason, the primary aim of this work is to add the population data for the period 2017–2022, which have not yet been published and report population changes in the period between 1976 and 2022.

Methods

Based on the distribution of breeding and wintering Saker Falcons in Slovakia, we can delineate a Western and an Eastern area for the species *(Figure 1)*. The distance between these two populations is approximately 150 kilometres. To date, nesting has not been recorded in the southern part of Central Slovakia. We adhered to these natural divisions during data collection and processing.

Data collection

Primarily, we employed the method of direct search for nests, initially aimed at revising historical nesting data from literary sources. Later, we expanded our monitoring to all potential biotopes, especially those with recorded occurrences of the species. Additionally, we regularly monitored all locations where nest boxes had been installed on transmission line towers, checking their occupancy. Each occupied nest site was then regularly inspected in subsequent periods. To date, at least 450 nest boxes have been installed in the Saker Falcon's nesting territories in the lowlands of Slovakia. These nest boxes facilitate easier and more accurate population monitoring. The success rate was monitored through direct observations of the occupied natural nests and nest boxes, mostly during the fledgling

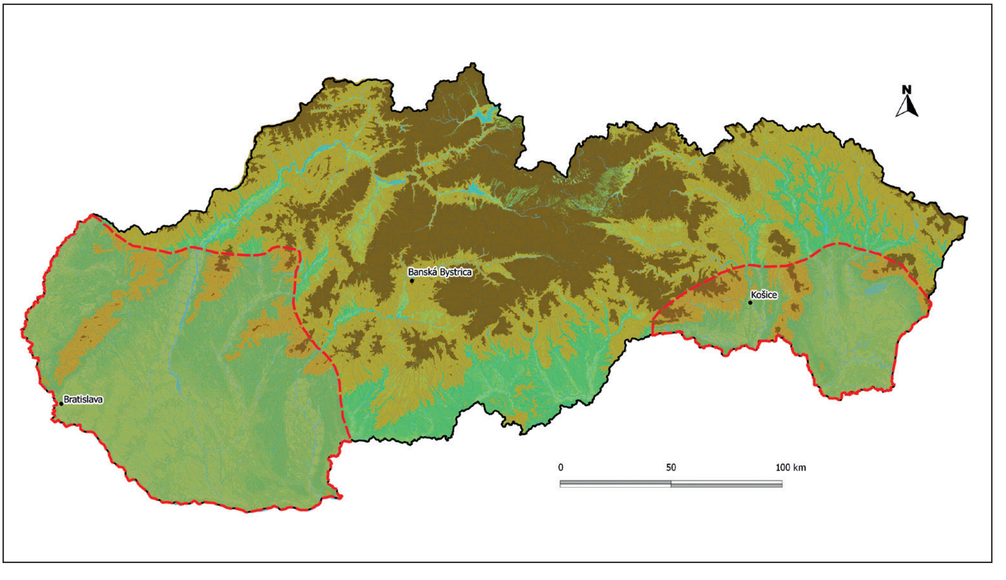

Figure 1. The distribution area of the Saker Falcon in Slovakia (1976–2022)
1. ábra A kerecsensólyom elterjedése Szlovákiában (1976–2022)

period. This monitoring included ringing the young and was supplemented by observations from a greater distance using telescopes and, as of 2020, drones.

Injuries and mortality events were recorded during monitoring; however, this study concentrates on population development. While we highlight the most significant mortality factors, a detailed analysis of these factors is not provided here.

Data processing and visualization

For data processing and visualization, we primarily used Office 365 MS Excel (ver. 2403). To analyse differences in reproductive performance, we applied a t-test using basic R (ver. 4.3.2) within the RStudio (ver. 2023.12.01) environment.

Results

Population development and nesting success rate

In the period 1976–2022, 117 nest sites were recorded in Slovakia, hosting in a total of 985 recorded nesting attempts, which resulted in 2,468 juveniles.

During the study period, the Saker Falcon population in Slovakia increased from one known pair to 46 pairs *(Figure 2)*. Between about the early 1990s and mid-2000s, a range shift was observed in both the Western and Eastern breeding pairs. Throughout this period, Saker territories gradually moved away from mountainous regions and expanded into lowland agricultural areas. However, differences in population size and dynamics were observed between the Eastern and Western regions.

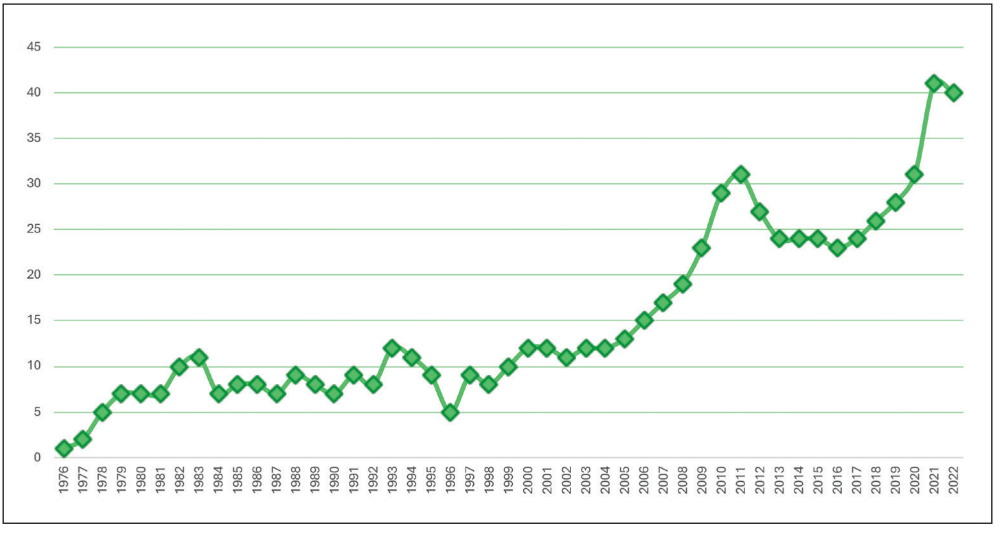

Figure 2. Development of Saker Falcon population in Slovakia (1976–2022)
2. ábra A kerecsensólyom állományának alakulása Szlovákiában (1976–2022)

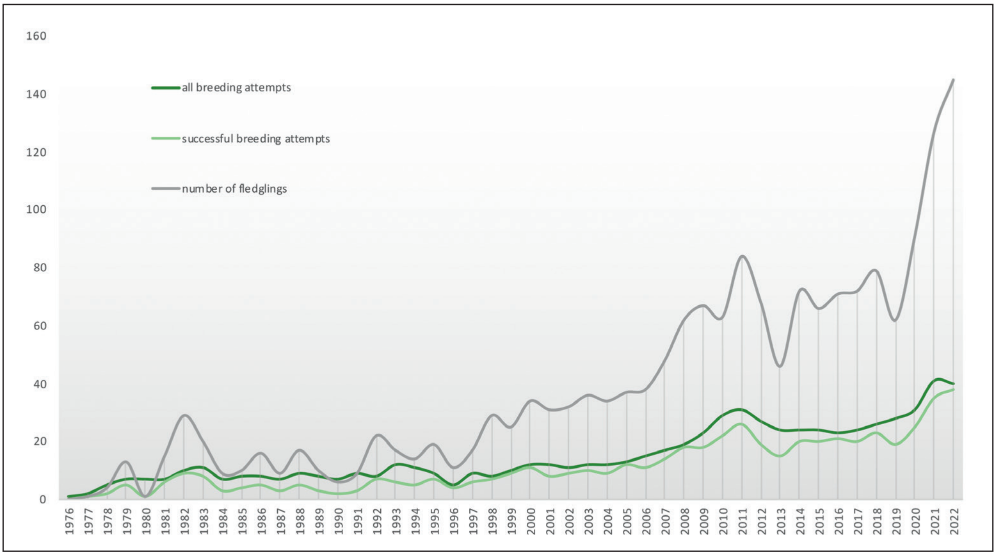

Figure 3. Development of the Saker Falcon population in Western Slovakia (1976–2022)
3. ábra A kerecsensólyom-állomány alakulása Nyugat-Szlovákiában (1976–2022)

Figure 4. Saker Falcon nest in tree on the floodplain of the Morava River, in May 1993. The female brought a European Hare *(Lepus europaeus)* to the nest killed by mower, when mowing meadows. Photo: J. Chavko
4. ábra Fán lévő kerecsensólyom-fészek a Morava folyó völgyében, 1993 májusában. A tojó egy kaszálógép által levágott mezei nyulat *(Lepus europaeus)* hozott. Fotó: J. Chavko

Western Slovakia

In Western Slovakia, we recorded 84 nest sites occupied by 79 pairs during the study period of 1976–2022. A total of 703 nesting attempts were made, out of which 534 were successful, resulting in the birth of 1,788 nestlings. We also recorded 169 failed nesting attempts. The mean brood size was 3.0 young birds per successful nesting attempt, and 2.4 young per all nesting attempts. The trend in population development was positive throughout the study period, with particularly significant growth observed after 1997 *(Figure 3)*. The development process was especially well-monitored in the case of pairs dwelling in nest boxes on transmission line towers.

During the reported period, there was a significant change in the nesting habitat preference of Saker Falcons. At the beginning of the study period, all known pairs in Western Slovakia nested in the forested environments of mountains and floodplains. Later, the population gradually shifted to lowland agricultural areas, where they began to use nest platforms and boxes installed on power transmission line towers.

Of a total of 84 known nest sites, in the beginning of the study period (1976–2008) 13 were recorded in the Little Carpathians, Kováčovské Hills and Strážovské Hills, five nest sites in floodplains (1988–1997) around the Morava River in the Borská Plain *(Figure 4)*, and subsequently 66 nest sites were recorded in the lowlands, in the agricultural areas of south-western Slovakia. The first nesting in agricultural area was recorded in Western Slovakia in 1988. The pair bred in a crow (*Corvus* sp.) nest on a transmission line tower. Following that year, the Saker Falcon population gradually expanded to the agricultural areas in the

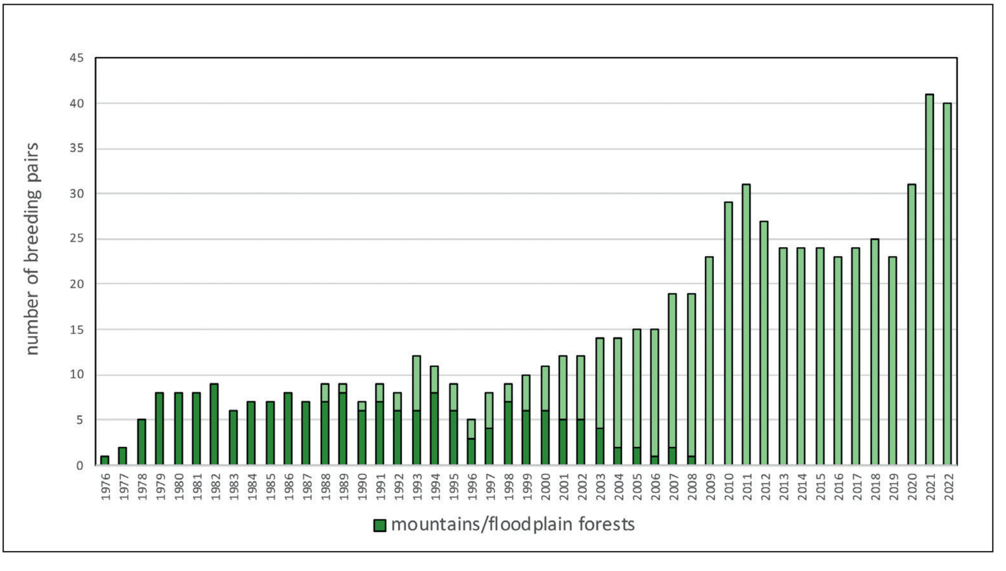

Figure 5. Changes in the Saker Falcon nesting habitats in Western Slovakia (1976–2022). Mountain and floodplains areas are highlighted in dark green, lowland agricultural areas in light green

5. ábra A kerecsensólyom fészkelőterületének változása Nyugat-Szlovákiában (1976–2022). A sötétzöld szín a hegyvidéki és az ártéren, míg a világosabb zöld az alföldi mezőgazdasági területen fészkelő párokat mutatja

Figure 6. An aluminium nest box can withstand also severe weather conditions (May 2021). Photo: J. Chavko

6. ábra Az alumínium fészekláda képes ellenállni a szélsőséges időjárási körülményeknek is (2021 május). Fotó: J. Chavko

Figure 7. A female Saker Falcon laid an egg in a nest built by ravens, but then left the nest (May 2004). Photo: J. Chavko

7. ábra Egy tojó kerecsensólyom lerakott egy tojást egy hollófészekbe, de azután elhagyta a fészket (2004 május). Fotó: J. Chavko

Figure 8. We also installed nest platforms in a few numbers on several transmission line towers, which falcons also like to occupy (ringing, May 2003). Photo: J. Chavko

8. ábra Kis számban fészektálcákat is helyeztünk ki néhány nagyfeszültségű távvezeték oszlopra, amelyeket a sólymok szintén előszeretettel foglalnak el (gyűrűzés, 2003 május). Fotó: J. Chavko

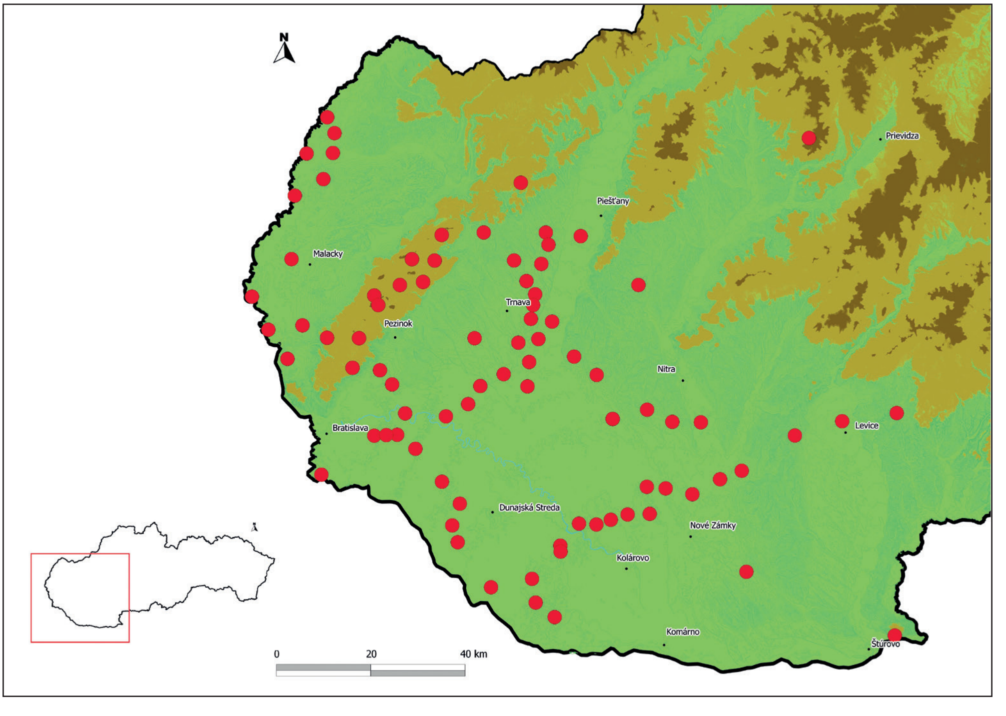

Figure 9. The distribution of nest sites in Western Slovakia (1976–2022)

9. ábra A fészkelőhelyek eloszlása Nyugat-Szlovákiában (1976–2022) lowland. Eventually, the species' breeding range in Western Slovakia has shifted from the mountains to the lowland, and all pairs but one have nested on transmission towers since 2009 *(Figure 5)*. The only exception was a single pair, which nested in an artificial nest in the Danube plain until 2011. About 95% of the new pairs have preferred nesting in nest boxes on transmission line towers *(Figure 6)*. A few nesting attempts occurred in nests of Ravens *(Corvus corax)*, built either on the metal structure of transmission line towers *(Figure 7),* or in the nest boxes, or on nest platforms also on transmission line towers *(Figure 8)*. The distribution of nest sites in Western Slovakia is shown in *Figure 9*.

Eastern Slovakia

In Eastern Slovakia, we recorded 32 nest sites occupied by 32 pairs in the period 1979–2022. A total of 282 breeding attempts were recorded, out of which 213 were successful resulting in 677 juveniles. The number of failed nesting attempts were 68. The mean brood size was 2.5 young birds per successful nesting attempts, and 1.9 young per all nesting attempts. The trend of population growth was slightly increasing until 2010, but we have been experiencing a downward trend since then *(Figure 10)*.

Of the total 32 known nesting sites, 9 were in mountain ranges, and 23 in lowland agricultural areas. In Eastern Slovakia, the first records of nesting, dating back to 1979, were on historic nesting grounds in the mountains. However, the breeding population's range gradually shifted from the mountains to the lowlands, mirroring the trend observed in Western Slovakia. The last nesting events in the Slovak Ore Mountains were recorded in 1981, in the Slovak Karst in 1995, and in the Slanské Hills in 1996. In the Slovak Paradise Mountains, only one successful nesting was recorded in 1982, which also occurred on a cliff. The first nesting of a pair in the lowland was documented in 1986 in the Košice Basin

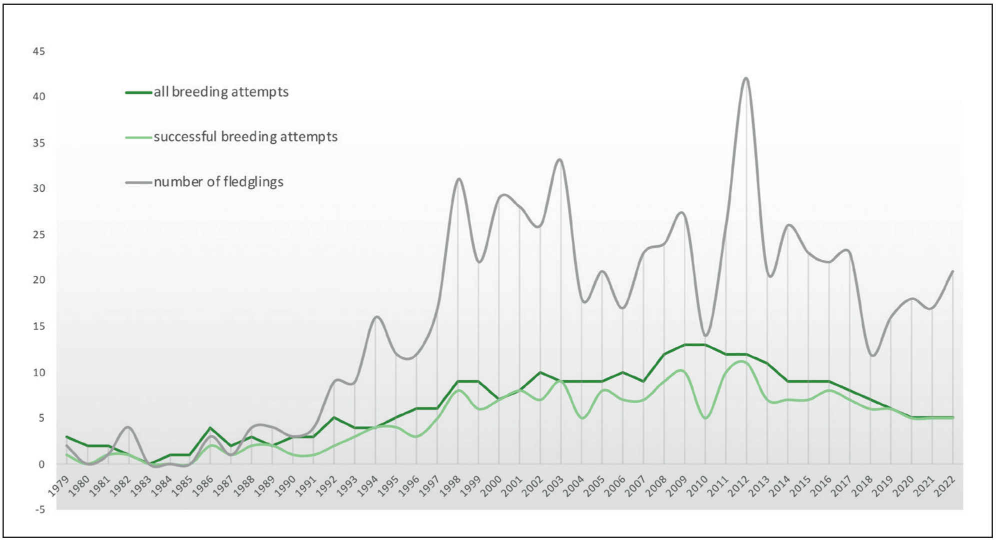

Figure 10. Population development of the Saker Falcon in Eastern Slovakia (1979–2022)
10. ábra A kerecsensólyom-állomány alakulása Kelet-Szlovákiában (1979–2022)

(South-Eastern Slovakia). Since 1997, all known pairs have nested in lowland agricultural areas, utilizing nest boxes installed on transmission line towers *(Figure 11)*. The complete shift from mountainous to lowland nesting sites in Eastern Slovakia occurred 13 years earlier than in Western Slovakia. The distribution of nesting sites in Eastern Slovakia is illustrated in *Figure 12*.

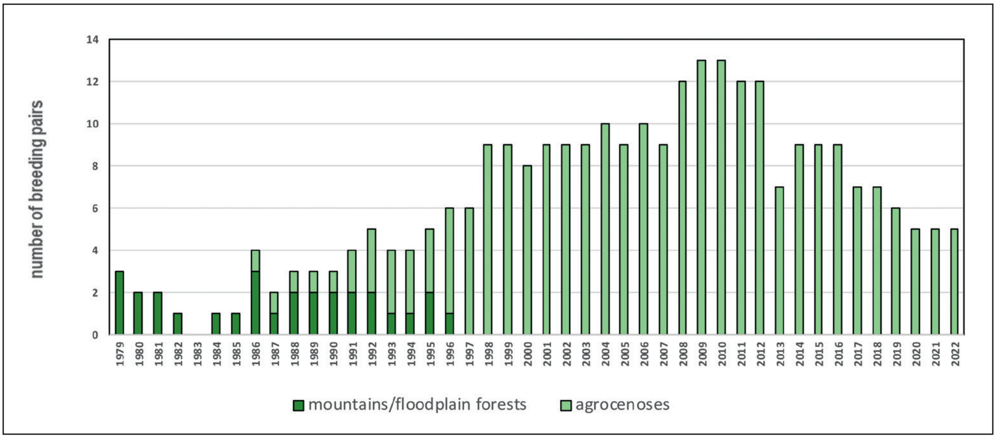

Figure 11. Changes in the Saker falcon nesting habitat in Eastern Slovakia (1979–2022)
11. ábra A kerecsensólyom fészkelőterület-változása Kelet-Szlovákiában (1979–2022)

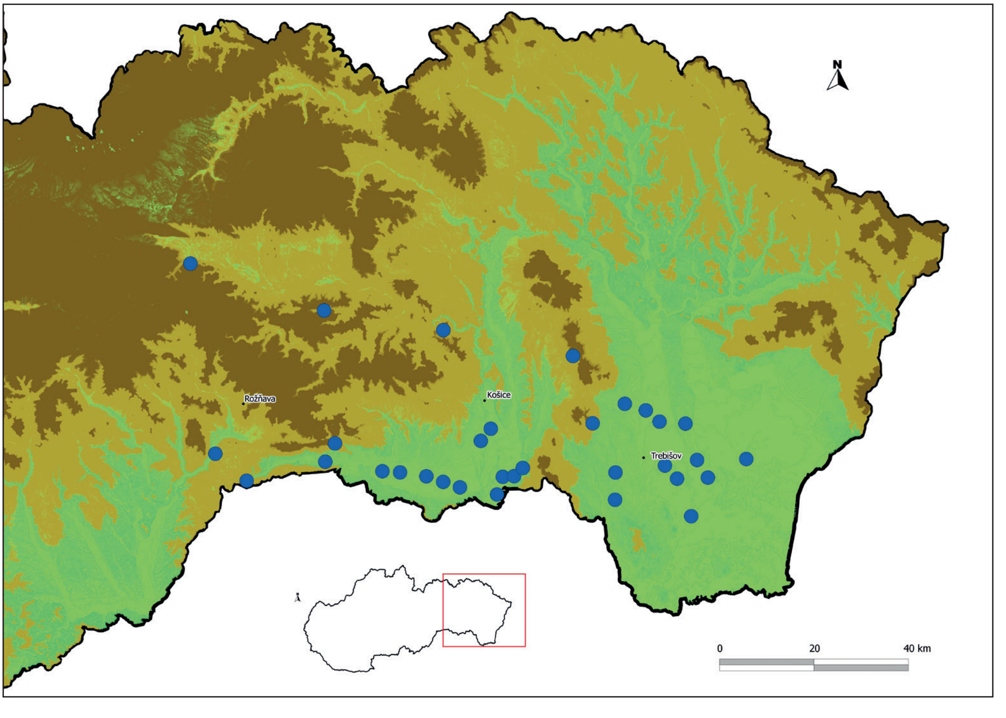

Figure 12. The distribution of nest sites in Eastern Slovakia (1979–2022)
12. ábra A fészkelőhelyek eloszlása Kelet-Szlovákiában (1979–2022)

Threats

During the period under review, we recorded three deaths because of a collision with power lines. In Western Slovakia four fledglings died in a nest box, and nine fledglings altogether died in Eastern Slovakia in three nest boxes when a lightning struck transmission line towers. Nevertheless, electrocution on flat consoles of 22 kV overhead lines can be considered the greatest threat where we recorded the death of a total of 14 individuals.

Discussion

Population development

During the study period, the most conspicuous change observed in the Saker Falcon population was the cessation of historical breeding territories in the mountains, which were present at the beginning of the conservation program. By the late 2000s, this resulted in the species' distribution area in Slovakia shifting entirely to the lowland. The last nesting attempt in a mountain range (Little Carpathians) in Slovakia was recorded in 2008.

Interestingly, the new territories formed mostly near larger cities, likely due to the availability of food, such as city-dwelling feral pigeons. Since the falcons predominantly used natural nests and artificial nest boxes on transmission lines, their distribution closely followed the routes of these power lines. The shift in nesting preferences was influenced by two main factors. First, the disappearance of pastures harbouring large colonies of European Ground Squirrels *(Spermophilus citellus)*, particularly near the foothills of the Little Carpathians, led to a significant reduction in food sources. The dwindling prey sources compelled Saker Falcons to cover greater distances, reducing energetic efficiency and leaving their broods more exposed to predators and adverse weather for extended periods. Second, the introduction of numerous nest boxes on transmission towers in lowlands, where food was more plentiful, provided new nesting opportunities. Additionally, the return of the Peregrine Falcon *(Falco peregrinus)* to Slovakia after 1994, taking over nesting sites on mountain cliffs, may have pushed Sakers from at least a few of these areas, as indicated by Chavko (2002b).

The marked increase in nesting pairs on transmission towers highlights that lowland areas remain attractive to Saker Falcons for their trophic resources, despite a general decline in prey diversity (Karp *et al.* 2012). The previously favourable nesting conditions in the mountains have gradually deteriorated due to the intensive economic exploitation of these habitat (Chavko & Deutschová 2012). Similar trends are increasingly apparent across various European countries (Donald *et al.* 2001, Butler *et al.* 2010, Vermouzek & Zámečník 2017).

However, this shift in habitat has evidently benefited the species, as seen in the improvement of their reproductive success. In the new, predominantly agricultural environment, the nesting success significantly increased from 57.1% in the mountains to 81.1% in the lowland, which is reflected also in mean brood size per all breeding attempts of the population in Western Slovakia *(Figure 13)*.

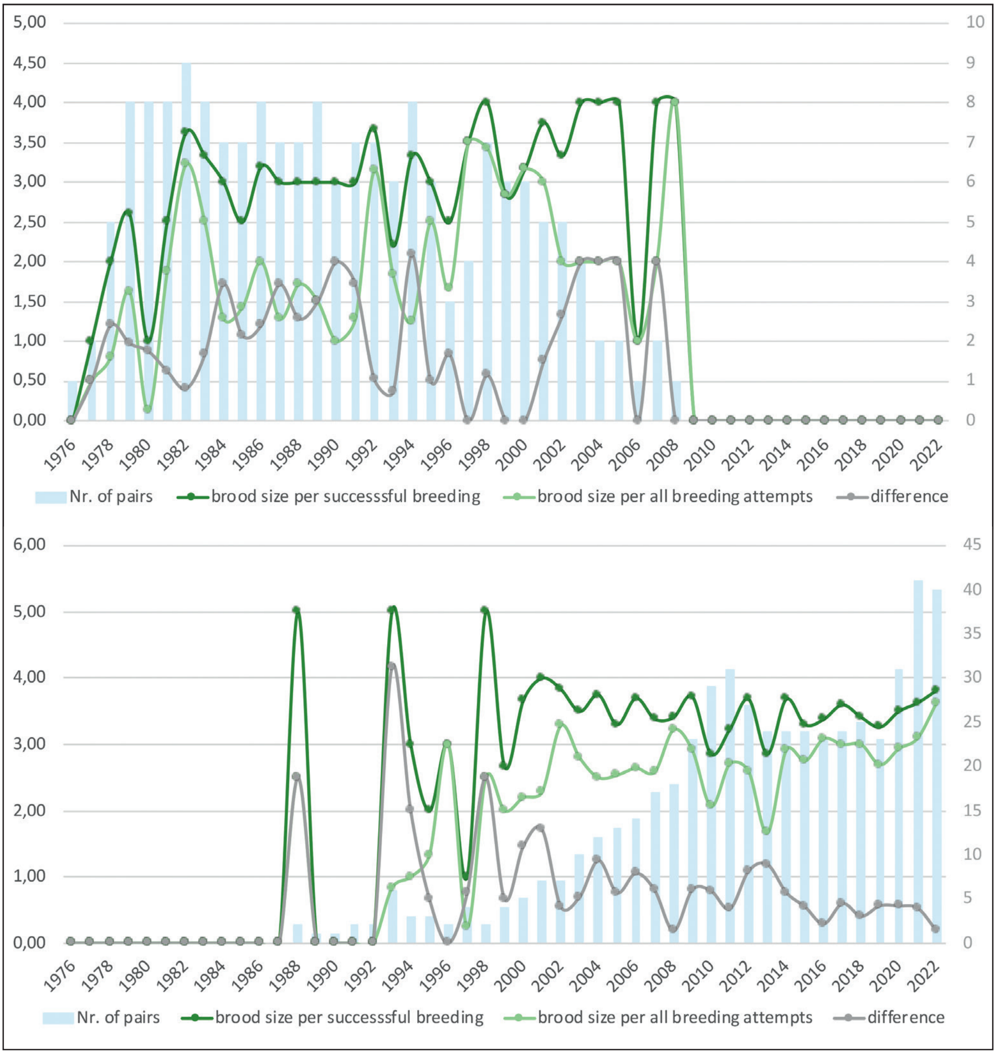

Figure 13. Reproductive performance of mountain (above) and lowland (below) breeding pairs in Western Slovakia. The number of breeding pairs is shown in light blue, with the corresponding y-axis on the right.

13. ábra A hegyvidéki (fent) és alföldi (lent) fészkelő párok reprodukciós sikere Nyugat-Szlovákiában. A fészkelő párok száma világoskékkel van jelölve, a hozzá tartozó y-tengely pedig jobbra található

Pairs in the mountains struggled, with the mean brood size often being two or fewer young per breeding attempt, rather than more. Conversely, excluding the initial years and the notably poor breeding year of 2013 for raptors, this value consistently exceeded two in the lowlands, sometimes even surpassing three. This difference in reproductive success cannot be attributed merely to the smaller sample size, as the lowland population maintained a stable, high reproductive outcome even with a limited number of pairs. The most plausible explanation for the poorer breeding performance of mountain pairs is a combination of factors: inefficient provisioning for the young due to reduced prey availability, a higher predation rate – especially due to the more pronounced presence of Goshawks *(Accipiter gentilis)* – reported in the 1980s and 1990s (Chavko 2010).

A high abundance of prey enhances reproductive success (e.g. Martin 1987, Ontiveros & Pleguezuelos 2000, Krištín *et al.* 2017). In the lowlands, this advantage was coupled with the wide availability of nest sites and a lower level of threats (Kovács *et al.* 2014), further supporting population growth. Particularly, the installation of nest boxes has induced a significant positive change in the nesting conditions for Saker Falcons within the intensively cultivated lowlands, as documented by Zink and Izquierdo (2012) and Chavko *et al.* (2014).

Threats

While reproductive performance is better in the lowlands, this habitat is not without its threats. A study on the post-fledging survival of juvenile Saker Falcons revealed high mortality rates among young birds shortly after fledging. None of the six monitored individuals survived the dispersion period, with at least three fatalities attributed to human activities – electrocution and hunting (Kouba *et al.* 2021). That highlights the problem that mid-voltage (22 kV) distribution lines pose a primary threat through electrocution (Dixon 2009, Kovács *et al.* 2014), which is a universal problem across the species' distribution range (Chavko 2002a, Beran *et al.* 2012, Kovács *et al.* 2014). It is reasonable to assume that electrocution represents the major threat to the species in Slovakia, and the actual number of electrocuted individuals is likely much higher than reported in this study. Many of the electrocuted falcons are never found, as their carcasses are quickly removed by predators such as the Red Fox *(Vulpes vulpes)* or the European Badger *(Meles meles)* (Ponce *et al*. 2010). Recently, this issue has gained more attention in Slovakia, with hazardous mid-voltage power line towers being secured as part of LIFE projects, particularly within the Sakers' home range (Gális *et al.* 2019a, 2019b). Saker Falcon mortalities were recorded on various crossarm types, with

Figure 14. Dangerous jumper in upper position on a 22 kV tower (left) and change of its placement under the plane of main wires (right). Photo: J. Chavko

14. ábra Veszélyes átkötés egy 22 kV-os vezeték oszlopán (balra), és módosítás után, amikor alsó helyzetbe került (jobbra). Fotó: J. Chavko the most dangerous being those with top-positioned jumpers and branching towers (Gális 2022). That type clearly represents the highest risk of electrocution to raptor species (Dixon *et al.* 2013). As a part of making power line poles safer for birds, jumpers were repositioned under the plan of main wires, as well as insulated conductors were applied *(Figure 14)*. Such measures may achieve 100% efficiency (Gális 2022).

Paradoxically, while high-voltage transmission lines facilitate nesting, they also present a significant collision risk to Saker Falcons, which is another factor causing injury or mortality.

The widespread decline in key prey species, driven by human activities such as the regular artificial control of the Common Vole *(Microtus arvalis)* during population peaks, poses a threat in lowland habitats. Specifically, the inappropriate use of rodenticides can endanger raptors through secondary poisoning.

Conclusions

In summary, in recent years, the species has exhibited population growth in Europe (e.g. Prommer *et al.* 2025, Škorpíková *et al.* 2025, Zink *et al.* 2025), as the downward trend has been halted in some countries, including Slovakia, thanks to targeted conservation efforts. Following a shift in habitat usage in Slovakia, the results of monitoring indicate a relatively dynamic increase in the population, especially in the lowlands of south-western Slovakia. Concurrently, Saker Falcons face persistent threats that contribute to unnecessary increases in mortality rates, with electrocution being particularly concerning. Addressing these hazards remains a critical priority for organizations dedicated to the conservation of Sakers and other birds of prey. Efforts to mitigate these threats involve a multi-faceted approach, including habitat restoration, modification of power lines to prevent electrocution, and raising public awareness about the importance of conserving these vital raptor species. By focusing on these areas, conservation groups aim to reduce mortality rates, ensuring the future of Sakers and enhancing the overall ecosystem health.

Acknowledgements

The conservation efforts to save and stabilize the Saker Falcon population in Slovakia have received substantial financial support from the European Union through the LIFE programme. Several projects aimed at this goal have been implemented in the region since 2006. Thanks to these projects, nest boxes were manufactured and installed as alternative nesting sites for the species. Additionally, the safety of power line poles and towers, as well as the wires of power lines, was enhanced to protect raptors against electrocution and collisions. Various methods of species monitoring, including the use of satellite-tracking devices, were also implemented. Efforts to prevent, detect, and address cases of illegal activities where birds are victims have also received support. The aforementioned activities have been conducted under the following projects: LIFE13 NAT/SK/001272 LIFE ENERGY (9/2014-12/2019), LIFE15 NAT/HU/000902 LIFE PANNON EAGLE (10/2016-1/2023), LIFE18 NAT/

AT/000048 LIFE EUROKITE (08/2019-01/2027), and LIFE19 NAT/SK/001023 LIFE DANUBE FREE SKY (9/2020-2/2026).

Our thanks for the support and cooperation goes to our colleagues from Raptor Protection of Slovakia: Slávka Siryová, Lucia Deutschová, Andrej Vďačný, Leonidas Prešinský, Richard Galaš, Zuzana Guziová, Jozef Mihók, Boris Maderič, Vladimír Nemček. At the same time, we would like to thank all energy companies in Slovakia, especially Slovenská elektrizačná prenosová sústava a.s. (SEPS), Východoslovenská distribučná a.s. (VSD) and Západoslovenská distribučná a.s. (ZSD), Ministry of Environment of the Slovak Republic, State Nature Conservancy of the Slovak Republic which with their active and responsible approach help to protect this species.

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The distribution, population and breeding success of Saker Falcon *Falco cherrug* in Serbia, 2020–2022

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Received: January 26, 2023 – Revised: November 10, 2024 – Accepted: November 12, 2024

Puzović, S. 2024. The distribution, population and breeding success of Saker Falcon *Falco cherrug* in Serbia, 2020–2022. – Ornis Hungarica 33(1): 127–140. DOI: 10.2478/orhu-2025-0007

Abstract This paper presents the results of research on the distribution, population and breeding success of Saker Falcon *(Falco cherrug)* in Serbia, in the period of 2020–2022. Detailed monitoring was carried out in the territory of Vojvodina, northern lowland part of Serbia, which included primarily survey of all routes of high-voltage transmission lines (2,600 km in length). A total of 586 georeferenced data were collected, of which 318 related to main reproductive period during March–June. Current breeding range of Saker Falcon in Serbia (Vojvodina) covers a relatively compact territory. Breeding range in 2022 covered cca. 14,500 km^2, situated in Vojvodina. The number of territories occupied by pairs or adult single birds increased from 44 in 2020 to 54 in 2022. In 2020, there were 21 successful pairs, in 2021, this number increased to 26, while in 2022 reached 30. Most of the successful breeding pairs occupied artificial nests installed on pylons of high voltage transmission power lines (75 metal boxes and 99 wooden platforms). Suitable habitats for reproduction of Saker Falcon in Vojvodina covers area of cca. 16,000 km^2, thus giving estimation of a total capacity of Vojvodina for Saker Falcon on cca. 84 breeding pairs.

Keywords: Saker Falcon, *Falco cherrug*, Serbia, distribution, population, breeding success

Összefoglalás Jelen tanulmány bemutatja a kerecsensólyom *(Falco cherrug)* elterjedésével, állományával és költési sikerével kapcsolatos, 2020 és 2022 közötti szerbiai kutatások eredményeit. A részletes felmérések a Vajdaság területén, Szerbia északi síkvidéki részén történtek, és elsősorban a nagyfeszültségű távvezetékek teljes nyomvonalára (2600 km hosszúságban) irányultak. Összesen 586 georeferált adat került rögzítésre, amelyek közül 318 a fő szaporodási időszakra (március–június) vonatkozott. A kerecsensólyom jelenlegi költési területe Szerbiában (Vajdaság) egy viszonylag kompakt területet foglal magába. A 2022-es fészkelőterület körülbelül 14 500 km^2-t fedett le. Az elfoglalt territóriumok száma, ahol párok vagy egyedülálló kifejlett madarak tartózkodtak, a 2020-ban megfigyelt 44-ről, 2022-re 54-re emelkedett. 2020-ban 21 sikeres pár volt, 2021-ben ez a szám 26-ra nőtt, míg 2022-ben elérte a 30-at. A sikeresen költő párok többsége mesterséges fészkeket foglalt el, amelyek nagyfeszültségű távvezetékoszlopokra telepített fémdobozokat (75) és fából készült platformokat (99) jelentettek. A kerecsensólyom számára alkalmas élőhelyek a Vajdaságban körülbelül 16 000 km^2-t fednek le, így a vajdasági kerecsensólyom állomány nagyságát körülbelül 84 fészkelő párra becsüljük.

Kulcsszavak: kerecsensólyom, *Falco cherrug*, Szerbia, elterjedés, állomány, költési siker

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Introduction

Saker Falcon *(Falco cherrug)* is a rare breeding bird species in Serbia. The majority of adult birds are resident and stay inside and/or around breeding territory throughout the year. The breeding range in Serbia is concentrated in the northern part (Pannonian plain – Vojvodina) *(Figure 1)*. There were some observations in the breeding season from highland grassland steppe plateaus in southeastern Serbia (Stara Planina Mt, Vardenik Mt, Dukat Mt.), in the last decade of the 20th century and the early 21th century, which are inhabited by European Ground Squirrels *(Spermophilus citellus)* (Petrov 1992, Sekulić 1995, Ham & Puzović 2000, Puzović *et al.* 2009, Janković 2010). The Saker Falcon is relatively evenly spread in the lowlands of Vojvodina, inhabiting agricultural land, steppes and saline grasslands. The most dense concentrations of occupied territories are in the regions of south, central and north Banat and in east and north Bačka (Rajković 2013/2014, Puzović *et al.* 2015, Rajković & Puzović 2018). The breeding population in Srem region, with more than 15 known pairs in 1990s, almost completely disappeared recently, probaly influenced by negative preassure from pigeon breeders (Puzović 2007a, Puzović 2008, Rajković & Puzović 2018).

Figure 1. Overview map of Serbia and neighboring countries.
1. ábra Szerbia és a szomszédos országok áttekintő térképe

Saker Falcons formerly used to breed on trees (Deliblato Sands and alluvian forests near large rivers) (Matvejev 1950, Ham 1982), rarely on loess walls (Titel Hill) (Ham & Puzović 2000) and possible on cliffs (Stara Planina Mt.) (Janković 2010, Sekulić & Radaković 2014). In the last 40 years, most of the occupied nests were located on pylons of high-voltage transmission power lines (hereafter pylon) in Vojvodina (Puzović 1988a, Ham & Puzović 2000, Puzović 2007a, Puzović 2008a, Rajković & Puzović 2018), in nests of Common Raven *(Corvus corax)* and very rarely of Hooded Crow *(Corvus cornix)*, as well as in artificial platforms and boxes. The first breeding of Common Raven in Serbia was recorded in 1979 near Temerin in Bačka (Balog 1992), and the breeding of Saker Falcon in Common Raven nest on pylons was firstly registered in 1982 near Samoš in Banat by Istvan Ham (Puzović 2008a). The only confirmed and successful breeding of Saker Falcon out of Vojvodina was recorded in Pomoravlje (Stig) area in central Serbia during 2007 and 2008, recorded by Goran Sekulić, in agriculture area on pylon, in Common Raven nest (Puzović *et al.* 2015).

During the 19th and in the first half of the 20th century, Saker Falcon was a very rare breeder in the Pannonian part of Serbia (Bačka and Banat), while in the rest of the country it was a winter guest and vagrant (Landbeck 1843, Matvejev 1950, Čornai 1952, Šćiban *et al.* 2015). The oldest recorded nesting sites were located in the vicinity of Pančevo, Dubovac, Kovilj and Titel (Schenk 1918). During the 1950s, it was found locally in southern Banat and used suitable nests on trees in forests along rivers (Szlivka 1959) and also forests on the slopes of Fruška Gora Mt. (Géroudet 1958). According to Pelle *et al.* (1977), in Vojvodina, it was rare breeder in the forests close to the Danube, and in Fruška Gora and Deliblato Sands. Antal *et al.* (1971) mentioned it for the alluvial forests near the Tisza River as well. Several breeding data for Bačka and Srem are provided by Marčetić and Medaković (1954), for the period 1951–1954 (Karapandža, Kazuk, Bogojevo, Plavna, Adica, Bačko Novo Selo, Bačka Palanka, Futog, Mačkov Sprud and Paragovo). There were no data from Kosovo and Metohija until the 1960s (Marčetić & Andrejević 1960), although there is a mounted skin of this species with an illegible label in the collection of the Museum of Kosovo. There is also a mounted specimen in the collection from 03.01.1966, which was previously wrongly determined as Peregrine Falcon *(Falco peregrinus)* (Ham & Puzović 2000).

The first monitoring of breeding population of Saker Falcon at local level has been carried out in Deliblato Sands protected area in 1970s and 1980s by Ham (1977, 1982) and in Srem region during the 1980s and 1990s (Puzović 1988b, Puzović 2007a). The first officially organised national breeding population survey was carried out in Serbia during 2007–2008 that was done by Bird Protection and Study Society of Vojvodina with support of International Wildlife Consultants Ltd. (IWC), Institute for Nature Conservation of Serbia, Provincial Secretariat of Environmental Protection and Sustainable Development, League for ornithological action and Joint Stock Company „Elektromreža Srbije“ (EMS). The main objective of the project was to survey all areas where the breeding of this species was possible and expected, with particular focus on electric power lines, steppe and saline grassland habitats and alluvial forests. In 2007 and 2008, almost all „portal“ type (lattice portal tower) and „jela“ type (single circuit tower-triangular configuration) pylons were surveyed in Vojvodina, Mačva and in North Pomoravlje (central Serbia).

In 2007, 40 occupied territories (eyries) with presence of adult Saker Falcons in the breeding period were found in Serbia, 39 of them in Vojvodina. There were 27 territorial pairs among which 20 were successful. More than 90% of all pairs nested in Common Raven nests. In Vojvodina, 15 territories were found in Banat, 14 in Bačka and 10 in Srem (Puzović 2007b). In 2008, 28 occupied territories (eyries) with presence of adult Saker Falcons in breeding period were found. There were 22 territorial pairs among which 18 were successful. In Vojvodina, 12 territories were found in Banat, 10 in Bačka and 6 in Srem (Puzović 2008c).

Monitoring of the breeding population of Saker Falcon on high-voltage transmission power lines was carried out in Vojvodina again in 2013 and 2014, under the organization of the Bird Protection and Study Society of Serbia (BPSSS), with a focus on incubated and successful pairs (Rajković 2013/2014). In 2013, 17 successful breeding pairs were recorded (Banat 10, Bačka 7 and Srem 0), and only 14 in 2008 (Banat 8, Bačka 5 and Srem 1).

In Vojvodina, during the first half of 1970s, there were only ten or a little more pair of Saker Falcon (Ham 1977), while at the beginning of the 1980s, there were 25–30 breeding pairs (Ham 1982). Vasić *et al.* (1985) estimated the breeding population in the northern plains of former Yugoslavia on 40 pairs for the same period, and specifically in Deliblato Sands up to 9 pairs. Snow and Perrins (1998), mainly based on information compiled by Voislav Vasić, estimated the size of the population in Serbia on 34–40 pairs for 1995, and the trend as a significant increase. The total population in Serbia for the period 1994–1996 was estimated on 51–65 breeding pairs (Ham & Puzović 2000). The breeding population, according to a two-year long survey (2007–2008), was estimated on 50–60 pairs (Puzović *et al.* 2009). For the period of 2008–2013, estimation was 22–32 breeding pairs in Serbia (Puzović *et al.* 2015). According to a two years survey, in 2013 and 2014, the total breeding population in Vojvodina was estimated on 16–21 pairs (Rajković 2013/2014), although that probably refer only to incubating and successful pairs, which are obviously representing only a part of the total national breeding population per year.

Population declining in the second half of the 20th century until the middle of the 1980s, when recovery had started, is probably attributed to increased negative anthropogenic pressure on habitats and individuals. However, successful adaptation for nesting in Common Raven's nest on electricity pylons, as newly built infrastructure in large agricultural lands without trees, as well as dietary reorientation to birds, mainly to Columbidae and Corvidae, has gradualy improved the situation (Ham & Puzović 2000, Puzović 2007a, Puzović & Krnajski 2007a, 2007b, Puzović 2008, Puzović *et al.* 2015). The breeding trend in the last two decades was identified as decline (Puzović *et al.* 2015).

During 2007 (June–October), the previously mentioned project partners firstly installed 50, and in 2008–2009, another 49 wooden platforms on pylons, and additonal six on trees. First confirmed breeding of Saker Falcon in wooden platform was recorded in 2013 near Kumane in Banat (Rajković 2013/2014). In 2014, 2015 and 2017 for a first time in Serbia, 30 metal (aluminium) nest boxes were installed on pylons. After that, during 2020–2022, additional 45 metal boxes were installed as well, with main coordination by experts from Institute for Nature Conservation of Vojvodina Province (INCVP) and realization by EMS workers. By the end of 2022, a dense network of artificial nests has been created that cover entire space of the northern lowland part of Serbia, with in total 180 nests (105 wooden platforms and 75 metal boxes), and with adopted task to reach 200 until 2024.

Material and Methods

During 2020–2022, monitoring of the breeding distribution and population, including success of reproduction of the Saker Falcon in the territory of Vojvodina was carried out, especially during the main reproductive period (March–June). Survey of all routes of high-voltage transmission lines was carried out (more than 2,600 km in length) annually, especially in detail on those where active territories of Saker Falcon were known from before, and where natural nests of Common Raven and artificial nests existed. Several other locations were also inspected, which, despite the absence of power lines as nesting base, have favorable conditions for Saker Falcon feeding. Most of the existing large nests of eagles *(Haliaeetus albicilla, Aquila heliaca, Clanga pomarina, Circaetus gallicus)* were also examined within the monitoring program related to those species. The priority was to survey all areas where the reproduction of this species is potentialy possible, focused on the areas with presence of electric power lines, steppe and saline habitats, forest zone beside large river flows and localities around settlements with pastures and traditional grazing.

The main field activities were carried out in the period of March until the second half of April, when the locations with the presence of adult birds (occupied territories-eyries) were determined. After that, those and other potential locations were particularly intensively visited to determine whether the pairs had started/continued breeding and what the breeding success rate was. These activities were particularly implemented in the period of 1 May–30 June. Some additional checks, if they were needed, have been carried out during July and August.

Except work on installation of artificial aluminum nest boxes and wooden platforms on pylons, detailed survey of all the previously installed nests was also carried out by the experts of INCVP, in cooperation with EMS and BPSSS, based on the signed cooperation agreement No. 04-802, from 23.03.2020. Almost all existing „portal“, „jela“ and „bure“ types of electric pylons were visited several times in Vojvodina, during 2020–2022. In total, 90 field working days were conducted.

All collected data and observations in the field were entered into the electronic database of georeferenced data, with the use of the „Terenska-Field” application, which was developed through IPA project for the purposes of establishing the Natura 2000 ecological network in Serbia. During three years of field research (2020–2022), a total of 586 units of information, georeferenced data, were collected and entered the electronic database, using the application „Terenska”. From that number, 310 data were collected in the March-July period, which primarily relate to the reproduction season of Saker Falcon in Serbia.

Results and Discussion

The current breeding range of Saker Falcon in Serbia (Vojvodina) covers a relatively compact territory *(Figure 2)*. There are no pairs that are isolated and situated more than ten kilometers away from the nearest neighboring pair or group of pairs. In 2020–2021, the breeding range contained areas of the entire Banat and the eastern part of Bačka, and covered about 13,400 km^2 *(Figures 3, 4)*. The breeding distribution in 2022 *(Figure 5)* shows that breeding range has slowly expanded, primarily to the areas of north-west and west Bačka, and to a small extent also to the middle part of eastern Banat. New pairs were formed near Svetozar Miletić and Sonta villages, which were more than 14 km and 38 km far from the earlier known nearest active nest. The increasingly frequent appearance of individuals in north-east Srem, where one pair tried to nest in 2022 near Novi Karlovci, after several years of absence in that region, is also noticeable.

Occupied territories are present and distributed relatively evenly inside the breeding range of the species in Banat and Bačka, with the fact that in 2022 the largest number of successful

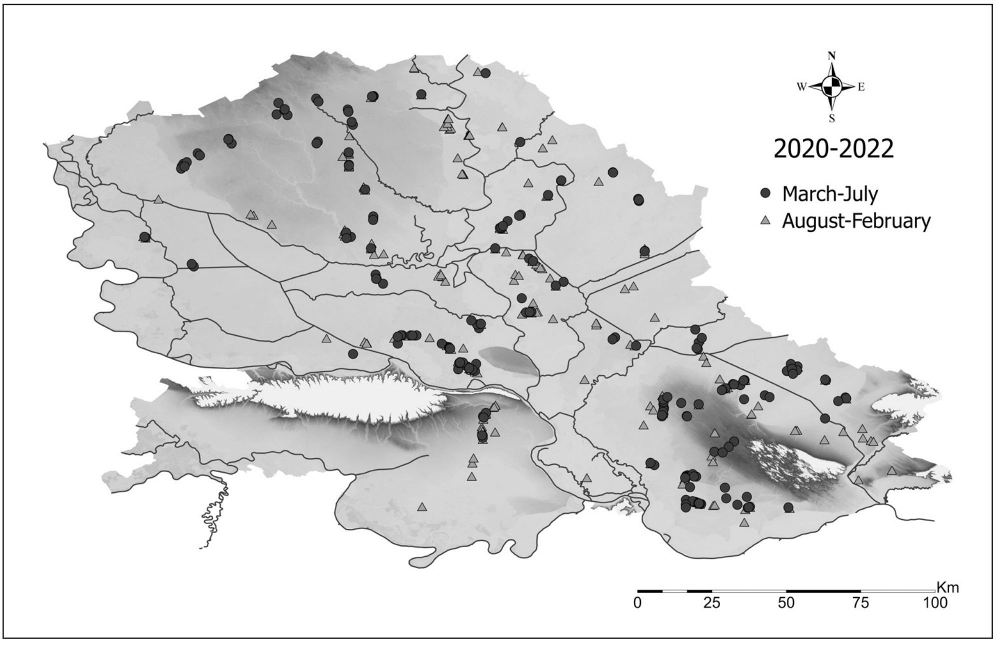

Figure 2. Observations of Saker Falcon in Vojvodina, in the period of 2020–2022 (circle: March-July, triangle: August-February)

2. ábra Kerecsensólyom *(Falco cherrug)* megfigyelések a Vajdaságban a 2020–2022 közötti időszakban (kör: március-július, háromszög: augusztus-február)

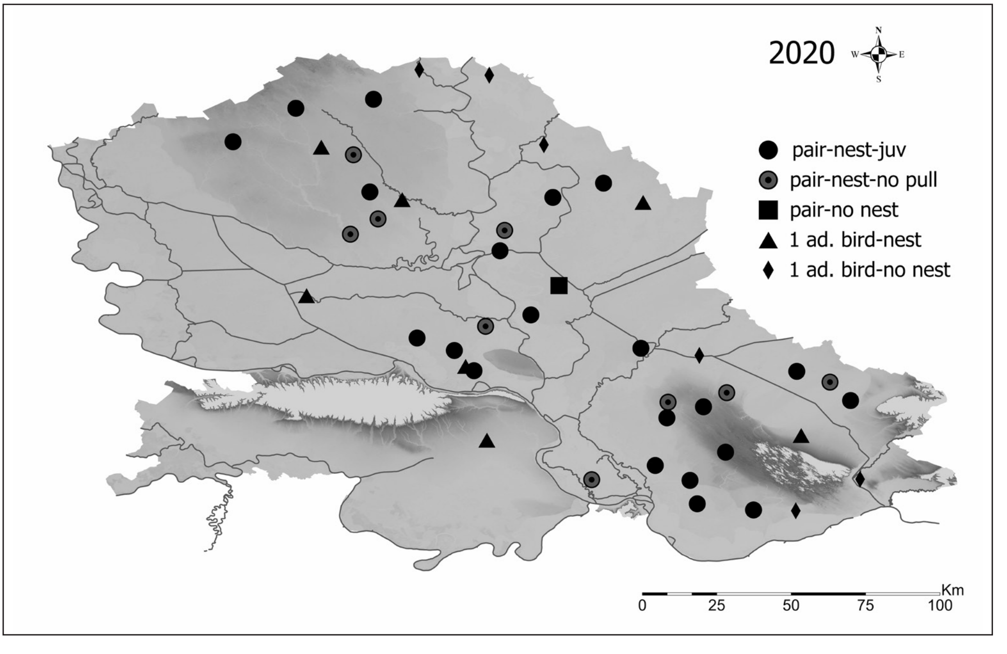

Figure 3. Occupied territories in the breeding period of Saker Falcon *Falco cherrug* in Serbia, in 2020

3. ábra A költési időszakban foglalt kerecsensólyom-revírek Szerbiában 2020-ban

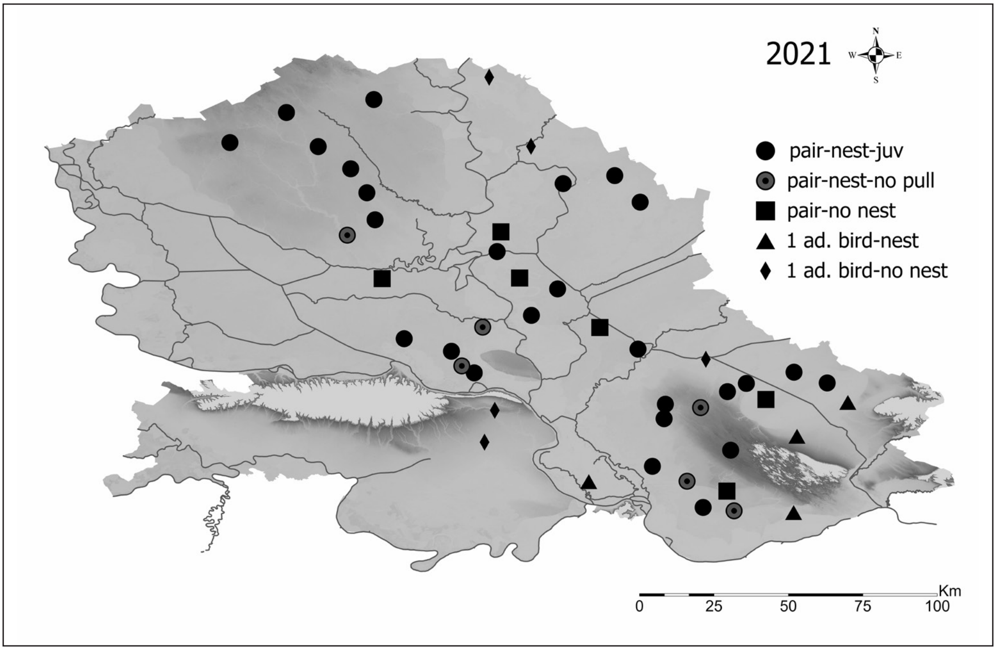

Figure 4. Occupied territories in the breeding period of Saker Falcon in Serbia, in 2021
4. ábra A költési időszakban foglalt kerecsensólyom-revírek Szerbiában 2021-ben

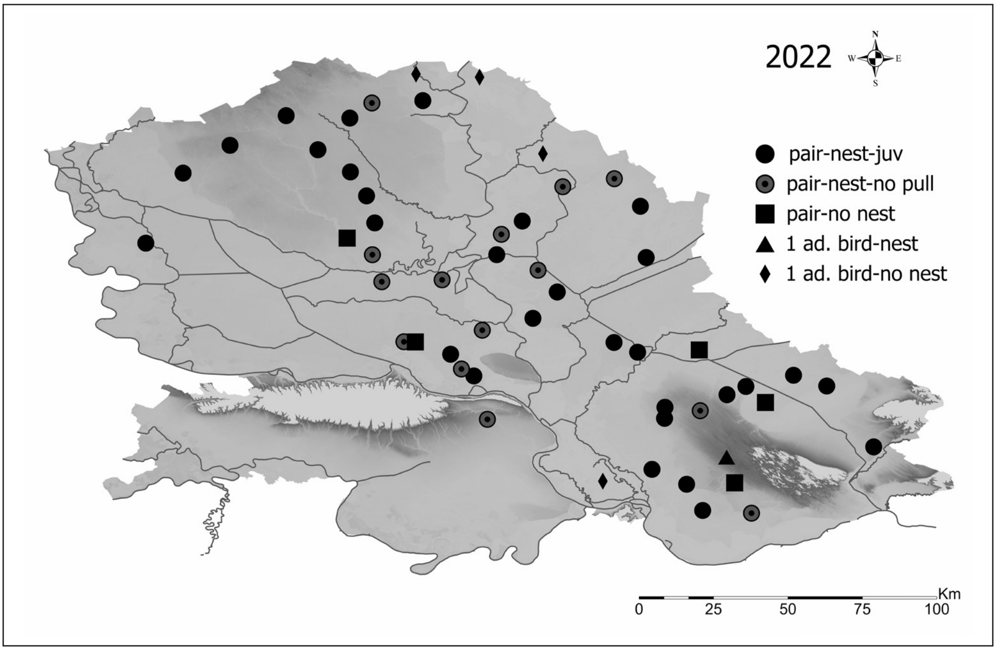

Figure 5. Occupied territories in the breeding period of Saker Falcon in Serbia, in 2022
5. ábra A költési időszakban foglalt kerecsensólyom-revírek Szerbiában 2021-ben

pairs were nested in central Banat and northern Bačka. The total breeding range in 2022 in Serbia (Vojvodina) therefore covered cca. 14,500 km^2.

During 2020–2022, adults were recorded in the reproductive period, in only a few localities in Vojvodina (Siget near Srpski Krstur and Jaroš near Mokrin, both in Banat), with no high-voltage transmission lines present in the wider area, so only potential breeding substrate are trees. According to oral information from colleagues dealing with eagles, in the same period, during the regular control of more than 150 existing nests of eagles *(Haliaeetus albicilla, Aquila heliaca, Clanga pomarina, Circaetus gallicus)* in the northern lowland part of Serbia, in forests, group of trees and on solitary trees, occupation by the Saker Falcon in the breeding period was not recorded.

Observations of Saker Falcon during 2020–2022 from the non-breeding period (August–February) were mostly recorded in the entire Banat and the eastern part of Bačka, where most of the breeding pairs are present as well, but a several number of recorded individuals, mostly sexually immatures in north-eastern Srem, is also noticeable, which suggests that Saker Falcon is slowly returning to that area.

Table 1. Breeding population of Saker Falcon in Serbia, 2020–2022
1. táblázat A kerecsensólyom fészkelőállománya Szerbiában, 2020–2022

Year / Region	Successful pair (nest-juv)	Unsuccessful pair (nest-no pull)	Pair on territory (no nest)	Single ad. on territory (nest)	Single ad. on territory (no nest)	Total
2020						
BAČKA	7	4	0	4	1	**16**
BANAT	14	5	1	3	4	**27**
SREM	0	0	0	0	1	**1**
Other parts of SERBIA	0	0	0	0	0	**0**
Total	**21**	**9**	**1**	**7**	**6**	**44**
2021						
BAČKA	10	3	1	0	0	**14**
BANAT	16	3	5	4	3	**31**
SREM	0	0	0	0	2	**2**
Other parts of SERBIA	0	0	0	0	0	**0**
Total	**26**	**6**	**6**	**4**	**5**	**47**
2022						
BAČKA	12	7	2	0	1	**22**
BANAT	18	6	3	1	3	**31**
SREM	0	1	0	0	0	**1**
Other parts of SERBIA	0	0	0	0	0	**0**
Total	**30**	**14**	**5**	**1**	**4**	**54**

There is a significant increase in the number of territories occupied by pairs or adult single birds in the breeding period of 2020–2022 in Serbia (Vojvodina), from 44 in 2020 to 54 in 2022 (122.7%). The number of localities with pairs present in the reproductive period also strongly increased from 31 in 2020 to 49 in 2022 (158.1%). Considering that the same method was applied during all three consecutive years, most probably these newly discovered adult individuals or pairs were not previously overlooked, and consequently it is a real population increase and expansion of breeding range. The number of successful pairs increased significantly, from 21 in 2020 to 30 in 2022, but also the number of pairs with an occupied nest but no successful breeding, increased from 9 in 2020 to 14 in 2022 *(Table 1)*.

The reason for the increase in the number of successful pairs is primarily due to occupation of previously repaired old nest boxes/platforms and installation of new ones which are suitable for breeding, with external bars for perching and wing strengthening and improved bottom of nests for incubation (shaggy rag floor cover was placed as a base and above it a layer of fine gravel, and in some cases third layer with a man-made nest consists of wooden branches). Moreover, a possible reason for the increase in the number of unsuccessful pairs is the occupation of new territories by unexperienced immature individuals, disturbance and unfavorable weather conditions.

Table 2. Breeding success of Saker Falcon in Serbia, 2020–2022
2. táblázat A kerecsensólymok költési sikere Szerbiában, 2020–2022

Year / Region	**Number of successful pairs**	**Total number of fledged individuals (Juveniles)**	**Average number of juveniles per successful pairs**	**Average number of juveniles per recorded pairs**	**Average number of juveniles per recorded occupied territories**
2020					
BAČKA	7	20	2.86	1.82	1.25
BANAT	14	40	2.86	2	1.55
SREM	0	0	0	0	0
Total/average	**21**	**60**	**2.86**	**1.91**	**1.36**
2021					
BAČKA	10	32	3.20	2.28	2.28
BANAT	16	44	3.14	1.76	1.37
SREM	0	0	0	0	0
Total/average	**26**	**76**	**2.92**	**1.95**	**1.58**
2022					
BAČKA	12	37	3.08	1.76	1.68
BANAT	18	59	3.27	2.18	1.90
SREM	0	0	0	0	0
Total/average	**30**	**96**	**3.20**	**1.96**	**1.77**

Out of the total number of recorded pairs (31) in breeding period during 2020, 21 pairs (67.7%) successfully fledged chicks. During 2021, the number of recorded pairs was 38, among which 26 were successful (68.4%), while in 2022, the number of pairs was 49, among which 30 were successful (61.2%). The highest number of fledglings from successful pairs was 5, in 5 cases, and the lowest number of fledglings was 1.

The total number of young individuals that successfully fledged from nests increased from 60 in 2020 to 96 in 2022, and the average number of reared young individuals per successful nest has grown from 2.86 in 2020 to 3.20 in 2022 *(Table 2)*. Positive trends in both cases are probably caused by favorable climatic conditions, without too much precipitation in the spring months (March–April), especially in 2022, as well as due to more than 40 newly installed nest boxes, and large number of the repaired ones.

During 2013–2014 in Serbia, almost all Saker Falcon pairs were nesting on high power line pylons in Common Raven nests, more precisely 87% of all recorded successful breeding pairs (Rajković 2013/1014). In the last three years, the situation has completely changed and a significant reason for that was certainly the numerous installations of metal boxes. Thanks to the increased availability of new artificial nests, evenly deployed in large open agriculture areas, and installed on pylons that are not too close to roads, buildings and settlements, in the last few years they have been massively occupied, both by pairs that were already present at the given locations, as well as by newly formed pairs. Although in 2013 only 1 out of 17 recorded successful pairs nested in an artificial nest (5.8%), during 2020 the share of

Table 3. Breeding places/occupied nests of successful pairs of Saker Falcon on towers of high-voltage transmission power lines in Serbia, 2020–2022

3. táblázat Sikeresen fészkelő kerecsensólyom párok fészkelőhelyei / foglalt fészkei nagyfeszültségű távvezeték oszlopokon Szerbiában, 2020–2022

Year / Breeding place	**Pylon type “Portal”**	**Pylon type “Jela”**	**Pylon type “Bure”**	**Total**
2020				
METAL BOX	2	6	0	8
WOODEN PLATFORM	2	1	0	3
RAVEN NEST	9	1	0	10
Total/average	**13**	**8**	**0**	**21**
2021				
METAL BOX	4	10	0	14
WOODEN PLATFORM	0	1	0	1
RAVEN NEST	7	3	1	11
Total/average	**11**	**14**	**1**	**26**
2022				
METAL BOX	7	13	0	20
WOODEN PLATFORM	1	1	0	2
RAVEN NEST	5	2	1	8
Total/average	**13**	**16**	**1**	**30**

successful pairs that nested in artificial nests was 52.2%, in 2021 it increased to 57.7%, and in 2022 it was 73.3% of all successfully breeding pairs in Serbia.

Although more wooden platforms (105) were installed compared to metal boxes (75), it is noticeable that there is much more occupancy rate by successful pairs of artificial metal boxes *(Table 3)*. That difference increases over time, so in 2022, 26.6% of existing metal boxes were occupied by successful pairs (20 of 75), compared to only 2.1% of occupied existing wooden platforms on pylons (2 of 94). If pairs that occupied artificial nests but were not successful in reproduction, are also included, then the importance of metal boxes for breeding additionally grows.

Three territorial pairs were also recorded (near Lokve and Jarkovac in Banat and near Bačko Gradište in Bačka), which occupied medium-voltage concrete transmission lines (35 kV) and the existing Common Raven nests on them. Those pairs were not breeding successfully.

On the line routes of transmission power lines where the pairs of Saker Falcon are line up along the route, the distance between adjacent pairs generally is not less than 6–7 km, while the shortest recorded distance between two adjacent active nests was 2.92 km near Padina in Banat and 3.76 km near Šajkaš in Bačka. The smallest distance of an active nest from the edge of a nearest settlement was 1 km, which was recorded in only one case. Three active nests were at 1.3 km from settlements, while most of the active nests, i.e. occupied territories were on more than 2 km distances from settlements.

Research in neighboring Hungary (Prommer *et al.* 2018), where there are similar environmental conditions as in Vojvodina (both within the Pannonian biogeographical region with similar agricultural methods, climate, etc.) has determined average home range for adult Saker Falcon in the reproductive period on 190 km^2. According to that it should be possible to estimate the total capacity of Vojvodina is cca. 84 breeding pairs of Saker Falcon, having in mind previous assessment that a suitable habitat for reproduction in Vojvodina covers an area of cca. 16,000 km^2.

Conclusions

The current breeding range of Saker Falcon in Serbia (Vojvodina) covers a relatively compact territory and gradually expands in the last few years. In 2020–2021, breeding range contained areas of the entire Banat and the eastern part of Bačka, and covered cca. 13,400 km^2, while in 2022, slowly expanded and covered cca. 14,500 km^2.

There is a significant increase in the number of territories occupied by pairs or adult single birds in the breeding period of 2020–2022 in Serbia (Vojvodina). The number of localities with pairs present in the reproductive period also strongly increased. All recorded pairs occupied pylons of high-voltage transmission power lines.

The number of successful pairs that nested in artificial nests increased significantly, from 52.2% to 73.3% of all successfully breeding pairs in Serbia during 2000–2022.

Out of the total number of recorded pairs (31) in the breeding period of 2020, 21 pairs successfully fledged young. In 2021, 26 pairs were successful, while in 2022, a total of 30 pairs were successful. Among successful pairs, the highest number of fledglings was 5 (in 5 cases), and the lowest number of fledglings was 1.

Acknowledgements

I would like to thank Nikola Stojnić for collaboration and help in improving the English version of the text, Aleksa Puzović and Snežana Đekić for making the maps, as well as to numerous other colleagues for their help during the fieldwork and for providing information related to Saker Falcon and eagle nests occupancy. Special acknowledgment goes to the employees and friends from Joint Stock Company „Elektromreža Srbije" who, with their selfless engagement, significantly contributed to the improvement of the Saker Falcon population in Serbia.

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Ornis Hungarica 2025. 33(1): 141–158.
DOI: 10.2478/orhu-2025-0008

Population recovery and spatial determinants of occupancy and breeding success in the Saker Falcon *(Falco cherrug)*: A study from Western Romania

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Received: May 09, 2024 – Revised: November 11, 2024 – Accepted: November 13, 2024

Prommer, M., Hegyeli, Zs. & Nagy, A. 2025. Population recovery and spatial determinants of occupancy and breeding success in the Saker Falcon *(Falco cherrug)*: A study from Western Romania. – Ornis Hungarica 33(1): 141–158. DOI: 10.2478/orhu-2025-0008

Abstract Despite the lowland area in Western Romania offering high-quality habitats for Saker Falcons, with abundant mammalian prey like the European Ground Squirrel (EGS), and proximity to the strong Hungarian population, Sakers mostly visited the region with few breeding attempts recorded before 2014. This changed after installing 83 aluminum nest boxes on high-voltage transmission line towers in a European Union funded conservation program, which encouraged settlement and led to a rapid growth in the Saker population. Our study, covering 2016–2023, analyzed population changes, focusing on nest box occupancy, nesting success, and brood size. Furthermore, we also investigated covariate effects by using generalized linear (mixed) models. By 2023, the population reached 43 pairs, with the nearest neighbor distance between occupied nest boxes decreasing from 9.9 km in the second year to 6.1 km in 2023. We evaluated 255 breeding attempts, 192 of which were successful, resulting in 794 young, while 63 attempts failed. The mean nesting success rate was 0.752±0.432 (n = 255), mean brood size per successful pair was 3.135±1.15 (n = 192), and mean brood size per all breeding attempts was 2.361±1.682 (n = 255). Evidence suggested that nest box occupancy positively correlated with the distance to nearest settlement, the cumulative grassland area within ten km, and the number of EGS colonies within 5 km of the nest boxes. The distance of nest boxes to the nearest EGS colony significantly and negatively impacted nesting success. Our results confirm that installing nest boxes can quickly establish a healthy population if nesting sites are the only limiting factor. These findings contribute to a more effective planning of future Saker conservation measures.

Keywords: Saker Falcon, Romania, nest box, occupancy, nesting success

Összefoglalás Annak ellenére, hogy Nyugat-Románia alföldi területei kiváló élőhelyet kínálnak a kerecsensólyom számára, gazdag emlős zsákmánnyal, például az európai ürgével, és e területek közel vannak az erős magyarországi populációhoz, a kerecsensólymok többnyire csak látogatóként jelentek meg a régióban, és kevés fészkelési kísérletet jegyeztek fel 2014 előtt. Ez megváltozott, miután 83 alumínium fészekládát telepítettek magasfeszültségű villanyoszlopokra egy Európai Unió által finanszírozott természetvédelmi program keretében, ami elősegítette a sólymok megtelepedését és gyors populációnövekedést eredményezett. Tanulmányunk, amely a 2016–2023 közötti időszakot öleli fel, a populáció változásait elemezte, különös tekintettel a fészekládák foglaltságára, a fészkelési sikerre és a fiókaszámra. Vizsgáltuk továbbá egyes magyarázó változók hatását általános lineáris (vegyes) modellek segítségével. 2023-ra a populáció 43 párra nőtt, a foglalt fészekládák közötti legközelebbi szomszéd távolság a második évi 9,9 km-ről 6,1 km-re csökkent 2023-ban. 255 költési kísérletet értékeltünk ki, amelyből 192 volt sikeres, 794 fiókát eredményezve, míg 63 kísérlet sikertelen volt. Az átlagos fészkelési siker 0,752±0,432 (n = 255), az átlagos fiókaszám sikeres páronként 3,135±1,15 (n = 192), az összes szaporodási kísérletre vonatkozó átlagos fiókaszám pedig 2,361±1,682 (n = 255) volt. Az eredmények arra utalnak, hogy a fészekládák foglaltsága pozitívan korrelált a legközelebbi település távolságával, a 10 km-en belüli összes füves terület nagyságával, továbbá az öt km-en belül található ürgekolóniák számával. A fészekládák távolsága a legközelebbi ürgekolóniáktól jelentősen és negatívan befolyásolta a fészkelési sikert. Eredményeink megerősítik, hogy ha az egyetlen korlátozó tényező a fészkelőhelyek hiánya, a fészekládák telepítésével gyorsan létrehozható egy egészséges populáció. Ezek az eredmények hozzájárulnak a jövőbeli kerecsensólyom-védelmi beavatkozások hatékonyabb tervezéséhez.

Kulcsszavak: kerecsensólyom, Románia, fészekláda, foglaltság, fészkelési siker

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Introduction

In the turn of the 19th and 20th centuries, the Saker Falcon (*Falco cherrug,* hereinafter referred to as 'Saker') certainly occurred in the southeastern part of the Carpathian basin (Csörgey 1897, Chernel 1899), and it was common in the lowlands of Romania, particularly along the Danube, and in the Danube Delta (Linţia 1954). Over the past hundred years, however, extensive human-induced habitat changes and direct persecution have drastically reduced their numbers. Today, this falcon species is categorized as Endangered on the Red List of breeding birds of Romania (MEWF 2022). In recent times, there is a new, emerging population of Sakers in the western part of the country along the Hungarian border. Those pairs form the edge of the increasing Central European Saker population. Besides, there are a few pairs in Dobrudja, southeast Romania, which represent the remaining westernmost part of the rapidly decreasing Eastern European population (Ajder *et al.* 2025, Fântână *et al.* 2025, Prommer *et al.* 2025).

The Saker once bred in the lowlands of Western Romania, though historical data remains sparse to estimate the former population size. The last confirmed breeding in this area occurred during the 1970s in the Mureş River floodplain (Libus, A. *pers. comm*). This region remains a vital habitat for the European Ground Squirrel *(Spermophilus citellus)*, hereinafter referred to as 'EGS') in Central Europe, hosting about 280 colonies. The EGS, along with the Feral Pigeon *(Columba livia* f. *domestica)*, is a preferred prey of the Saker, a species specializing on small mammals of open areas (Baumgart 1991). Just like the Common Hamster *(Cricetus cricetus)*, which is also widespread in the region (Hegyeli *et al.* 2015), and can become a locally important prey for Sakers during population outbreaks. While EGS are now largely confined to the remaining shortgrass pastures, the Common Hamster predominantly inhabits agricultural areas, where it can become a pest during population outbreaks. Furthermore, the population of the Common Hamster exhibits larger fluctuations than that of the EGS, making it a less reliable food source on an annual basis.

Despite the favorable foraging situation, the largely treeless, agricultural landscape offers few natural nesting opportunities, particularly because nests of corvids were routinely removed from high-voltage transmission line towers during annual maintenance. Between 2001 and 2013, ten artificial nest platforms were erected in suitable tree habitats. In 2006, a pair of Sakers was seen using one of these platforms, although no breeding activity was documented (Hegyeli *et al.* 2019).

Between 2006 and 2014, during the first and second major Saker Falcon conservation programs in Central Europe funded by the European Union's LIFE Fund, 92 Sakers were equipped with satellite-receiving tracking devices (Prommer & Bagyura 2023). The data collected from these devices highlighted regions in Western Romania where the falcons spent extended periods. In addition, a survey took place in 2011 focusing on transmission lines using the experience from Hungary, where a high percent of the population breeds on such transmission line towers. One pair and another occupied territory were confirmed during the survey. In 2013, as part of the conservation work, the first young Saker was mounted with a tracker in Western Romania. Then, in the same year and in 2014, a total of 83 aluminum nest boxes were installed on transmission line towers within areas previously identified by the field survey and the movement patterns of the tracked Sakers. The locations (transmission line towers) were selected based on the tracks of satellite-tracked falcons, presence of favorable habitat, and the distance to settlements and asphalt roads. Our efforts were highly rewarded: as early as 2014, we identified six occupied territories from which 14 young successfully fledged (Hegyeli *et al.* 2019).

In this study, following our monitoring efforts, we aim to process the data gathered in the 2016–2023 period and to examine changes in the occupancy of nest boxes, as well as to explore demographic parameters (such as reproductive performance: nesting success and brood size) behind the population dynamics of the Saker in Western Romania. We also intend to identify potential factors impacting these parameters. Specifically, our hypotheses are as follows: (i) the distance to the nearest foraging area will have a negative effect on occupancy and reproductive parameters, with shorter distances associated with higher probabilities of occupancy, greater nesting success, and larger brood sizes; (ii) we assume that occupancy and reproductive performance positively correlate with the number of available EGS colonies and the cumulative areas of grassland; and (iii) we hypothesize that an increasing distance from the nearest settlement will positively influence both the probability of occupancy and reproductive performance.

Methods

Study site

The study site is in Western Romania, on the eastern edge of Central Europe. It is a 10–80 km wide strip running parallel to the Hungarian border, bordered by Serbia to the south and Ukraine to the north *(Figure 1)*. With its surface area of 17,100 km^2, it represents 7% of Romania's area (Grecu 2010). Geographically, it lies on the eastern edge of the Carpathian Basin lowlands. Accordingly, the climate and vegetation are similar to those of the Hungarian Great Plain and the Vojvodina province in Serbia, as these regions are part of the same lowland.

The average elevation of the study site is around 100 meters above sea level, with a minimum of 75 m and a maximum of 200 m. The terrain is mostly flat in the southern part, with elevation slightly rising towards the north and east. The average annual temperature is 11 °C in the Banat Plain, and decreases towards the north, with a value of 9.7 °C in

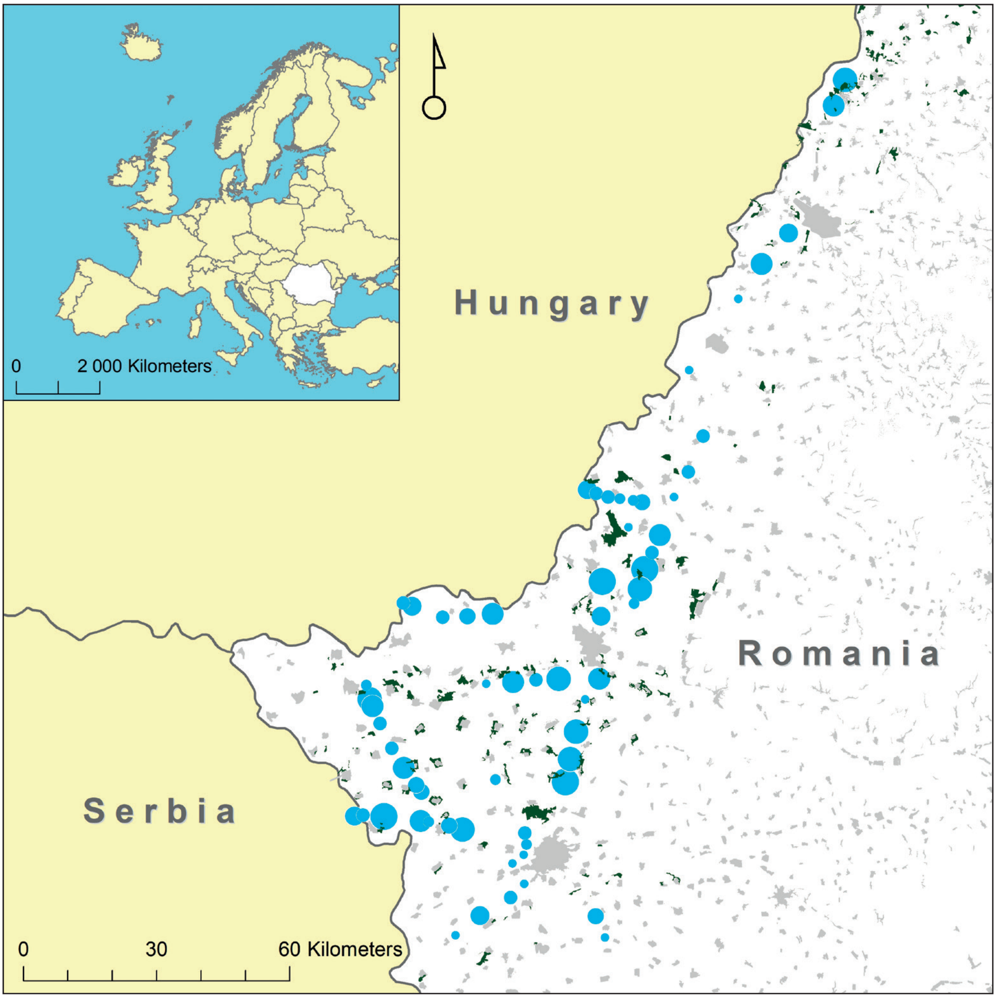

Figure 1. Romania in Europe (inlet) and the study area in Western Romania. Blue circles indicate the locations of the nest boxes; the size of each circle represents the number of years the given box was occupied. Dark green patches represent the grassland areas with colonies of the European Ground Squirrel *(Spermophilus citellus)*, and the settlements are shown in light grey (not all are shown to the east)

1. ábra Románia Európában (kis térkép) és a kutatási terület Nyugat-Romániában. A kék körök jelzik a fészekládák elhelyezkedését; minden kör mérete jelzi, hogy hány éven át volt lakott az adott fészekláda. A sötétzöld foltok az ürge *(Spermophilus citellus)* kolóniáknak otthont adó gyepeket jelölik, a településeket pedig világosszürke színnel ábrázoltuk (a keleti részen nincs minden település feltüntetve)

Satu Mare. Values of average January temperatures range from -1 °C to +3 °C, while July temperatures range from 20 to 22 °C. Average annual rainfall is 540–550 mm in the west and 700 mm in the east, with maximum amounts of 80-100 mm in June (in the Someș Plain). The annual number of snow days is 20. The prevailing winds are westerly, with an average annual speed of over 3 m/s, with a maximum of 23–27 m/s (Grecu 2010).

The area, once covered by riverine forest-steppe and steppe, is now predominantly used for agriculture. It encompasses four main cities – Satu Mare, Oradea, Arad, and Timișoara – which also serve as the administrative centers of Satu Mare, Bihor, Arad, and Timiș counties, respectively, as well as 14 smaller towns. These smaller settlements are characterized by their generally sizable populations (often over 3,000 people) and by the relatively large distances between them.

Grassland areas with EGS colonies

The study region supports a viable population of EGS. For processing spatial information about nest boxes in relation to spatial covariates, we utilized GIS layers of grasslands (primarily pastures) with known EGS colonies. Each grassland area was considered to host one EGS colony, thereby equating the number of colonies with the number of grassland areas, a method that closely approximates reality regardless of the areas' sizes. Our focus on EGS and grasslands is supported by literature (Bagyura *et al.* 1994, Nedyalkov *et al.* 2014, Chavko *et al.* 2019), and corroborated by unpublished local studies, which utilized nest cameras and analyzed prey remains, and demonstrated the high proportion of EGS in the Sakers' diet during the breeding period (Hegyeli *et al*. unpublished).

Nest boxes

A total of 83 nest boxes were installed on transmission line towers (ranging from 110 to 400 kV) managed by different electricity distribution companies (Electrica S.A., ENEL România, and C.N.T.E.E. Transelectrica S.A.). The towers range from 21 to 41 meters in height, with the nest boxes typically installed on the lower (cross) arms of the towers, at a minimum height of 17 meters from the ground. The 60 cm × 60 cm boxes are made of aluminum (Fidlóczky *et al.* 2014), and most of them are oriented with two open sides facing southeast to shield against the prevailing winds and precipitation. To encompass the entire population and all breeding attempts, we included a pair occupying a natural nest, bringing the total number of nesting sites to 84. No other pair in natural nest was known during the study period. For simplicity, we will refer to all these nesting sites as "nest boxes" throughout the rest of the article. We used the nest boxes' GPS coordinates for spatial analyses.

Data collection

The dataset for this study was compiled through annual monitoring by the NGO Milvus Group starting in 2016. During the monitoring, nest boxes were visited at least twice in the breeding season: first at the start of the season (March to early April) to check occupancy, and then during the pre-fledging period, when nesting success and brood size were recorded, and the young were ringed occasionally. All the observations were made from the ground with a telescope. While the population began to increase as early as 2014, there was no monitoring conducted in 2015 due to various reasons. Consequently, our analysis is based solely on the data collected from the period 2016 to 2023.

Raw data for calculating covariates were collected from the EGS monitoring program (location of EGS colonies and grasslands) and publicly available GIS data sources.

Data processing

We calculated basic demographic parameters such as occupancy rate, changes in occupancy status, mean nesting success, and brood size using standard statistical methods. We calculated covariates that were not readily available, such as distances, and used assumed ranges for other calculations, such as the number of available colonies and cumulative area of grassland within specific distances.

We employed QGIS ver. 3.22.3 (QGIS Development Team 2021) for processing the GIS data and performing calculations and analyses. Since the nesting locations were artificially created, we did not calculate the NNI for occupying pairs.

We employed generalized linear mixed models (GLMMs; Agresti 2015) using R (version 4.3.2) within the RStudio computing environment (version 2024.04.1; R Core Team 2023) to test the effects of covariates on both nest box occupancy and nesting success, with year included as a random effect. Occupancy, nesting success, and brood size were the response variables, and the predictors included nest box distances to the nearest EGS colony and nearest settlement, as well as the number of colonies, and the areas of grassland patches with colonies within two, five, and ten km of the nest boxes.

Both occupancy and nesting success are binary outcomes (occupied/unoccupied and successful/failed, respectively). Therefore, we used a binomial GLMM with a logit link function in the model:

$$\log\left(\frac{\mu}{1-\mu}\right) = X\beta + Zu$$

where

- μ is the probability of successful breeding (response variable);
- X is a vector of predictor variables (covariates);
- β is a vector of coefficients corresponding to each of the predictor variables in X;
- Zu represents the random effects structure, where Z is the design matrix for random effects, and u is the vector of random effects (e.g. for region or year), and
- $g(\mu) = \log\left(\frac{\mu}{1-\mu}\right)$ is the logit link function that connects the linear predictor $X\beta$ to the probability of successful breeding μ.

Brood size varied between 1 and 5 (positive integers), so we used a Poisson distribution in the GLMMs. In these models, the random effects term Zu accounted for variability among years, allowing us to model unobserved heterogeneity and improve the accuracy of estimated fixed effects.

However, the GLMM encountered convergence issues for nesting success due to a lack of variance in the random effect. Since the random effect showed minimal or no impact, we excluded it and opted for a simpler Generalized Linear Model (GLM), which proved to be stable.

The GLM was:

$$\log\left(\frac{\mu}{1-\mu}\right) = X\beta$$

where the components of the equation are as defined above.

We standardized continuous covariates by subtracting means and dividing by standard deviations. Subsequently, we used the models to test the level of significance with a predetermined significance level (α) of 0.05 (Sokal & Rohlf 2011) to test our hypotheses.

We further investigated the significant covariate effects by calculating the effect size, quantified using odds ratios. Odds ratios were obtained by exponentiating the regression coefficients from the GLM models, providing an interpretable measure of the change in odds of the outcome associated with a one-unit increase in each covariate (Cohen 1988, Nakagawa & Cuthill 2007). Odds ratios greater than one indicate a positive association with the outcome, while those less than one indicates a negative association. We calculated statistics and visualized results in the R computing environment (R Core Team 2023).

In certain figures, we applied locally weighted smoothers (LOESS) to enhance the interpretability of data patterns through locally weighted regression. This method captures trends in the data without imposing a specific parametric structure, enabling a clearer depiction of relationships within the observed data.

Results

Occupancy

During the study period, a total of 84 nest boxes were available for Sakers. The observed mean nearest neighbor distance between all installed boxes was 4,414 m, which remained constant during the study period as no boxes were added or removed. Given that the nest boxes were attached to the same transmission line towers, the nearest neighbor index (NNI) showed clustering (n = 84, NNI = 0.412, Z-Score: -10.304).

Out of all nest boxes 67 (equating to 79.76%) hosted at least one nesting event (breeding attempt or successful breeding) out of the recorded 255 events. The boxes were unoccupied (no nesting event was recorded) on 417 occasions. Only four boxes saw occupancy in all eight years. Seventeen boxes were never occupied by Sakers throughout the study period. The observed mean nearest neighbor distance was highest (9,924 m) in the second year, 2017, and then it gradually decreased to 6,114 m by 2023 *(Figure 2)*.

The occupancy status of the individual boxes changed from year to year; however, this variation was independent of the population's absolute size and the annual population growth rate *(Figure 3)*. The mean change rate (and standard error, SE) was 0.2551±0.00931 (n = 672), which varied moderately, ranging from 0.2262 (from 2018 to 2019 and from 2021 to 2022) to 0.2857 (from 2020 to 2021 and from 2022 to 2023).

Further investigating occupancy, we compared occupied and unoccupied nest boxes in relation to the covariates. We found strong evidence that occupied nest boxes were located farther from

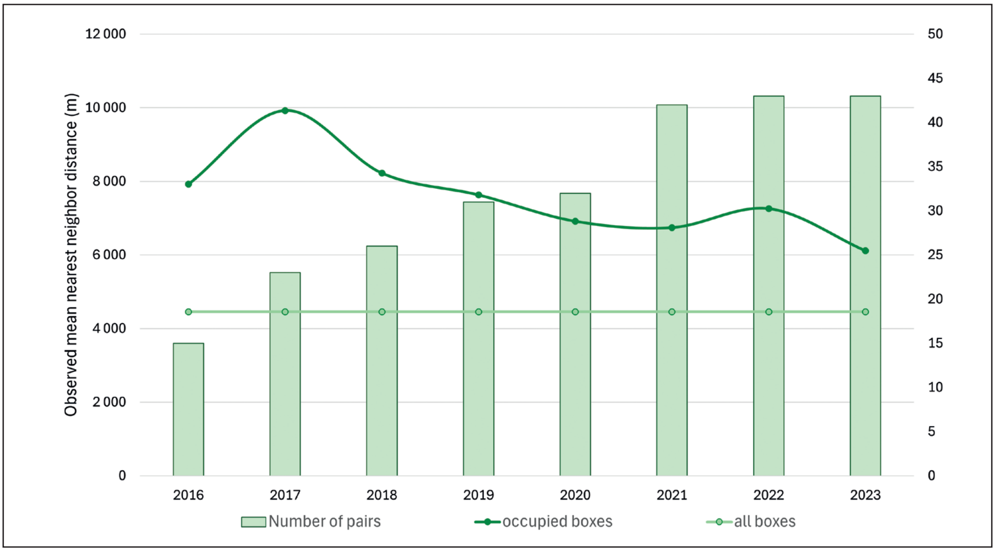

Figure 2. Population size, observed nearest neighbor distance between all the installed nest boxes (constant value) and occupied nest boxes (annually changing with the population change) in the period 2016–2023.

2. ábra Az állományméret és a legközelebbi szomszéd távolság az összes (állandó érték), valamint a foglalt (az állomány változásával évente változó érték) fészekládák között a 2016 és 2023 közötti időszakban

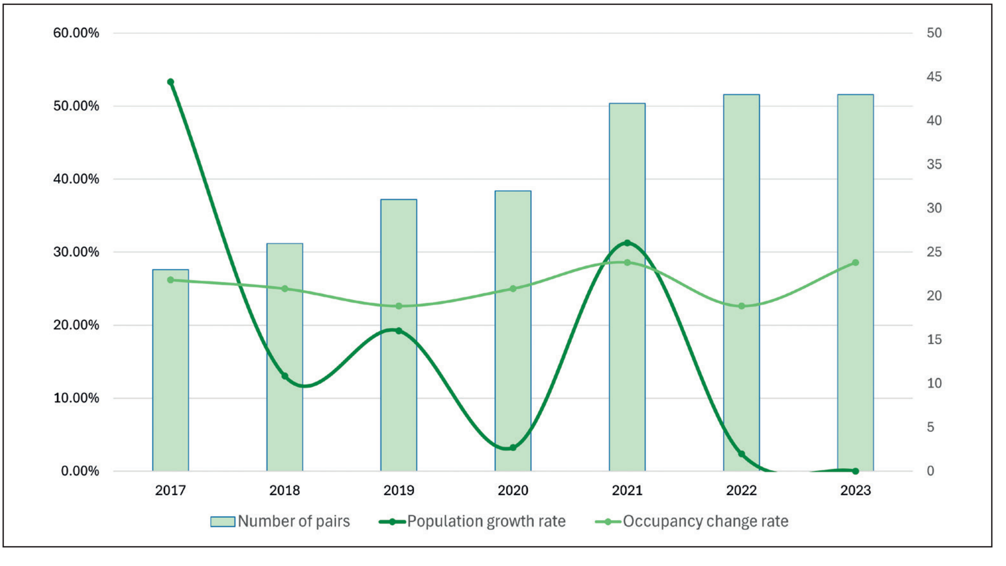

Figure 3. Changes in number of pairs, population growth rate, and nest box occupancy status. Latter means the rate at which status of nest boxes (occupied ⇆ unoccupied) changed from one year to another

3. ábra A párok számának, a növekedési rátának, valamint a fészekládák foglaltsági állapotának változása. Utóbbi azt fejezi ki, hogy a milyen arányban változott a fészekládák státusza (foglalt ⇆ üres) az egyes évek között

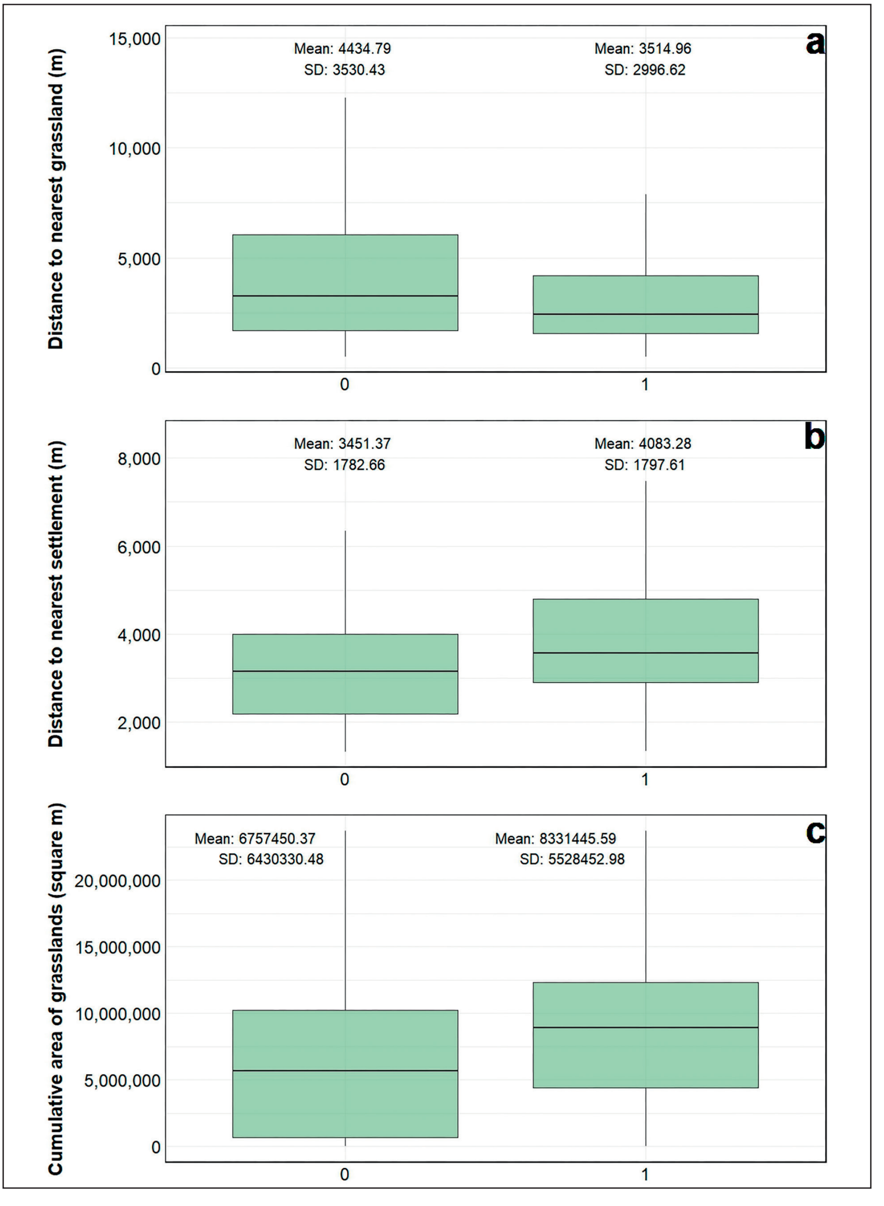

Figure 4. Differences between unoccupied (0) and occupied (1) nest boxes were analyzed with respect to various covariates. There is strong evidence for the effects of (a) the distance to the nearest settlements (estimate ± SE = 0.413±0.089, z = 4.633, p < 0.001) and (b) the cumulative area of grasslands within ten kilometers of the nest boxes (estimate ± SE = 0.251±0.121, z = 2.08, p = 0.038)

4. ábra Az üresen álló (0) és a lakott (1) költőládák közötti különbségeket különböző magyarázó változók tekintetében elemeztük. Erős bizonyítékot találtunk az alábbi tényezők hatására: (a) a legközelebbi települések távolsága (becslés ± SE = 0,413±0,089, z = 4,633, p < 0,001), valamint (b) a költőládáktól számított tíz kilométeres körzeten belüli gyepek együttes területe (becslés ± SE = 0,251±0,121, z = 2,08, p = 0,038)

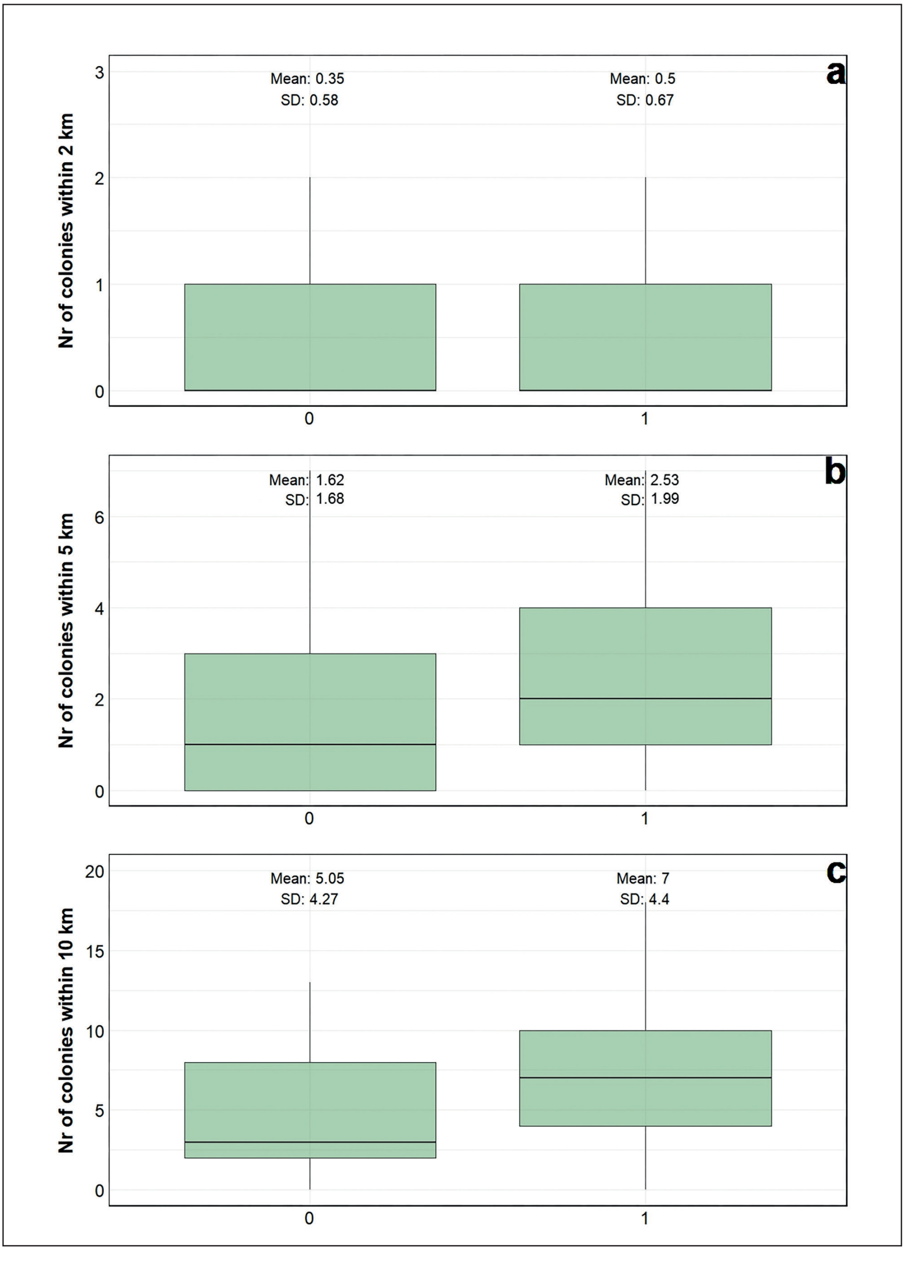

Figure 5. Differences between unoccupied (0) and occupied (1) nest boxes were analyzed with respect to the number of available EGS colonies within specific distances. We found strong evidence for an effect of the number of colonies within five kilometers of the nest boxes on occupancy (estimate ± SE = 0.385±0.158, z = 2.441, p = 0.015)

5. ábra Az üres (0) és a foglalt (1) költőládák közötti különbségeket elemeztük az elérhető ürgekolóniák számának függvényében, meghatározott távolságokon belül. Erős bizonyítékot találtunk arra, hogy a költőládától számított öt kilométeres körzetben lévő kolóniák száma hatással van a költőládák foglaltságára (becslés ± SE = 0,385±0,158, z = 2,441, p = 0,015)

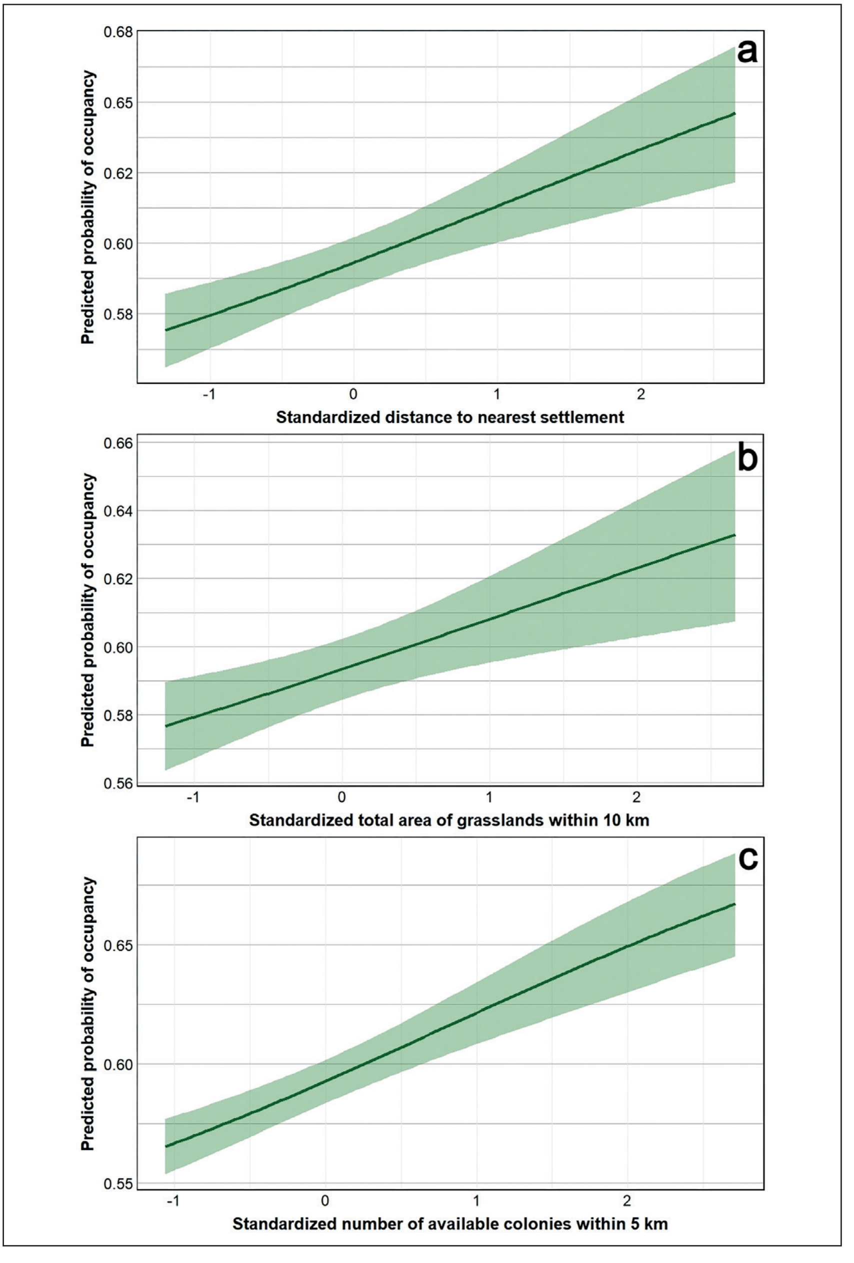

Figure 6. Covariates with a significant effect on nest box occupancy. Distance to the nearest settlement (a), cumulative area of grasslands within a ten km radius (b), and number of EGS colonies within five km (c) have a positive effect on occupancy rate. The light green area represents the 95% confidence interval

6. ábra A fészekládák foglaltságára jelentős hatással bíró magyarázó változók. A legközelebbi településtől való távolság (a), a tíz km-en belül található összes gyepterület nagysága (b), valamint az öt km-en belül található ürgekolóniák száma (c) pozitív hatással van a foglaltságra. A világoszöld sáv a 95%-os konfidencia intervallumot jelöli settlements (estimate ± SE = 0.413 ± 0.089, z = 4.633, p < 0.001) and were surrounded by a larger cumulative area of grasslands within a 10 km radius (estimate ± SE = 0.251±0.121, z = 2.08, p = 0.038) *(Figure 4)*. Additionally, occupied nest boxes had more EGS colonies within a 5 km radius (estimate ± SE = 0.385±0.158, z = 2.441, p = 0.015) *(Figure 5).*

The effect size results, represented as odds ratios, indicated that for each additional EGS colony within five km, the odds of nest box occupancy increased by 47% (OR = 1.47). Distance from settlements showed an odds ratio of 1.51, and the cumulative grassland area within a ten km radius had an odds ratio of 1.29, indicating a 51% and 29% increase in the odds of occupancy, respectively. Significant effects on occupancy are visually represented in *Figures 6*, while detailed results of significance testing, and effect size calculations can be found in *Table 1*.

Reproductive success

During the study period from 2016 to 2023, the known population of pairs increased from 15 to 43. In total, 255 breeding attempts were recorded, with 192 being successful and 63 unsuccessful. The frequency of successful breeding attempts paralleled the growth in population size *(Figure 7a)*. The average nesting success rate for the period was 0.752±0.432 (n = 255), with a range from 0.677±0.475 in 2019 (n = 31) to 0.86±0.35 in 2022 (n = 43), as depicted in *Figure 7b*. No annual trend in nesting success was discernible. Strong evidence indicated that the distance to the nearest EGS colony had a significant reverse impact on nesting success (-0.6±0.236, z = -2.548; p = 0.011) *(Figure 8)* with substantial effect size *(Table 1)*.

We recorded a total of 794 young in the study period. The average number of fledglings per successful breeding attempt was 3.135±1.15 (n = 192), with yearly averages ranging from 2.545±1.128 in 2016 (n = 11) to 3.706±0.985 in 2017 (n = 17) *(Figure 7c)*. Across all breeding attempts, the mean brood size was 2.361±1.682 (n = 255), varying from 1.867±1.505 in 2016 (n = 15) to 2.739±1.864 in 2017 (n = 23). We found no evidence of covariate effects on brood size. The brood size distribution was normally distributed (Shapiro-Wilk normality test, W = 0.90361, p = 0.4302) *(Figure 9)*.

Table 1. Detailed results of significance testing and effect size calculations for covariates with significant effects

1. táblázat A szignifikáns hatást mutató magyarázó változók szignifikancia próbáinak és a hatások számított nagyságainak részletes eredményei

Model (response variable ~ covariate)	**Significance testing**				**Effect size**	**Comment**
	estimate	*SE*	*z value*	*p value*	*odds ratio*	
occupancy ~ distance to settlement	0.413	0.089	4.633	< 0.01	1.51	moderate effect
occupancy ~ cumulative grassland area within 10 km	0.251	0.121	2.080	0.038	1.29	moderate effect
occupancy ~ number of EGS colonies within 5 km	0.384	0.158	2.441	0.015	1.47	substantial effect
nesting success ~ distance to colony	-0.600	0.236	-2.548	0.011	0.55	substantial effect

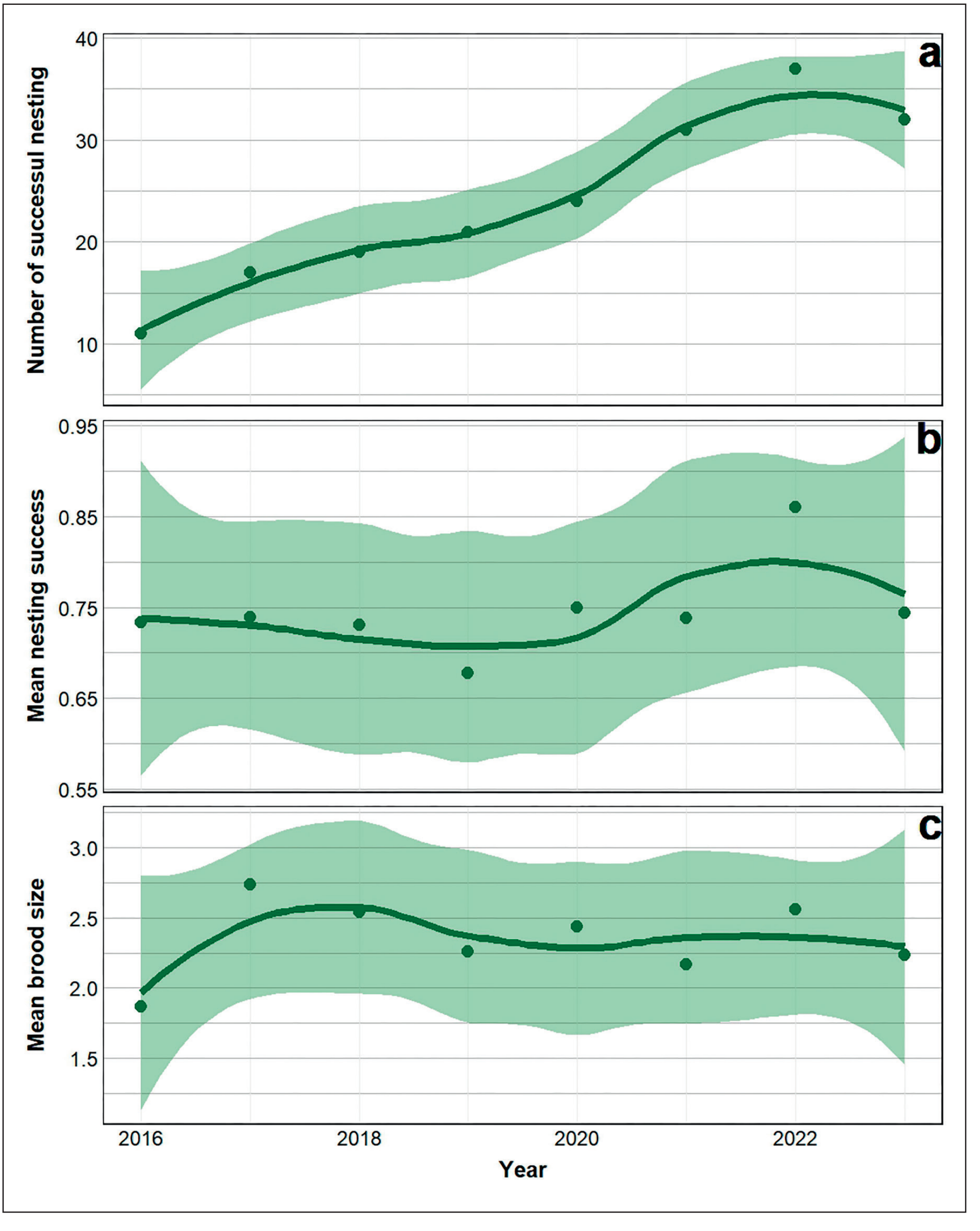

Figure 7. Demographic parameters of the Saker population in Western Romania in the period 2016–2023 a) number of successful breeding; b) mean breeding success; c) mean brood size per successful breeding. Lines are fitted using LOESS; the light green area highlights the 95% confidence interval

7. ábra A nyugat-romániai kerecsensólyom állomány demográfiai paraméterei 2016 és 2023 között: a) a sikeres költések száma; b) átlagos költési siker; c) sikeres költésenkénti átlagos fiókaszám. A vonalak LOESS módszerrel illesztettek, a világoszöld terület a 95%-os konfidencia intervallumot jelöli

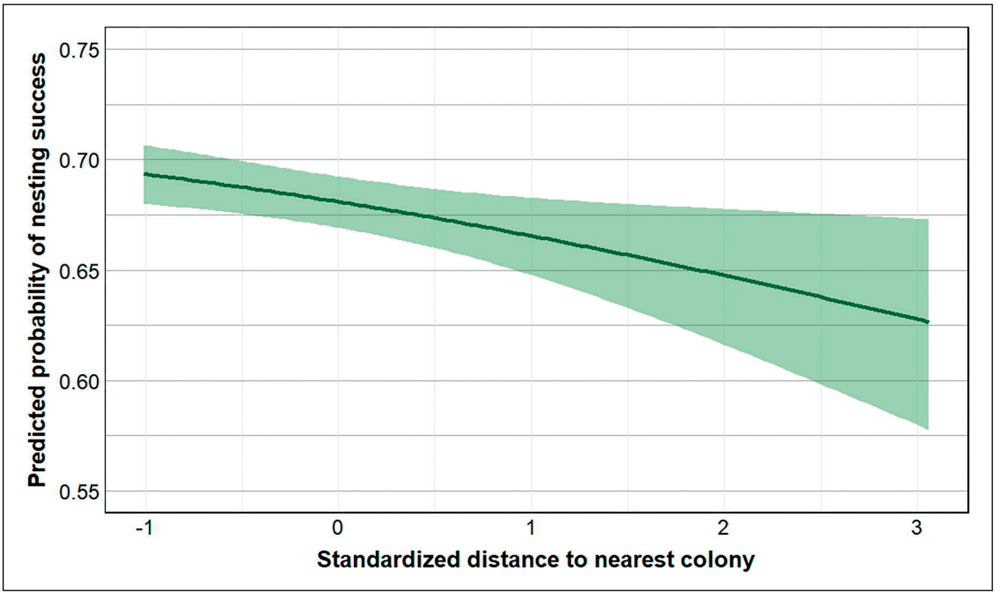

Figure 8. The significant effect of distance to nearest EGS colony on the probability of nesting success. The light green area shows a 95% confidence interval

8. ábra A legközelebbi ürgekolóniától való távolság szignifikáns hatása a fészkelési siker valószínűségére. A világoszöld sáv a 95%-os konfidencia intervallumot jelöli

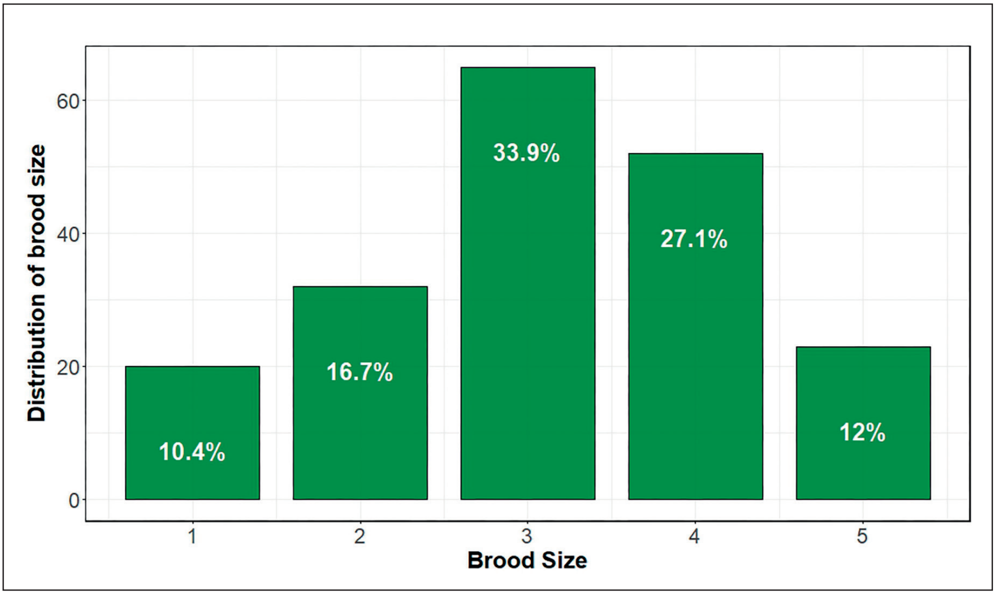

Figure 9. Distribution of brood sizes from 192 successful nesting attempts, resulting in 602 young

9. ábra A fészekaljankénti fiókaszámok eloszlása 192 sikeres fészkelésből, ami 602 fiókát eredményezett

Discussion

The effectiveness of artificial nesting sites such as nest platforms and nest boxes in facilitating the growth and expansion of Saker populations in otherwise suitable areas has been demonstrated in Austria, Hungary, Slovakia, and Mongolia (Chavko *et al.* 2014, 2019, Fidlóczky *et al.* 2014, Rahman *et al.* 2014, 2016, Zink *et al.* 2025). Falcons do not construct their own nests, hence in areas lacking pre-existing nests built by other species or natural cliffs to lay eggs, they do not breed. However, these regions are still utilized as indicated by satellite-tracking data, showing that falcons are quick to exploit new nesting opportunities when they become available. This approach has also been successful in Western Romania.

Historical data on the population size of Sakers in Western Romania are limited, making it difficult to establish a reliable baseline. The region's breeding population began to rapidly expand after 2014, following the implementation of active conservation measures under European Union-supported LIFE projects, which provided nesting sites for the species. This expansion coincided with the stabilization of the Hungarian population, which had by then seemingly saturated its available habitats (Bagyura *et al.* 2017). The rapid occupancy of the installed nest boxes suggests that the habitat and prey availability in the region were highly favorable for Sakers. Notably, (1) there was only three known breeding in the region prior to this in natural nests, (2) the sudden emergence of more than a dozen pairs shortly after the installation of the boxes, and (3) juvenile dispersal data from Hungary indicate that the initial breeders likely immigrated from neighboring countries, primarily Hungary, but possibly also from Serbia, Slovakia, Austria, or the Czech Republic. The observation of a female ringed in 2020 in Romania and found breeding in Hungary in 2022 (Hungarian Bird Ringing Centre 2024) lends further credence to this theory. Satellite-tracking data suggests, however, that it is less likely that Sakers immigrated from the declining populations in Eastern Romania or south-southwest Ukraine.

The connection between breeding success and the proportion of mammals in the diet of Sakers was established in a recent study in Mongolia (Zhang *et al.* 2024). In Central Europe, earlier studies (Bagyura *et al.* 1994, Chavko *et al.* 2019) and unpublished data (Hegyeli *et al*. unpublished) indicate that the EGS constitutes a significant part of the Sakers' diet. Thus, the abundance of EGS in Western Romania likely explains the population boom in Sakers once nest boxes were introduced in areas previously devoid of nests but otherwise suitable for habitation.

The number and proximity of foraging grounds to the nest implies a more favorable cost-benefit ratio in terms of energy expenditure. This may explain the higher occupancy rate of nesting boxes, where more colonies are within five km, and the greater nesting success in nest boxes nearer to grasslands that host EGS colonies. The importance of the number of available EGS colonies on occupancy may be related also to the annual fluctuations in population sizes of individual colonies. A higher number of colonies near the nest boxes may increase the likelihood that some colonies maintain sufficiently high EGS densities to support "economically viable" hunting, even if other colonies experience depletion. However, further studies are needed to confirm or refute this hypothesis. The larger cumulative area of grasslands within a ten km radius may also contribute positively, as more extensive grassland areas are likely to encompass more accessible EGS colonies. Additionally, greater distances from the nearest settlement may reduce disturbances during the breeding season, potentially enhancing breeding success.

Interestingly, while the proximity and number of hunting grounds appear to explain occupancy and, to some extent, nesting success, these covariates do not seem to influence brood size. We cannot exclude the possibility that brood size is more closely related to the population density of EGS colonies than to the proximity or number of available colonies; however, this hypothesis requires further investigation. Acquiring such data is particularly challenging due to the extensive time and effort involved, especially since, in addition to Saker reproductive success data, density data for all colonies in the area would need to be collected. Satellite-tracking of Sakers (Prommer & Bagyura 2023) has shown that breeding adults are willing to travel up to 25 km daily to visit specific EGS colonies, often bypassing other, presumably less favorable colonies along the way. This behavior likely indicates the importance of EGS density, and it aligns also with a study demonstrating the benefits of *'flying the extra mile'* when the distant foraging ground offers a more abundant or easily exploitable resource (Soriano-Redondo *et al.* 2021).

In summary, our results reaffirm that Sakers respond positively to conservation interventions under favorable habitat conditions. We demonstrated that the availability of prey, measured by the proximity, number, and size of grassland areas hosting EGS colonies, affects occupancy and, to some extent, nesting success, though not brood size. Furthermore, the findings suggest that Sakers are likely to compensate for annual fluctuations in prey availability by primarily occupying nest sites with the broadest access to potential foraging grounds with EGS colonies. Our results suggest the Sakers' strong preference for EGS when available. In Hungary and Slovakia, the dramatic decline in the EGS population (Cserkész 2018) has removed them from the Sakers' diet (Bagyura *et al.* 1994, 2017, Chavko *et al.* 2019), leading to a dietary shift towards domestic pigeons, which may increase conflicts with pigeon fanciers. Additionally, there are indications that a lower proportion of mammalian prey in the diet may be associated with reduced productivity (Karyakin *et al.* 2022). Therefore, it is of utmost importance that pastures hosting EGS colonies are conserved – not only for the benefit of these two species but also for other steppe-dwelling species. Additionally, these grasslands must be maintained on a scale large enough to allow ecological processes to function properly, such as accommodating spatio-temporal changes in prey-predator dynamics.

Acknowledgements

This work was made possible thanks to projects LIFE09 NAT/HU/000384 and LIFE13 NAT/HU/000183, funded by the LIFE Program of the European Union. We are most grateful to János Bagyura (MME-BirdLife Hungary), and colleagues from Milvus Group: Lőrinc Bărbos, Szilárd J. Daróczi, Attila Dósa and Attila Marton for their invaluable help in the monitoring activities.

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Ornis Hungarica 2025. 33(1): 159–176.
DOI: 10.2478/orhu-2025-0009

The Saker Falcon *(Falco cherrug)* in Southern Romania: population, trend and habitat requirements in the breeding season

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Received: March 03, 2022 – Revised: November 08, 2024 – Accepted: November 09, 2024

Fântână, C., Veres-Szászka, J., Szabó, J., Bugariu, S., Todorov, E., Drăgan, D., Damoc, D., Veres-Szászka, N., Domșa, C., Pui, A., Benkő, Z. & Pál, L. 2025. The Saker Falcon *(Falco cherrug)* in Southern Romania: population, trend and habitat requirements in the breeding season. – Ornis Hungarica 33(1): 159–176. DOI: 10.2478/orhu-2025-0009

Abstract We summarise the monitoring efforts for the Saker Falcon *(Falco cherrug)* in Southern Romania between 2016 and 2023, presenting population size and short-term population trend. Using the degree of occupancy of 31 artificial and 5 natural nests, we analyse the species' preferences when choosing nesting sites in relation to the presence of grasslands, agricultural lands, settlements and woodlands around the nest. Considering the large-scale wind farm developments of the past 15 years in the Saker's Dobrudjan range, we also analyse the effect of wind farms on nest site selection. We estimate the size of the Saker population in Southern Romania to 7–9 pairs. The core of this population is in Dobrudja, with occasional breeding attempts in the rest of Southern Romania. While the species has occupied nests with relatively large areas of grassland in their 10 km radius, the proximity of grasslands around the nest is not a key factor in nest site selection. The Sakers avoided occupying nests with turbines closer than 2 km to them and the average number of turbines was significantly lower to up to 10 km around the nest in the occupied territories.

Keywords: Saker Falcon, Southern Romania, nest occupancy, habitat use, wind farms

Összefoglalás A dél-romániai kerecsensólyom-állomány 2016 és 2023 közötti felméréseinek eredményeit összegezzük, bemutatva az aktuális populációméretet és rövidtávú trendet. Emellett 31 költőláda és 5 természetes fészek adatai alapján elemezzük a faj fészekválasztási preferenciáját a gyepek, szántók, települések és erdők fészek körüli jelenléte szempontjából. Tekintve az elmúlt 15 év nagyléptékű szélerőmű-beruházásait a kerecsensólyom dobrudzsai elterjedési területén, a szélerőműparkok fészekválasztásra gyakorolt hatását is vizsgáljuk. A dél-romániai kerecsensólyom-állományt 7–9 párra becsüljük. Az állomány magja Dobrudzsában található, alkalmankénti költési próbálkozásokkal Dél-Románia többi részén. Bár a faj olyan fészkeket foglalt el, amelyek viszonylag nagy gyepfelülettel rendelkeznek a 10 km-es körzetükben, a gyepek közelsége nem kulcsfontosságú a fészekválasztásban. A kerecsensólymok nem foglaltak el olyan fészkeket, amelyek 2 km-nél közelebb voltak egy szélerőműhöz, és a turbinák átlagos száma is alacsonyabb volt a foglalt fészkek 10 km-es körzetében.

Kulcsszavak: kerecsensólyom, Dél-Románia, fészekfoglalás, élőhelyhasználat, szélerőművek

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Introduction

The Saker Falcon *(Falco cherrug)* used to be a widespread species in the lowlands of Romania at the beginning of the 20th century, being frequent especially on the Danube corridor and in the Danube Delta (Linția 1954). Following a century of human induced habitat alteration and direct persecution, nowadays the species has become increasingly rare at a national level, being considered as Endangered species according to the Red List of breeding birds of Romania (MEWF 2022). Currently the species is breeding in two geographically distinct strongholds, one in the western part of the country near the border with Hungary, part of the Pannonic or Central European Saker population and another in the southeastern part of Romania, in Dobrudja *(Figure 1).*

The Dobrudjan stronghold represents the southern limit of the East European (or Pontic) population which is continuing to the north, in Moldavia, Ukraine and Southern Russia (Bauer 2020), with a distribution that is following especially the Pontic steppe region and continuing further east in Asia. In the past, these two populations had a more-or-less continuous distribution, through the Southern Romanian Plain, where in the present, the breeding evidence is rather occasional, and Bulgaria, where during the last years the breeding evidence involved birds from reintroduction programs (Gradinarov *et al.* 2019). The most recent official estimates for Romania regarding the Saker Falcon indicate a population size of 6–10 pairs for the period of 2009–2013 (Societatea Ornitologică Română & Asociația Grupul Milvus, 2015) and 4–30 pairs for 2013–2018 (Fântână *et al.* 2021).

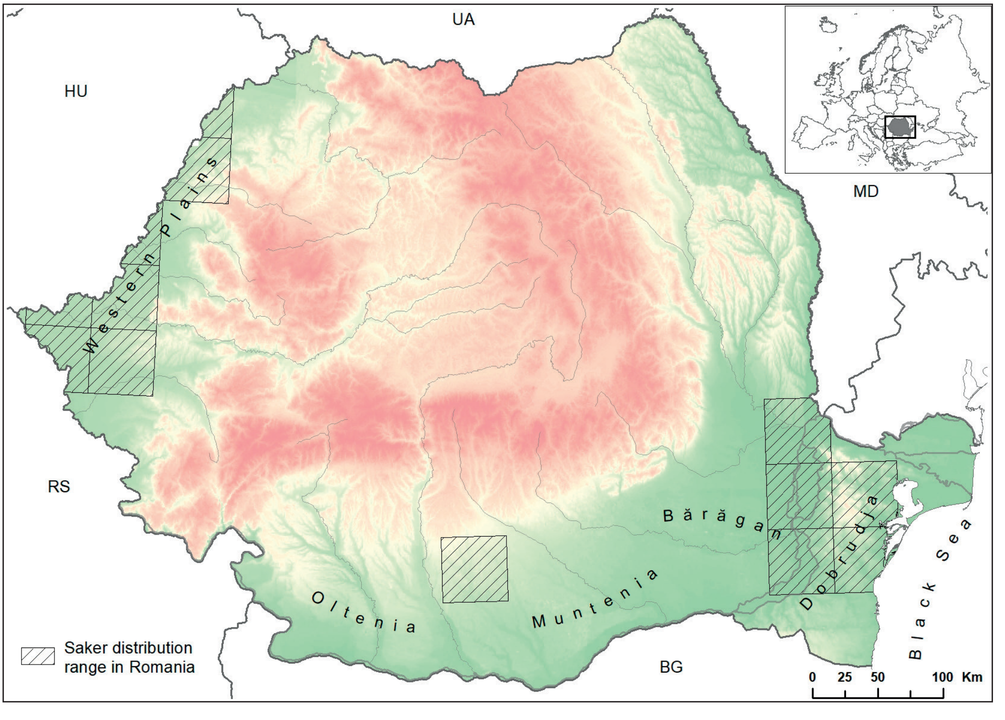

Figure 1. The current range of the Saker Falcon in Romania
1. ábra A kerecsensólyom jelenlegi elterjedése Romániában

The present article is dealing only with the Southern Romanian breeding pairs of the Saker Falcon, concentrating on the monitoring efforts between 2016 and 2023 in Dobrudja and the Romanian Plain (Oltenia and Muntenia regions) and analysing the degree of nest occupancy in relation with habitat types and settlements. Currently, the range of the Saker Falcon in Dobrudja is the subject of a large-scale expansion of wind farms, driven by the European Decarbonisation (COM 2015, 2022) and Energetic Independence Strategies (COM 2022). While there is a strong pressure for the use of wind energy, several studies show that while being a direct threat to soaring birds due to collision, wind farms are also responsible for the displacement of resident and migrating birds due to nesting and foraging habitat destruction (Thealander *et al.* 2003, Keil & Motter 2005, Fielding *et al.* 2006, Smallwood & Thealander 2008, Schaub 2012). The construction of maintenance roads and generally increased human activity can further impact a species sensitive to disturbance as the Saker Falcon (Tingley 2003). Based on available data, we also try to assess the effect of the presence of windfarms on nest site selection.

Materials and Methods

Trend and population size

To assess the population size, as a first step, from the historical range covered by Sakers in Southern Romania, we have selected, following especially the lowland distribution, the most suitable areas based on habitat and casual Saker observations. The resulting area has a surface of 28,065 km^2 and was the baseline area covered by censusing efforts in 2016, 2017, 2022 and 2023. Due to the large surface of the baseline area as well as human and time limitations, this area was not covered synchronously during one singular breeding season but in stages, covering different regions in different years. During this period, we covered the entire area by using two main methods: visual observation from preselected points and detailed investigation of suitable nesting locations.

Due to the large size of the area that had to be surveyed, census efforts undertaken outside Dobrudja, along the Romanian Plain in the historical regions of Oltenia and Muntenia have been spread over four years. In 2016 we covered, synchronously, in April, with 6 observers in two days, the area between the Danube River in the west, the Siret River's confluence with the Danube in the north and Bucharest in the west. In 2017, the effort was directed, synchronously, in April, with 6 observers in two days, toward west of Bucharest, to the Olt River and small areas west of the Olt River. In 2022, we visited again some of the areas we covered in 2016 and 2017 to confirm our findings. The general area surveyed was extended in Oltenia, to west of the Olt River as far as Drobeta Turnu-Severin, towards the Serbian Borders. Thus, Southern Romania has been covered in 2022, non-synchronously by eight observers in 22 days, in March – April. In 2023, the monitoring efforts in Southern Romania spanned 17 working days by three observers and were directed to the eastern part of the Bărăgan Plain, covering the areas along the Danube and in the western parts of the Romanian Plain in the counties Teleorman, Olt, Dolj and Mehedinți *(Figure 2)*.

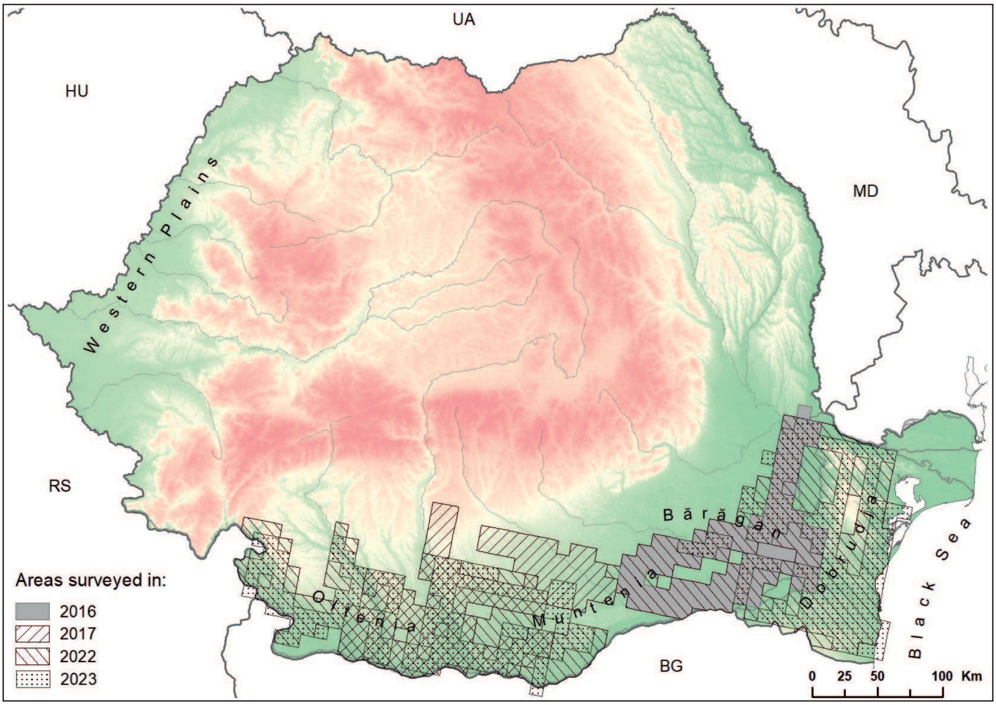

Figure 2. The coverage of census efforts in Southern Romania between 2016 and 2023
2. ábra A 2016 és 2023 között Dél-Romániában felmért területek

We visited Dobrudja, which represents the core area for the species' distribution in Romania, more frequently, the known territories being monitored also in 2019, 2020 and 2021, apart from the visits made in 2017, 2022 and 2023.

To assess the trend of the population, we monitored all the known occupied territories in 2017, 2019, 2020, 2021, 2022 and 2023. We implemented the monitoring scheme in Dobrudja with two observers for two days in March – April in 2017, 2020 and 2021, with three observers for four days in May and June in 2019 and with 5 observers in 2022, in March – April for 15 days. In 2023, the monitoring efforts in Dobrudja lasted 16 days and were implemented by five observers. In 2022 and 2023, we also managed to check the breeding success in May. We compared the results with the baseline index, established by the number of territories detected in Dobrudja between 2011 and 2014, during the LIFE09 NAT/HU/000384 "Conservation of *Falco cherrug* in Northeast Bulgaria, Hungary, Romania and Slovakia" project, implemented in Romania by the Milvus Group Association and the Romanian Ornithological Society. As shown below, the breeding population in Southern Romania, outside of Dobrudja, is almost non-existent, thus we did not use data from there for the trend calculation. To resume, the time series which have been used to calculate the trend is based on the years 2012, 2013, 2017, 2018, 2019, 2020, 2022 and 2023.

To assess the health of the Dobrudjan population, from 2022 we have started to collect systematically a series of demographical parameters based on the number of pairs and the number of nestlings, namely the breeding success (calculated as the number of successful breeding/all breeding attempts) and brood size (nestlings/successful pairs). Based on data from 2022 and 2023, we have compared the value of these demographical parameters with the corresponding values from the Central European population.

Breeding requirements/habitat use

During the period of 2012–2013, as part of the "Conservation of *Falco cherrug* in Northeast Bulgaria, Hungary, Romania and Slovakia" project, 31 artificial nests have been installed in Dobruja's Saker range. We visited all known natural nests and artificial platforms during the monitoring efforts to assess the species' preference for such structures. Collecting the data from censuses as well as completing it with additionally known territories, we obtained a data set of 186 entries regarding 36 nests for the period between 2012 and 2023.

We obtained the locations of active wind turbines as well as the year of their commissioning from The Wind Power database (2023), and by manual search using Google Earth satellite images. To assess their effect on the nest site choices of Saker Falcons, we measured both the distance of each nest from the nearest turbine operational in the year of assessment as well as the number of turbines in a 1, 2, 3, 4, 6, 8, 10, 15 and 20 km radius around the nests.

To assess the habitat preferences for nesting sites as well as the sensitivity to human disturbance, we used a CORINE vector layer (CLC2018, European Environmental Agency 2018), based on which we calculated the distances of each nesting site (including artificial nest box and natural nest) from the nearest patch of grassland and arable land, as well as from the nearest village. Additionally, we calculated the area of four key habitat types: grassland, agricultural land, forests and settlements, using three buffer categories: 4, 7.8, and 10 km, based on the minimum, average and maximum home range sizes identified by Prommer *et al.* (2018). Based on the findings of Prommer and Bagyura (2015), we excluded from the analysis all land falling in the 300 m range of individual wind turbines, as well as those tightly encircled by them, because we determined them as uninhabitable for Saker Falcons.

For analysing the data, we used the QGIS Software (QGIS Development Team 2022) and the R statistical environment (R Core Team 2023). Considering the small and uneven datasets (33 occupancies and 153 vacancies), as well as the lack of normal distribution and difference in variances, we used Wilcoxon's rank sum test for data analysis.

Results

Trend and population size

In Southern Romania, outside Dobrudja, we found only very few breeding Saker Falcons during our four-year monitoring. A breeding attempt was recorded in 2017, in Teleorman County, when a pair was detected occupying an old Raven *(Corvus corax)* nest in April. At the subsequent visits, in May we did not observe chicks or adults at the same nest, so we presumed that the brood has failed. Additionally, an adult bird was observed near the Olt

River in 2022, on two occasions in the last week of March, in an area with available old nests built by Long-legged Buzzards *(Buteo rufinus)* and Hooded Crows *(Corvus cornix)*. In 2023, an adult bird has spent the breeding season, between March and June, in a defined area in Dolj county but despite intensive search in the area, no nest has been detected. Except for these two cases recorded during the Saker census, the rest of the Saker detections from Southern Romania, outside of Dobrudja, were casual observations, most of them located in Oltenia, some from Bărăgan and mainly of immature birds without breeding evidence. Based on the current data, we estimate the population of the Saker in Southern Romania, outside of Dobrudja to 0–2 pairs.

From Dobrudja, we have data from a monitoring scheme undertaken in 2017, 2019, 2020, 2021, 2022 and 2023. The monitoring effort was constant in the period of 2017–2020 and was considerably increased in 2022 and 2023, when new areas were surveyed. In most years, we found 3–4 territories, except for 2022 and 2023, when we detected 5 territories in the first case and 7 territories in the second. We have additional casual observations far away from these territories, but mostly immature birds. Based on this data, we estimate the Dobrudjan population to 5–7 pairs.

Therefore, for Southern Romania, we are estimating a population of 4–9 breeding pairs, for the period of 2016–2022. Towards the end of the monitoring period, in 2022 and 2023, the data indicate a population of 7–9 pairs. During this period, we registered 33 cases of occupancy from 13 nests, where most nests were occupied only a single year, while one was registered as being occupied by a breeding pair in 7 different years between 2012 and 2023.

For the period 2012–2023 the trend for the Dobrudjan population is showing an increase (linear model, estimate=0.25, SE=0.12, t=2.04, P=0.097, R^2=0.35) *(Figure 3)*, but it must be noted however that the monitoring effort has not been equally distributed between the years, with a lower monitoring effort in 2012, 2013, 2017 and 2020.

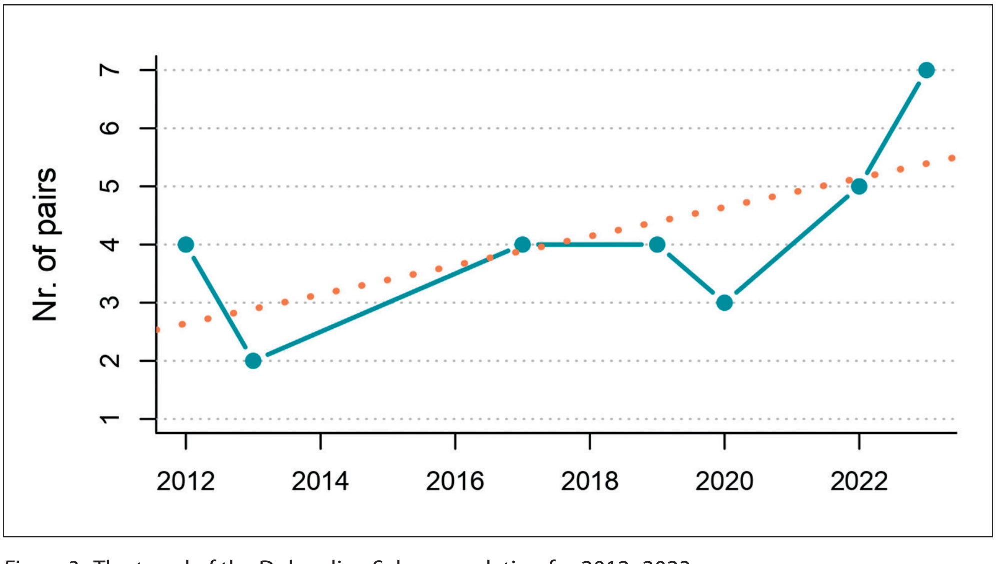

Figure 3. The trend of the Dobrudjan Saker population for 2012–2023

3. ábra A dobrudzsai kerecsensólyom-állomány alakulása 2012 és 2023 között

In 2022 and 2023, a series of demographical parameters have been collected *(Table 1)* to compare the Dobrudjan subpopulation with the Central European population. Despite some differences, which will be detailed below, most of the values are consistent, or close to the values of demographical parameters for the Central European population.

Table 1. Demographical parameters of the Saker's Dobrudjan Population
1. táblázat A kerecsensólyom dobrudzsai populációjának demográfiai paraméterei

Demographical parameters	2022	2023
No. Pulli	13	14
Mean Brood Size	3.25	2.33
Breeding success	0.8	0.86

Breeding requirements/habitat use

Regarding the use of artificial nests, our data suggest that in a 10-year period the Saker pairs in Dobrudja shifted almost completely towards artificial nests. All of the four known breeding attempts of Sakers from 2012 were in old Hooded Crow nests. The shift occurred during the period of 2015–2016 and for a time, between 2018 and 2021, all known Saker breeding attempts were detected in artificial nests *(Figure 4)*. In 2017 a breeding pair was detected outside Dobrudja, in Teleorman county, in an abandoned nest of Common Raven. In 2022, a pair bred successfully in an old nest of Long-legged Buzzards in Dobrudja, while in 2023, we had two pairs using Long-legged Buzzard nests, one of them having transitioned from an artificial nest box following a failed breeding the year before.

Occupied Saker nests were both further away (Wilcoxon's rank sum test, W=1898.5, P=0.013) *(Figure 5)* and had significantly less grassland areas around them in a 4 km radius than unoccupied nests (W=3494.5, P<0.001) *(Figure 6)*, though the difference became not significant when calculating with a 10 km radius (W=2876, P=0.105).

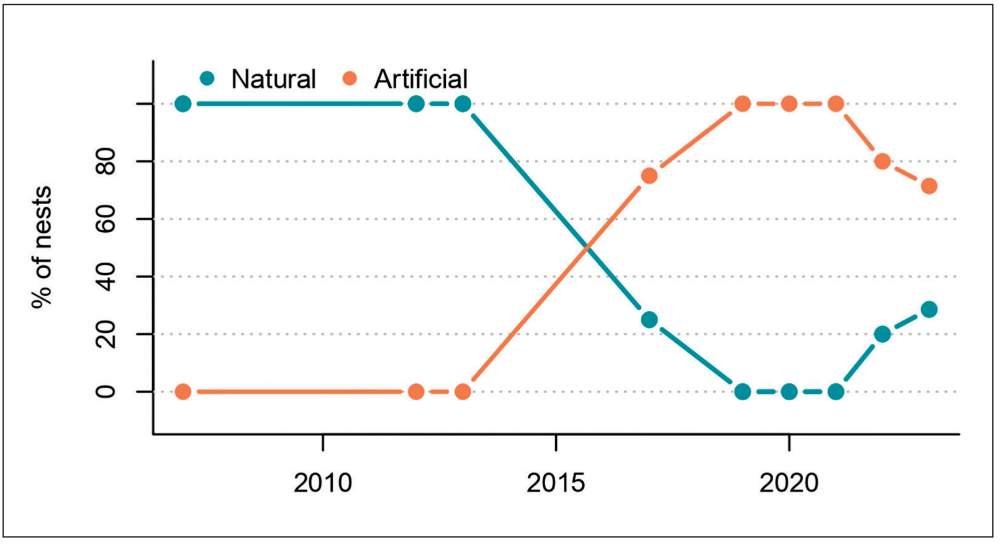

Figure 4. Ratio of occupied natural and artificial nests between 2007 and 2023
4. ábra A foglalt természetes és mesterséges fészkek arányának változása 2007 és 2023 között

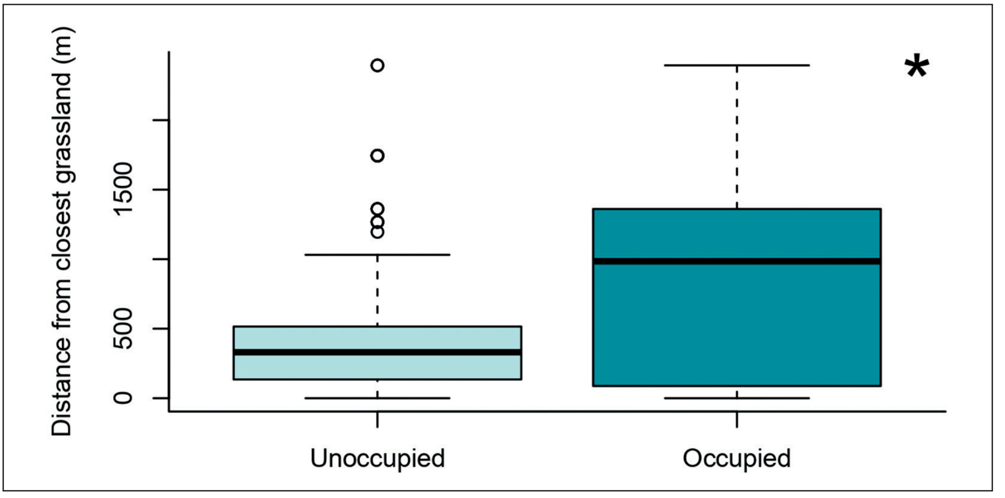

Figure 5. Distance of occupied and unoccupied nests from the closest grassland
5. ábra A foglalt és nem foglalt fészkek távolsága a legközelebbi gyeptől

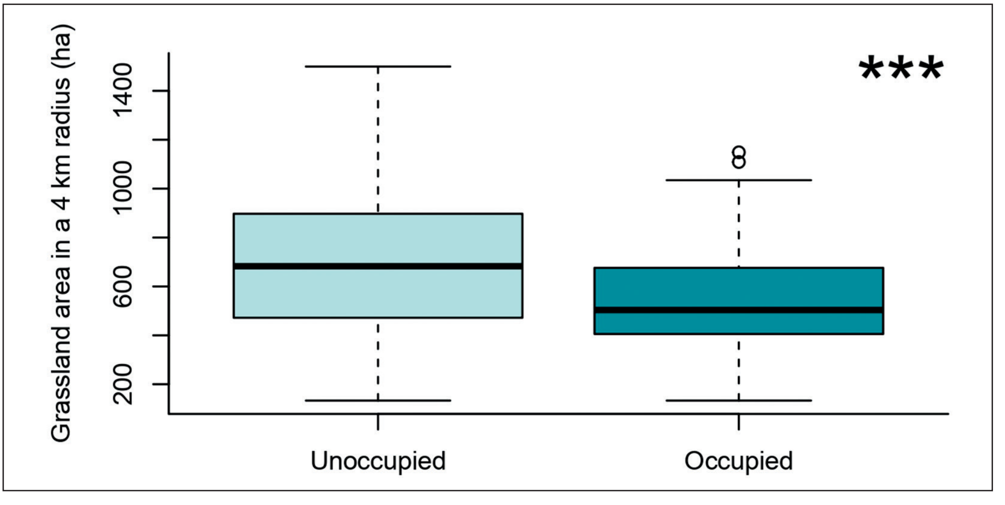

Figure 6. Grassland area in the 4 km radius of the occupied and unoccupied nests
6. ábra A foglalt és nem foglalt fészkek 4 km-es körzetében található gyepek összfelülete

The area of agricultural land was significantly larger in occupied territories in all distance categories (W=1074.5, P<0.001) *(Figure 7)*. We found no significant difference between occupied and unoccupied nests in terms of distance to agricultural habitats (W=1695, P=0.24).

The human settlement area was significantly smaller in occupied territories (W=3036.5, P=0.034) *(Figure 8)*, and the distance of the nest from the settlements also had a significant effect on site choice, occupied nests being further away (W=1975.5, P=0.025) *(Figure 9)*.

Occupied territories had significantly fewer woodland habitats compared to unoccupied ones in all buffer categories (W=3655, P<0.001) *(Figure 10)*.

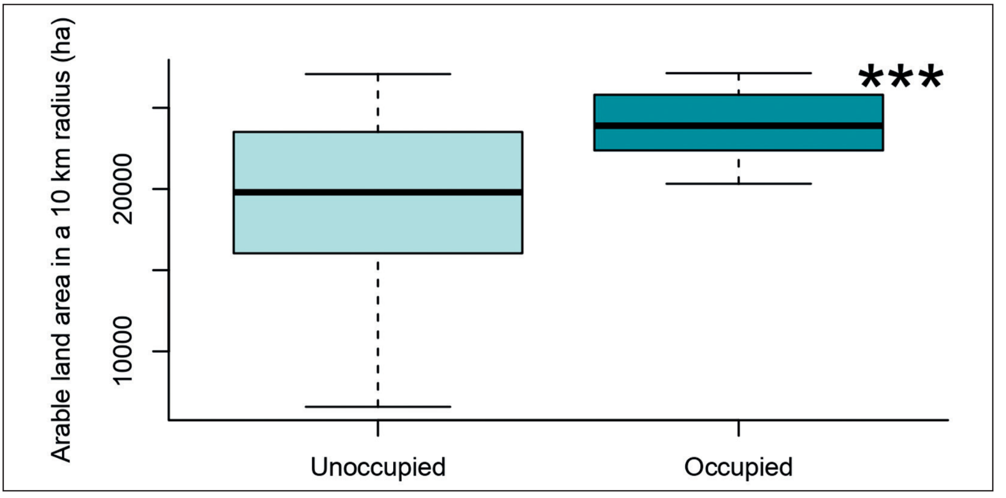

Figure 7. Farmland area in the 10 km radius of the occupied and unoccupied nests
7. ábra A foglalt és nem foglalt fészkek 10 km-es körzetében található szántók összfelülete

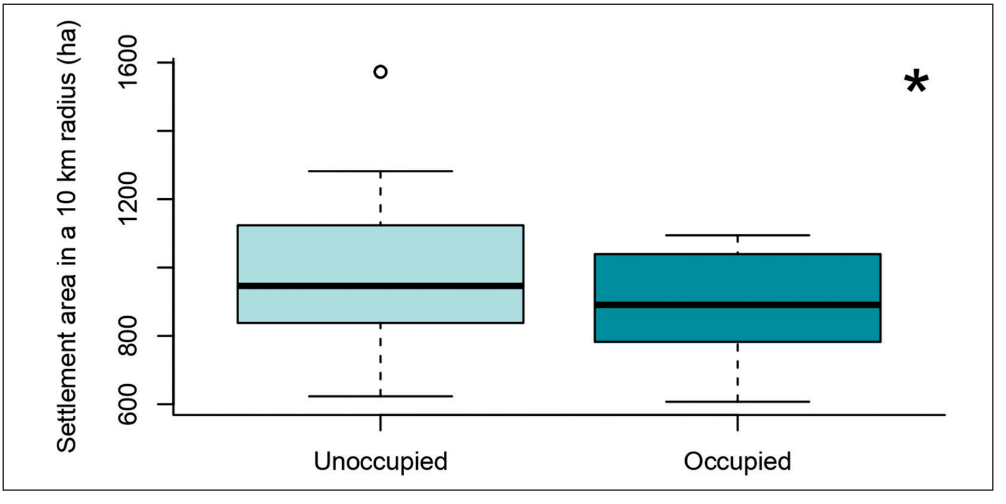

Figure 8. Settlement area in the 10 km radius of the occupied and unoccupied nests
8. ábra A foglalt és nem foglalt fészkek 10 km-es körzetében található települések összfelülete

The effect of the wind turbine proximity was only significant when excluding the nestboxes falling outside of the current range of the species (W=1223.5, P=0.031) *(Figure 11)*, the closest occupied nest being found at 2 km from a turbine.

The number of turbines in different distance categories was significantly higher around unoccupied nests for up to 10 km (W=84575, P=0.008) *(Figure 12)*, the maximum area taken up by wind farms being under 6% around occupied nests for up to a radius of 20 km.

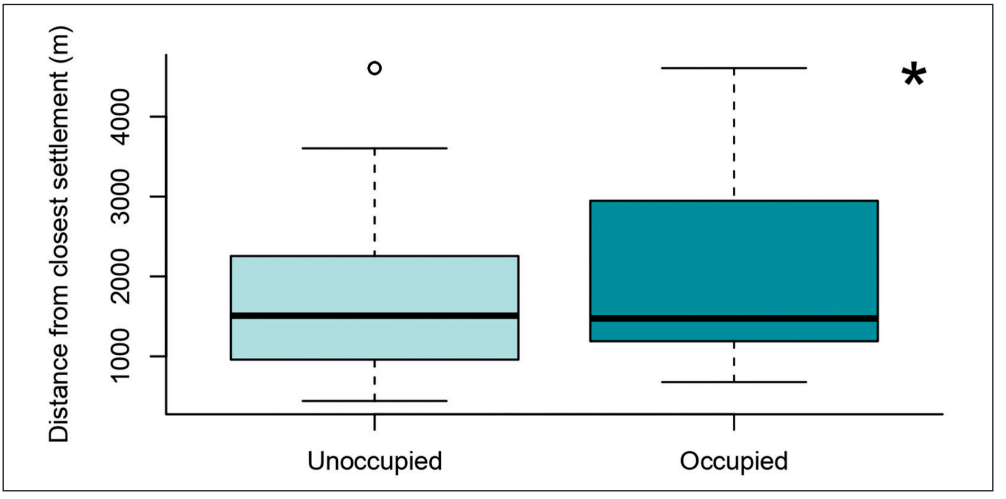

Figure 9. Distance of occupied and unoccupied nests from the closest settlement
9. ábra A foglalt és nem foglalt fészkek távolsága a legközelebbi településtől

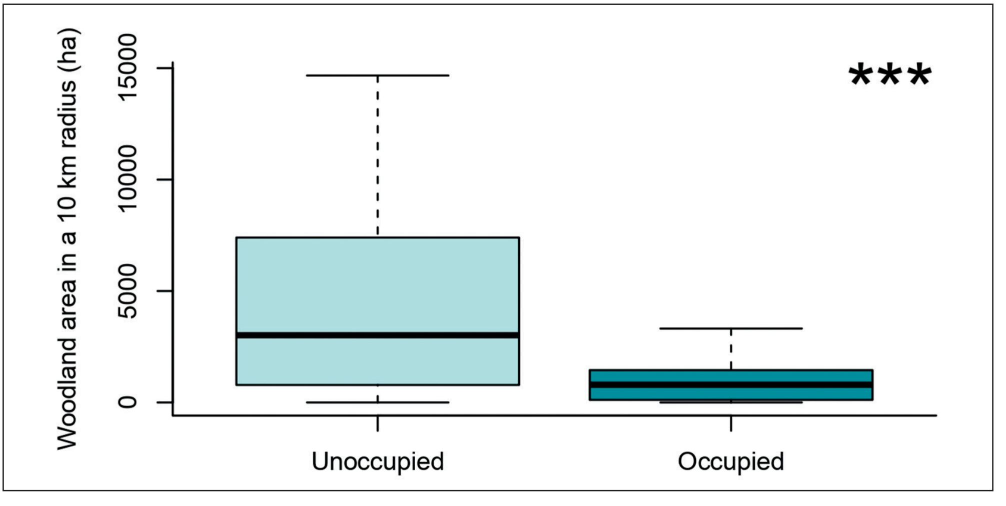

Figure 10. Woodland area in the 10 km radius of the occupied and unoccupied nests
10. ábra A foglalt és nem foglalt fészkek 10 km-es körzetében található erdők összfelülete

Discussion

Trend and population size

With 7–9 pairs, the Saker population in Southern Romania has a very small size. The core of the population is in Dobrudja, with scattered breeding attempts in the rest of Southern Romania. At the same time, many areas in the potential range were searched only once in this period, therefore we cannot exclude the possibility that some pairs were missed. Even so, casual observations of adult Sakers are also lacking in most of the range outside of

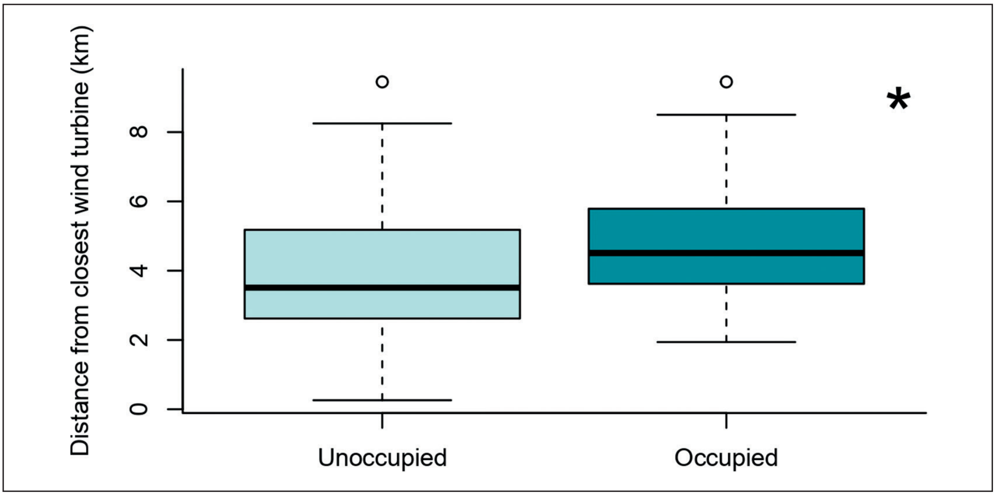

Figure 11. Distance of occupied and unoccupied nests from the closest wind turbine
11. ábra A foglalt és nem foglalt fészkek távolsága a legközelebbi szélerőműtől

Dobrudja, so probably the real size of the population is not considerably bigger than our estimate.

The short-term trend (for the period of 2012–2023) for this population is showing an increase. However, due to the fact that the monitoring effort was considerably increased in 2022 and 2023, when more breeding pairs were found, we cannot exclude the possibility that the perceived increase in population size is an artefact, and the real trend could be considered stable. Using a generation length of 6.08 years (Bird *et al.* 2020), the calculated population trend is covering almost two generation lengths (1.81 generations). Considering historical accounts which present the species as "frequent" in the plains along the Danube and in the Danube Delta, we can assume that the long-term trend is strongly decreasing. Even if the trend for two generations is increasing, assuming a maximum of 18 mature individuals, the regional population of Sakers in Dobrudja qualifies as Critically Endangered based on the D1 criterion. This status is more severe than the status of the whole Romanian population which is considered Endangered (MEWF 2022), mainly due to the higher numbers of the western population. On a larger scale, if we include the other populations in the Pontic range, the 'Critically Endangered' status likely would not apply, especially considering the possibly declining but still considerable Ukrainian population, which brings the estimated Eastern European population to between 168 and 333 pairs in 2022 (Prommer *et al.* 2025).

At a national level, there is a discrepancy between the populational trends and the speed of recovery of the two populations breeding in Romania. Even if both populations benefited from the same conservation measures, the Sakers breeding in Western Romania have a larger number of breeding pairs and the trend is strongly ascending (Hegyeli *et al.* 2019). The European Ground Squirrel *(Spermophilus citellus)* population, one of the main preys of the Saker, is considerably more abundant in Dobrudja compared to the western part of the country (Baltag *et al.* 2016), thus we consider that the speed of recovery is not necessarily related to the food availability in Dobrudja.

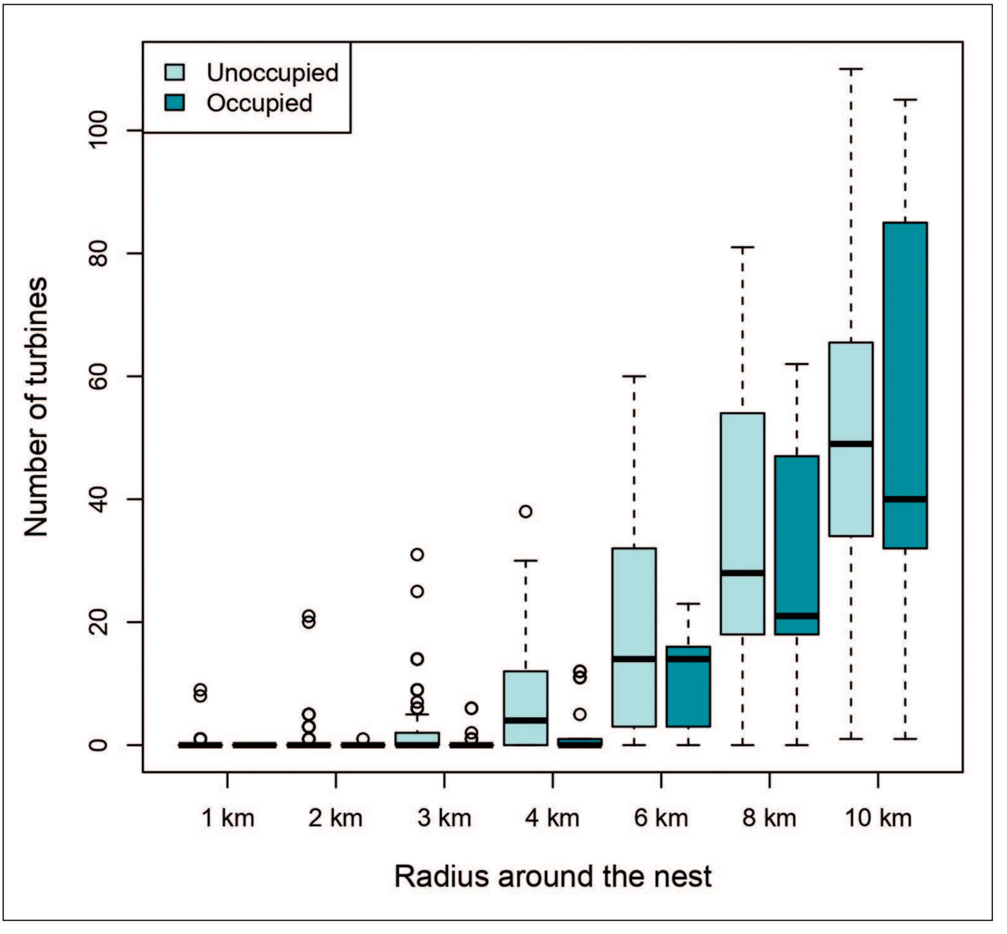

Figure 12. Number of wind turbines in the 1, 2, 3, 4, 6, 8 and 10 km radius of the occupied and unoccupied nests

12. ábra A foglalt és nem foglalt fészkek 1, 2, 3, 4, 6, 8 és 10 km -es körzetében található szélerőművek száma

One of the possible reasons for the different speed of recovery of the two groups could be the immigration rate, which could be higher in the case of the western birds. While the previous statement is only a speculation, the immigration of new breeding birds could occur mainly through the establishment of adult birds from the Ukrainian and Moldavian population, which are in the closer proximity of Dobrudja. This type of colonisation has occurred in the western part of Romania where, through the observations of ringed birds, has been established that a significant part of the breeding birds came from Hungary (Hegyeli *et al.* 2019), the closest natural population in that case being represented by the Central European population. The exchange of genes between the Central European and Pontic populations is considered to be insignificant and isolated (Prommer *et al.* 2014), so the colonisation by new pairs should appear from Moldavian or Ukrainian pairs, which are geographically closer. In the case of the breeding population of Dobrudja, the probability of colonisation with adult birds from Ukraine or Moldavia is unknown due to the lack of data both from ringed and satellite tagged birds from these countries. Recent monitoring efforts suggest that the Moldavian population became extinct (Ajder *et al.* 2025) and the trend in Ukraine is unknown, so the potential of immigration could be reduced for the Sakers in Dobrudja, and even more so further west, for a colonisation in Southern Romania.

Exceptionally, immigration of breeding birds could also happen from birds born in other populations which could establish for breeding in Dobrudja or Southern Romania. Studies based on satellite telemetry have shown that both Hungarian (Prommer *et al.* 2012) and, in a smaller percent, Ukrainian (Prommer *et al.* 2014) immature birds have appeared both in Dobrudja and Southern Romania. In the literature, there are also accounts of birds belonging to the Central European population that have established temporary settlement areas in Dobrudja (Prommer *et al.* 2014). Birds from Ukraine have the tendency to disperse towards east/northeast (Prommer *et al.* 2014) in the post-fledging period, so the likelihood of such birds to disperse to Southern Romania is rather small. The telemetric study on the Ukrainian birds had a limited number of specimens, so the author of the study considered that a more ample study with more birds could show different results (Prommer *et al.* 2014). Most of the immatures from the Central European population that dispersed to Eastern Europe returned to their natal areas to breed when reaching adulthood (Prommer *et al.* 2012), thus the probability of an immigration by this type of colonisation is negligible (Prommer *et al*. 2012, 2014). To date, there is only one known case for a falcon hatched in the Central European population that bred in the Pontic population, in Crimea (Prommer *et al.* 2014, Hegyeli *et al.* 2019).

A series of demographical parameters (mean brood size and breeding success) are available in literature for the Saker' Central European population (Prommer *et al.* 2025). The values of these parameters are comparable with the values for the Saker pairs that breed in Dobrudja. The mean brood size of 3.25 in 2022 for the Dobrudjan pairs is above the values of the mean brood size for most of the countries from the Central European population in the same year, being exceeded only by the value of Slovakian pairs (Prommer *et al.* 2024). By contrast, the breeding success (0.8) in 2022 for the Dobrudjan pairs was noticeably smaller than the similar value (0.89) for the Central European population. For the moment, we do not have enough data to explain this difference in the breeding success, but taking into account the high value of the mean brood size probably this is not related to possible differences in the food richness or availability between the two populations. For a more comprehensive and meaningful comparison, a larger data set for the Dobrudjan pairs is required.

Breeding requirements/habitat use

Previously metal artificial nests have been extensively used in the Central European strongholds but not in the Pontic area, where only a few wooden artificial nests were installed in the past. The occupancy rate of those nests was low. The installation of 31 metal nest boxes on power line pylons allowed us witnessing how the species that naturally used to occupy other species' nests shifted its preference to artificial nests.

Once the artificial nests became available, the Sakers occupied the new opportunities leaving natural nests built by other species. In 2012 when the artificial nests were not available, all known four breeding attempts were in Hooded Crows' old nests. In Hungary, this type of nest ensured the smallest breeding success for the species with a 46% degree of failure for the Saker broods laid in old Hooded Crow nests (Bagyura *et al.* 2012). Before the instalment of artificial nests, this was the most frequent nest type available for Sakers in Dobrudja too. Other, bigger natural nests built e.g. by Ravens were scarce, considering the low abundance of Ravens in the areas occupied by Sakers at that time. After the installation of the artificial nests, no breeding attempts in Hooded Crow nests have been detected. Once safer opportunities became available, the species moved toward those, following the same trend as in Hungary (Bagyura *et al.* 2012) and Slovakia (Noskovic *et al.* 2016). In 2016 and 2022, we managed to register breeding attempts in old Raven and Long-legged Buzzard nests. Considering that, it is likely that some breeding attempts in natural nests were overseen during the monitoring due to the insufficient coverage of the areas where the species can appear. In 2023, however, we have registered one case when a shift towards a natural nest happened. This pair had a failed breeding attempt during the 2022 season in an artificial nest, and in the next breeding season they moved to a neighbouring natural nest, which in 2022 was occupied by a Long-legged Buzzard pair. This last case is singular and does not affect the general conclusion, namely that the species moves towards artificial nests, if these structures are associated with an increase in reproductive success.

While we found a contradictory relationship between occupied Saker territories and both grassland proximity and area, this can be explained by the birds' willingness to travel greater distances in search of more abundant feeding sites, as found by Prommer *et al.* (2018). It should be noted that all occupied nests had over 2,000 ha grassland habitats in their 10 km radius. Another explanation could also be a shift in diet as found by Chavko *et al.* (2014, 2019) in the Slovakian population, where up to 62% of the Sakers' diet consisted of feral pigeons. This would also explain the Sakers occupying territories with larger agricultural areas, though there is need both for telemetric data and diet analysis for the Sakers breeding in Dobrudja to confirm it. We would also need more data to clarify whether Saker Falcons avoid nest boxes surrounded with larger forest areas because of smaller hunting grounds (Nemcek *et al.* 2016), or because the trees offer alternative nesting sites. This latter theory is also supported by the fact that one of the earliest documented pairs in the region, in the Măcin Mountains, while breeding on a cliff, had a 52% forest coverage in a 10 km radius around the nest.

Regarding restrictive factors, the birds also showed a preference for less populated areas and nests further away from settlements, but we documented, though only a single instance of, an occupied nest as close as 700 m to a village. One of the territories that was occupied at least 6 times for the past 9 years is also only 1,200 m from the nearest settlement.

In line with the findings of Prommer and Bagyura (2015), the birds avoided to occupy nest boxes less than 2 km from wind turbines. We also have a documented case in Dobrudja of a pair attempting, then abandoning breeding as wind turbines were being erected first at less than 900, then at under 300 m from the nest (Fidlóczky 2013). Excepting the historical territory in the Măcin Mountains and the one in Teleorman county (at more than 250 km from the other nesting sites), all nests had wind farms in their 10 km radius. Still, at all

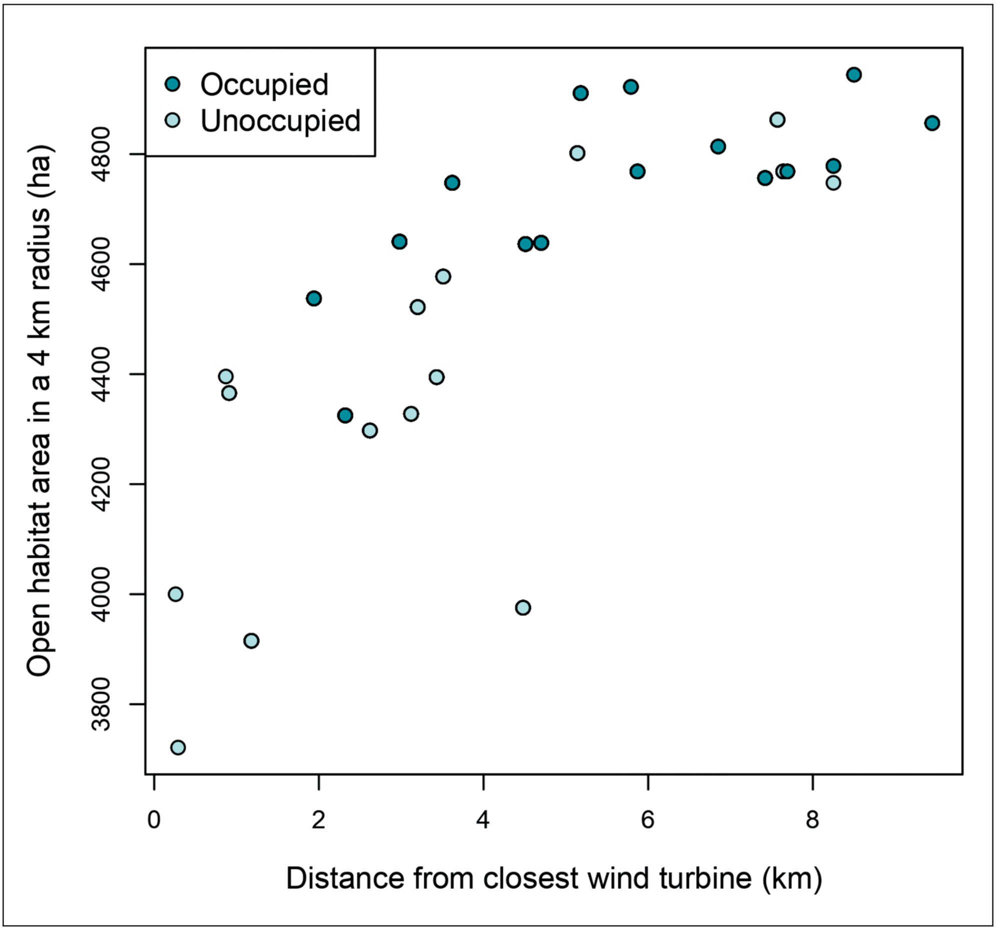

Figure 13. Open habitat area in the 4 km radius and distance to closest wind turbine from the occupied and unoccupied nests
13. ábra A foglalt és nem foglalt fészkek 4 km-es körzetében található gyepek összfelülete és a fészkek távolsága a legközelebbi szélerőműtől

distance categories, up to 10 km, the number of turbines was significantly lower in the occupied territories, showing that the birds would occupy a nesting site up to 2 km from a wind turbine, as long as the wind farms take up less than 6% of the area and there is at least 25,000 ha of open habitat in a radius of 10 km around the nest *(Figure 13)*. Though we lack telemetry data from the Sakers breeding in this region, and thus do not have information regarding their movements and the exact shape of their home ranges, based on the studies of Prommer and Bagyura (2015) as well as Nemček *et al.* (2016), we can assume that they generally avoid the windfarms and hunt in the available open habitats. Considering the large-scale development of wind farms in the past and foreseeable future in Dobrudja, as well as the rather limited range of Sakers in this region, great care should be taken in both planning and approval of new wind farms, to not further restrict their distribution by cutting them and other raptor species off from their breeding and feeding grounds.

Acknowledgements

The artificial platforms which have been the base of our analyses regarding habitat use were funded and mounted during the LIFE09 NAT/HU/000384 "Conservation of *Falco cherrug* in Northeast Bulgaria, Hungary, Romania and Slovakia" project. Field work from 2022 was funded by the LIFE20 NAT/BG/001162 "Securing the recovery of the Endangered Saker Falcon in Bulgaria and Southern Romania" project. Both projects were supported by the LIFE-Nature fund of the European Union. Monitoring efforts in 2016, 2017, 2019 and 2020 were funded by the Romanian Ornithological Society/Birdlife Romania.

We would like to thank the following people who have supported in a way or another the work for this paper: Marius Drugă, who was part of SOR's team during the implementation of the LIFE09 NAT/HU/000384 "Conservation of *Falco cherrug* in Northeast Bulgaria, Hungary, Romania and Slovakia" project, Attila Nagy and Lőrincz Bărbos from the Milvus Group Association, for kindly providing their data regarding the Sakers from their 2019 expedition in Dobrudja, Zsolt Hegyeli from the Milvus Group Association, for providing information regarding the breeding population of Sakers from Western Romania, Cornel Cotorogea, who voluntarily provided data in 2021, Paul Țibu, who participated in the fieldwork in 2016 and Alexandru Birău, who participated in the field work in 2022 and 2023.

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Ornis Hungarica 2025. 33(1): 177–187.
DOI: 10.2478/orhu-2025-0010

The status and risk of extinction of Saker Falcon *(Falco cherrug)* in the Republic of Moldova

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Received: January 30, 2023 – Revised: December 28, 2023 – Accepted: October 18, 2024

Ajder, V., Ursul, S. & Baltag, E. Ș. 2025. The status and risk of extinction of Saker Falcon *(Falco cherrug)* in the Republic of Moldova. – Ornis Hungarica 33(1): 177–187. DOI: 10.2478/orhu-2025-0010

Abstract The Saker Falcon *(Falco cherrug)* is one of the most threatened birds of prey species of the Eurasian steppe zone. While conservation efforts are successful and populations are growing in Central Europe, in the Republic of Moldova, the population is declining due to low conservation efforts and high environmental pressures on this species. Due to the present survey effort, the breeding areas of Saker Falcon was designated as an Important Bird Area (IBA) site to conserve the species population from the Republic of Moldova. But, habitat loss, main prey decline – Speckled Ground Squirrel *(Spermophilus suslicus)* – lack of nests, intensive agriculture, electrocution, poisoning, shooting, and trapping for falconry have been identified as threats to the Saker Falcon population in the country. Besides these threats, in the last two years, the State Electric Enterprise „Moldelectrica" carried out technical maintenance works on the high voltage power transmission lines, which resulted in removing any existing nests situated on the pillars, including Raven *(Corvus corax)* and Saker Falcon nests. Consequently, in the last two years, none of the Saker Falcon's known occupied territories were confirmed. Given these circumstances, it is extremely urgent to take action and save the Saker Falcon population in the Republic of Moldova. The first step towards efficient conservation is to install artificial nest boxes on high-voltage poles, otherwise, the species risks extinction in the country.

Keywords: bird of prey, Eurasia, steppe, high-voltage pillars

Összefoglalás A kerecsensólyom *(Falco cherrug)* az eurázsiai sztyeppzóna egyik legveszélyeztetettebb ragadozómadár-faja. Amíg a sikeres természetvédelmi erőfeszítések eredményeképpen Közép-Európában nő, Moldovában a védelmi intézkedések gyengesége és a fajra irányuló kedvezőtlen környezeti hatások erőssége miatt csökken az állomány. Az itt bemutatott felméréseknek köszönhetően a Moldovai Köztársaságban a kerecsensólyom élőhelyeit Fontos Madárélőhellyé (IBA) nyilvánították. Ennek ellenére, az élőhelyek elvesztése, a fő zsákmányfaj – a pettyes ürge *(Spermophilus suslicus)* – állományának csökkenése, a fészkelőhelyek hiánya, az intenzív mezőgazdaság, az áramütés, a mérgezés és a solymászati célú befogás a kerecsensólyom-állományt veszélyeztető tényezőként vannak számontartva a Moldovai Köztársaságban. Mindemellett az elmúlt két évben a „Moldelectrica" Állami Áramszolgáltató Vállalat karbantartási munkákat végzett a nagyfeszültségű távvezeték hálózaton, amelynek eredményeképpen eltávolítottak minden fészket, beleértve a holló *(Corvus corax)* fészkeit, és a kerecsensólymok által használt fészkeket is. Mindezek következményeként nem találtuk meg egyetlen korábban ismert kerecsensólyom-revírben sem a fajt. A körülményeket figyelembe véve sürgős intézkedéseket kell tenni a kerecsensólyom-állomány megőrzésére a Moldovai Köztársaságban. A faj megőrzésére tett első lépésként fészkelőládákat kell kihelyezni a nagyfeszültségű távvezeték oszlopokra, különben nagy eséllyel kipusztul a faj az országból.

Kulcsszavak: ragadozómadár, Eurázsia, sztyepp, nagyfeszültségű távvezeték-oszlop

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Introduction

Birds of prey are at the top of the trophic web, controlling prey populations and covering large areas as home ranges with a diverse habitat mosaic (Peery 2000), which enables them to find suitable prey to survive. These characteristics recommend them as an ecosystem health indicator, as their presence certifies the abundance of suitable populations of prey. Some of these species are declining because of ecosystem degradation, thus creating an imbalance in the ecological network which can lead to a lower biodiversity structure.

The Saker Falcon *(Falco cherrug)* is a Eurasian bird of prey listed as Endangered because the population trend analysis indicates that it may be undergoing a very rapid decline (Birdlife International 2022) in species range, even if in some European countries the population has increased in the last 20 years (Chavko 2010, Kovács *et al*. 2014, Bauer 2020, Fântână *et al.* 2022). The meta-population in the Pannonian Basin (in Hungary and neighboring countries) is the most stable one across the global range (Prommer *et al.* 2018). These different trends in the Saker Falcon national populations are mainly influenced by conservation actions or, in some cases, especially in those when the species is declining, the lack of them at the national or regional level. The absence of conservation strategies is mostly connected with habitat degradation which leads to low nesting opportunities and to lower prey availability.

In the Republic of Moldova, human pressure on the species grew in the middle of the 20th century, when massive surfaces of natural land were transformed into farmlands because of the agricultural policy in the Soviet Union (Averin *et al.* 1971). After the collapse of the USSR, the large arable land blocks were divided into smaller blocks with diverse land use, including fallow land. That resulted in a mosaic-like landscape pattern that could sustain a high degree of biodiversity. Nowadays, however, the extent of that mosaic of habitats is decreasing again, as smaller blocks are merged into large blocks to increase food production management. In some cases, the large farmland plots incorporate parts of the grassland areas which were intended for animal grazing, just to be able to grow the crop fields. To achieve high yield in these agricultural lands, farmers use high amounts of fertilizers and pesticides to protect the crops (ECHA 2022). All those substances have the potential to affect biodiversity from the lower level of the trophic web, bioaccumulating in the upper levels where raptors are situated, creating an ecotoxicological pressure on the environment (Strungaru *et al.* 2018).

In addition to the habitat changes and ecotoxicological problems, populations of Speckled Ground Squirrel *(Spermophilus suslicus)* – the main prey of the Saker Falcon – started to decrease in the Republic of Moldova (personal observations). The reasons for this decline are rather unknown up to now, but the phenomenon seems to be widespread on a large scale, including also the Ukrainian population (Mikhail Rusin *pers. comm.*).

Despite the protection instituted by the legal framework of the country, there are no effective conservation measures for the Saker Falcon in the Republic of Moldova, as is the case for other large birds of prey. That is largely due to the lack of data on its distribution and ecology in the Republic of Moldova. Before 2013, the species was poorly studied due to the low number of ornithologists in the country. Most of the data from that period is recorded *in verbis* with very few proofs and without any systematic survey. Since 2013, we have been collecting data systematically in order to assess the avifauna structure in the Republic of Moldova. The process began with the project „Monitoring Important Bird Areas in Moldova to Improve Conservation Management" (2013–2014) funded by Conservation Leadership Programme (Ajder 2014). The data collection continued to be carried out by our team even after the project ended, and we have increased our efforts to survey the Saker Falcon and to achieve a better conservation status through other projects developed in the Republic of Moldova and Ukraine. Further data was collected through the project "Continuation of Saker Falcon and Steppe Biodiversity Conservation in Ukraine" (2015–2016) funded by Rufford Foundation (Prommer 2015). For the first time, the entire High Voltage Power Transmission Line from the South-East of Republic of Moldova was monitored. During the survey, we collected important ecological information, such as diet, other breeding birds nearby, and the nearest souslik colonies. The annual Saker Falcon breeding population survey continued up to 2022, but in some years the field studies were affected by the low number of ornithologists or field volunteers.

The aim of this article is to update the information on the Saker Falcon breeding population from the Republic of Moldova, by presenting the past and present situation of this species in relation to the threats and habitat use at a national scale.

Material and Methods

Study area

The study area covers the territory of the Republic of Moldova (33,843.5 km^2), which is situated between the Prut and Dniester rivers. The human population in the study area is approximately 2.6 million inhabitants (National Bureau of Statistics from Moldova, 2022). The landscape in the central part of the country is represented by hilly areas and relatively low plains, with the highest altitude of 429 m (Bălănești hill, Nisporeni district). The land use is mostly agricultural with fragmented parcels, forest patches and pastures, resulting in a mosaic of artificial and natural habitats *(Figure 1)*. The southern part of the country is characterized mainly by steppe and grasslands, which are suitable habitats for the Saker Falcon and its main prey in the region – the speckled ground squirrel.

Field studies

The Saker Falcon monitoring, started in 2013, was focused on the southern part of the Republic of Moldova, and mostly on the areas along the main high voltage power line. The power line crosses the Moldovan-Ukrainian border several times due to the irregular border between the two countries *(Figure 2)*. A total length of 100 km of the high-voltage power line was surveyed, and 389 pylons were checked to identify and count active nests or individuals of Saker Falcon. The observations were conducted with binoculars and spotting scopes, from 10.00 AM till 18.00 PM. The observations took place on calm days, without rain or strong winds.

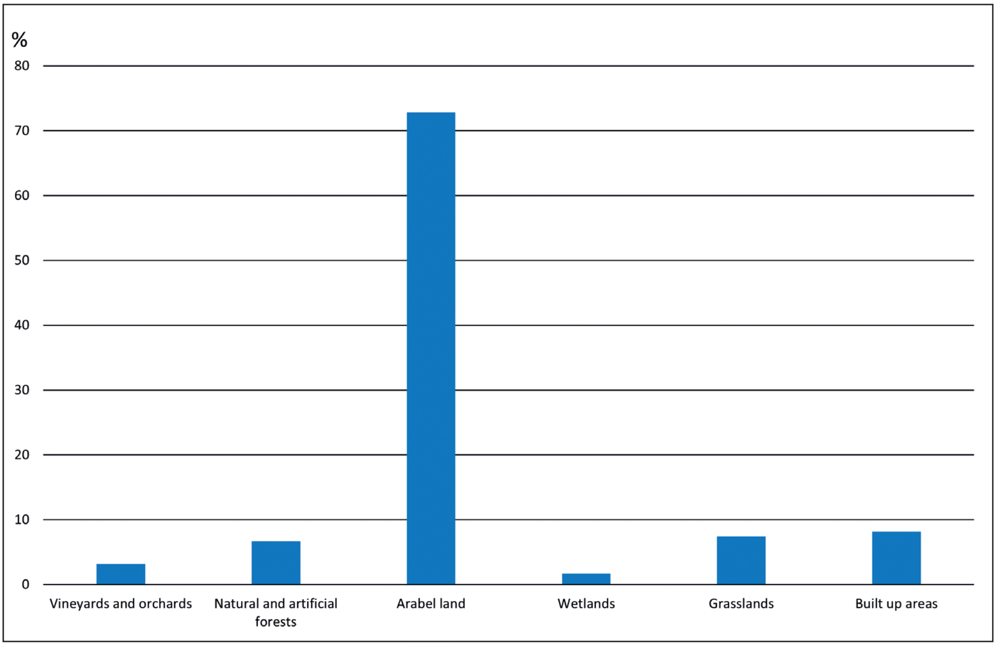

Figure 1. Land use structure for the Republic of Moldova according to the Statistical Yearbook of the Republic of Moldova (Statistica Moldovei 2022)

1. ábra A területhasználat Moldovában a Moldovai Köztársaság Statisztikai Évkönyve szerint (Statistica Moldovei 2022)

All the transects were monitored during the breeding period, between the beginning of April and the end of July and consisted of two separate sets of field observations. The first set of transects (April–May): to identify the breeding pairs and collect data on habitat selection and prey availability in the south and south-eastern part of the Republic of Moldova. The second set of transects (June–July): to identify the breeding success of the Saker Falcon pairs, targeting only the

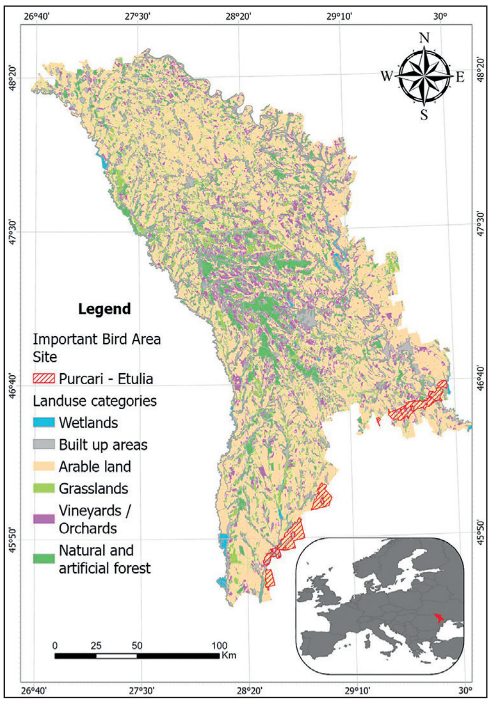

Figure 2. The route of the high-voltage line along with the Important Bird Area proposal (Purcari – Etulia) for Saker Falcon conservation in the Republic of Moldova

2. ábra A nagyfeszültségű átviteli hálózat nyomvonala és a javasolt Fontos Madárélőhelyek (Important Bird Area) terület (Purcari – Etulia) a Moldovai Köztársaság területén nesting locations and collecting data about the number of fledglings (if possible) and the activity of the adults (the prey and its source).

The fieldwork was carried out by a team of up to four experienced ornithologists and their assistants. The team was covering the entire length of the high-voltage power line for one day or a maximum of two days in case the observers had to spend more time with one nest/pair in order to check its status. The survey was conducted by car, with the team driving below the high-voltage power line. Each pillar and its surrounding landscape were carefully inspected with binoculars and spotting scopes. When a nest or an individual of Saker Falcon was spotted, the surveying team carefully monitored it to check exactly their status. Only the presence of a nest with incubating individuals or with juveniles was considered as breeding territory. All the field data were entered into census protocols designed for raptor breeding counts, and they were further integrated into a GIS database.

During the field survey, we recorded all the possible threats to identify the type of conservation actions needed to support the species. Special attention was given to the presence of Raven *(Corvus corax)* nests on the high-voltage power line pylons, which could serve as nests also for Saker Falcons. The land use structure was downloaded from FAO 2014, and it was used to quantify their preference for specific areas. To calculate the land use structure around the Saker Falcon nests, a buffer area of 5 km radius was generated using "Buffer Analysis Tool" in ArcGIS Pro v. 2.9.2, after which we extracted a percentage of each land use category inside of this area, using "Clip Analysis Tool".

During the field surveys, we also recorded the locations of the Speckled Ground Squirrel colonies as the main prey for the Saker Falcon population, but due to the lack of available mammologists, a comprehensive population study of this species could not be accomplished.

Results

Population

During the 2013–2023 period, the maximum number of active pairs observed was 4, in 2016, while the lowest was 0, in 2021 and 2022 *(Table 1)*. The highest fledgling number was also recorded in 2016: 7 chicks from 4 nests *(Figure 3)*. The lowest number of chicks was recorded in 2014 and 2020 – only 1 chick. For the last three years (2021–2023), no active pairs were recorded, which means no fledglings were observed either *(Table 1)*.

The land use structure around the Saker Falcon nests was covered mostly by arable land (65.4%), while wetlands represented the lowest coverage (4.56%), followed by vineyards/orchards (4.01%) *(Table 2)*.

Threats

During the survey period, we have recorded three main threats for the Saker Falcon population from the Republic of Moldova. The first one is habitat degradation, in which small plots of agricultural fields are converted to large croplands and farmlands. While the

Table 1. Saker Falcon breeding population from the Republic of Moldova during the 2013–2023 period

1. táblázat A kerecsensólyom fészkelőállomány alakulása a Moldovai Köztársaságban a 2013–2023 közötti időszakban

Index	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Number of adult birds	6	6	6	8	8	6	8	6	0	0	0
Number of active nests	3	1	2	4	2	3	3	1	0	0	0
Number of abandoned nests	0	2	1	0	2	0	1	2	0	0	0
Number of chicks (minimum number of birds identified in the nest)	3	1	3	7	2	4	2	1	0	0	0
Highest number of chicks/nest	1	1	2	4	1	2	1	1	0	0	0
Percent of coverage high-voltage power line	50	90	100	60	60	50	50	40	40	70	90

steppe area is undergoing degradation due to low level of grazing which leads to scrub encroachment and eventually afforestation, as the climax vegetation is forested steppe.

The second threat is represented by the decline of the Speckled Ground Squirrel population. We observed the phenomenon on site because the few colonies known to us became extinct.

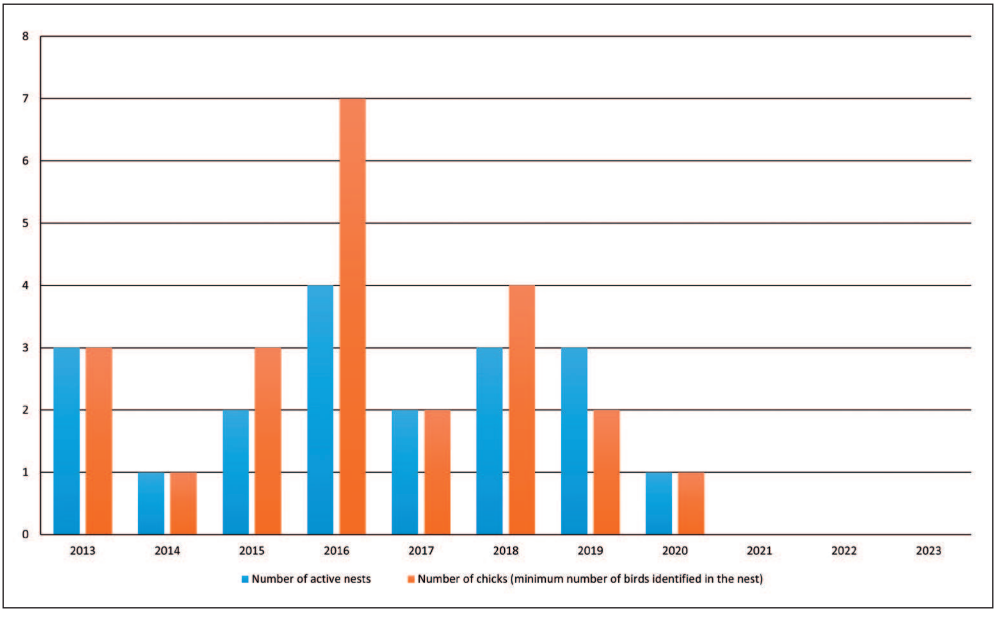

Figure 3. The number of active nests and chicks for the Saker Falcon population from the Republic of Moldova during the 2013–2023 period

3. ábra Az aktív kerecsensólyom-fészkek és a fiókák száma a Moldovai Köztársaság területén a 2013–2023 közötti időszakban

Table 2. Land use composition in a radius of 5 km around the Saker Falcon nets
2. táblázat A területek művelési ágak szerinti megoszlása a kerecsensólyom-fészkek körüli 5 km-es sugarú körben

Land use category	Coverage percent	Land use composition
Wetlands	4.56	Lakes, rivers, fish farms, marshland
Built-up areas	9.62	Villages, industrial areas, towns
Arable land	65.41	Irrigated and non-irrigated cropland
Grassland	8.78	Pastures, grasslands with bushes
Vineyards / Orchards	4.01	Vineyards and orchards
Natural and artificial forest	7.64	Natural and artificial forests, lines or patches of trees

We have documented the process, but unfortunately we do not have a comprehensive study to quantify this decline.

A third threat is linked to an ongoing forestation campaign initiated in our country in 2023, known as Forest Generation "Generația Pădurilor." This initiative aims to identify open spaces, typically used as pastures and grasslands, for the purpose of planting forests. However, this effort inadvertently gives rise to a significant issue. The conversion of grasslands into forests poses a challenge by altering the habitat suitable for the Speckled Ground Squirrel, disrupting existing colonies and entire ecosystems. This could be categorized as habitat degradation, taking on a more radical aspect. In the vicinity, particularly within the designated Important Bird Area "Purcari – Etulia" dedicated to Saker Falcon conservation, we identified 24 such areas affected by this conversion.

The absence of large nests on high-voltage electrical pillars represents the fourth threat. This became particularly evident over the last three years when the State Electric Enterprise "Moldelectrica" physically removed all nests, sticks, and small branches from the pylons.

We have also identified a series of threats that affected other bird species in the area: electrocution, poisoning and illegal shooting. Although we did not document any mean that those threats affect the local population of Saker Falcon, we cannot exclude potential incidents involving the species.

In addition, the discussions, and fears about possible trapping of adults and fledglings and/or taking chicks from nests for falconry remain in place, even though we did not record any such actions during our survey.

Discussion

According to Osterman, the Saker Falcon was a common bird in Moldova at the beginning of the 20th century (Averin *et al.* 1971). Unfortunately, there is no estimation of the breeding population, not even for the middle of the 20th century. Further research done by Averin, Gania and Uspenskii (Averin *et al.* 1971) had shown that between 1956 and 1968 there were ten Saker Falcon pairs present in eight small forests with a total area of 84.5 km^2 scattered around the country. The breeding range had rapidly changed in a relatively short period of

Figures 4a, b Saker Falcon nesting and feeding habitats in the Republic of Moldova
4a és b ábra Kerecsensólyom fészkelő- és táplálkozóhelyek a Moldovai Köztársaságban

time – only 50 years. Drastic changes occurred in the breeding ecology as well: according to the Red Book of Moldova (Duca *et al.* 2015), in the last century, the Saker Falcon was spread in small numbers in meadow forests and rocky areas along the Dniester River. Since then, the species switched from trees and sometimes cliffs to high-voltage electrical pylons, being concentrated nowadays mainly in the southern part of the country. Currently, the Saker Falcon nesting areas are situated in open habitats, mainly surrounded by arable fields and grasslands. Most of them are closely positioned to the Speckled Ground Squirrel colonies. During our survey, we did not find any Saker Falcon pair breeding on trees or cliffs. Instead, all the nests found so far were situated on high-voltage power line pylons *(Figures 4a, b)*.

Figure 5. Saker Falcon adults near the nest on an electric pylon
5. ábra Öreg kerecsensólymok egy távvezeték oszlopon lévő fészek mellett

The last official data claims that in 2007 the breeding population of Saker Falcon was estimated at 5–13 pairs (Munteanu *et al.* 2007). In the following 6 years there were no studies on Saker Falcon, so we do not have any data on their breeding population. In the first year of our survey (2013), the documented population consisted of only 3 breeding pairs, while a modest increase was observed in 2016 when 4 breeding pairs were recorded. During the survey period the number of individuals fluctuated, but this could be influenced by some changes in the nest location. Therefore, the Saker Falcon population from the Republic of Moldova seems to be part of the south-eastern Ukrainian population, and it is probably linked to the south-eastern Romanian population as well.

Nest locations did not change through the survey period except for one case, when the pair moved from one pillar to another in 2017. They remained in the same area, but they used an alternative nest on another pylon at 500 m from the original nest *(Figure 5)*. A potential reason for change was maybe the sleet and snowfall in mid-April (20th and 21st), which severely affected the central and southern parts of the country. Due to this harsh weather event, two pairs abandoned the breeding process, and the other two pairs were supposed to start to breed again judging by the size of the juveniles, with a one-month gap. During the 2017 breeding season, we recorded only one young fledgling in each of the two active nests at the middle of July. For these reasons, the late April snowfall is presumed to have affected the breeding of the Saker Falcon in 2017.

Raven nests on electric pillars are of a crucial importance for Saker Falcon breeding in Vojvodina (Rajković 2015), just as in the Republic of Moldova. Without those natural nests, it is highly necessary to install artificial boxes for falcons to ensure suitable breeding areas. That action is urgent, especially now, when the conservation status of the Ukrainian population could be affected by Russian aggression. The installation of artificial nest boxes is very successful in supporting local populations in Hungary (Bagyura *et al.* 2012), Austria, Slovakia (Chavko *et al.* 2014), Serbia (Rajković 2015), Southeastern (Romanian Ornithological Society *pers. comm.*) and Western Romania (Milvus Group *pers. comm.*). During 2020–2022, consequently to the maintenance works on the high-voltage lines performed by the State Electric Enterprise Moldelectrica, all the nests were removed. As a result, no active pair was observed during the monitoring in known breeding areas or in other sites close to them.

The main threat to the Saker Falcon population in the Republic of Moldova is habitat loss, followed closely by the population decline of main prey species and the lack of nests. While the first two threats require a more elaborate strategy, the third one could be resolved with a relatively low amount of effort. Other potential threats identified towards the Saker Falcon population in the Republic of Moldova are intensive agriculture, electrocution, poisoning, shooting, and trapping for falconry. While we did not record any incidents related to the last three threats involving Saker Falcons, we documented such incidents involving other species of birds of prey, which lead us to consider those threats as potential risks. These threats ware not evaluated due to the low number of ornithologists in the Republic of Moldova and a low detectability rate. Still, we cannot exclude it, especially in this area where the authorities are not aware of the practice.

The first main result of this survey was the designation of an Important Bird Area (IBA) site to conserve the Saker Falcon population from the Republic of Moldova (Ajder 2014, BirdLife International 2023). That site covers the entire Saker Falcon distribution in the Republic of Moldova, including steppe and non-intensive agricultural fields. The IBA database has been used to propose the entire area as an Emerald site, which has international recognition. However, the legal process of national adoption of the Emerald Network is still ongoing, thus the Saker Falcon population and its breeding area do not yet have a real legal protection in the Republic of Moldova now. Even if the process has been completed, the Emerald Site covers only a part of the IBA site (less than 25%) due to a set of changes imposed by the governmental department in charge of this process.

Acknowledgements

We would like to express our gratitude to the monitoring team, including Laurențiu Petrencu, Gheorghe Țîcu, Alexandru Țurcan, Laura Taftur, Mihai Ghilan and Mikhail Rusin, whose valuable observations contributed to our understanding of the status of the speckled ground squirrel in the study area. Additionally, we extend our thanks to the teams involved in the projects ‘Monitoring Important Bird Areas in Moldova to Improve Conservation Management’ and ‘Continuation of Saker Falcon and Steppe Biodiversity Conservation in Ukraine,’ where precious data was collected. The study adhered to the laws of the Republic of Moldova.

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Ornis Hungarica 2025. 33(1): 188–193.
DOI: 10.2478/orhu-2025-0011

Recent breeding records of Saker Falcons *(Falco cherrug)* in Bulgaria

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Received: March 15, 2024 – Revised: April 25, 2024 – Accepted: November 09, 2024

Arkumarev, V., Klisurov, I., Demerdzhiev, D., Petrov, R., Stamenov, A., Andonova, Y., Gradinarov, D. & Dixon, A. 2025. Recent breeding records of Saker Falcons *(Falco cherrug)* in Bulgaria. – Ornis Hungarica 33(1): 188–193. DOI: 10.2478/orhu-2025-0011

Abstract The population of Saker Falcon *(Falco cherrug)* in Bulgaria suffered dramatic decline during the 20th century due to habitat destruction, nest robbery, illegal killing, poisoning, electrocution and other threats. The last well documented successful breeding of the species dates back to 1997. In 2011 a reintroduction program with captive-bred Saker Falcons was launched in Bulgaria to recover the species. Here, we present recent breeding records of Saker Falcons in three breeding territories in south Bulgaria. For the period 2017–2023, we recorded 7 breeding attempts in which 15 nestlings were successfully raised.

Keywords: endangered species, reintroduction, population recovery, breeding success

Összefoglalás A kerecsensólyom *(Falco cherrug)* populációja drámai csökkenést szenvedett el Bulgáriában a 20. században az élőhelyek elpusztítása, fészekrablás, illegális vadászat, mérgezés, áramütés és más veszélyeztető tényezők miatt. A faj utolsó, jól dokumentált, sikeres költése 1997-ben volt. 2011-ben Bulgáriában fogságban tenyésztett kerecsensólymokkal indítottak visszatelepítési programot. Itt bemutatjuk a kerecsensólymok legújabb költési adatait három dél-bulgáriai költőterületen. A 2017–2023 közötti időszakban 7 költési kísérletet regisztráltunk, amelyek során 15 fióka repült ki.

Kulcsszavak: veszélyeztetett fajok, visszatelepítés, populáció helyreállítása, költési siker

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Introduction

The Saker Falcon *(Falco cherrug)* is a large falcon species with wide breeding range spanning from Central Europe to Eastern Asia. Due to a rapid population decline in most of its range, the species was uplisted to Endangered species in 2012 in the IUCN Red List of Threatened Species (BirdLife International 2024).

In Bulgaria, the Saker Falcon was reported as relatively common species especially in Dobrudzha in the 19th century (Farman 1869, Elwes & Buckley 1870). Until the mid-20th century, the population is largely depleted, and the species is already reported as rare (Patev

1950). Various factors contributed for the marked decline of the population. The national campaign for extermination of birds of prey in Bulgaria that took place during the first half of the 20th century most probably was among the main factors lead to decline (Arabadzhiev 1962). Other threats for the species were habitat destruction due to changes in agricultural practices and land management, intensification of the use of chemicals, activities which lead to the decline of European Ground Squirrel *(Spermophilus citellus)* populations. In the 1970s the population was believed to be not more than 50 pairs located mostly in the low mountains and highlands (Baumgart 1971, 1977). By the mid-1980s the population declined to only 15 pairs (Michev 1985). The population decline continued over the next decades most notably due to nest robbery, poisoning and habitat destruction (Iankov *et al.* 2013). In the 2000s, it was estimated that only 4–12 breeding pairs remained in Bulgaria (Nankinov *et al.* 2004, Nagy & Demeter 2006). Despite the numerous observations of adult birds in suitable breeding habitat in the period of 2000–2015 (Iankov *et al.* 2013, Ragyov *et al.* 2014), the last well documented successful breeding of the species was in 1997 in Western Balkan Mountain, where a pair raised two chicks (Stoyanov 2001).

A reintroduction program with captive-bred Saker Falcons from European origin was initiated in Bulgaria in 2015, following preparatory activities and pilot releases from 2011, aiming to recover the species as a breeder (Dixon *et al.* 2020, Lazarova *et al.* 2021, Petrov *et al.* 2021, 2022). Here, we present the first records in 20 years of confirmed breeding of Saker Falcons in Bulgaria and data on nest occupancy and breeding success.

Materials and Methods

We carried out intensive and systematic surveys for Saker Falcons in Bulgaria in suitable habitats (based on historical data, recent observation and availability of suitable breeding habitats). The survey efforts were intensified after detecting the first occupied breeding territory in 2017. Moreover, all observations of Saker Falcons during the breeding season were registered and evaluated. As potential breeding substrates, electric pylons, trees in riverine forests and cliffs in the footsteps of the mountains were defined. In the selected regions, the suitable breeding habitats were monitored most intensively between February and July. However, sporadic observations were done throughout the year. Observations were made in optimal meteorological condition with good visibility, no strong winds or rain. The high-voltage power lines were surveyed using a transect method, while the riverine forests and rocky areas were surveyed by observations from stationary viewpoints (Anderson 2007). Special efforts were done to read the rings of the individuals and identify their origin and year of release.

A territory was defined as occupied by a pair when courtship behaviour and display were observed (Steenhof & Newton 2007). The occupied breeding territories were visited at least 3 times during the breeding season to assess the breeding success. The breeding success (number of fledglings/number of incubating pairs) was calculated.

Results and Discussion

The breeding of the Saker Falcon in Bulgaria was confirmed only south of the Balkan Mountains. In the period 2017–2023, we recorded three breeding territories occupied by Saker Falcon pairs in the country. In total, 7 breeding attempts were recorded, 15 chicks were successfully raised until the age of fledging and 6 nestlings died before fledging. The average breeding success was 2 fledglings/incubating pair *(Table 1)*.

Territory A was occupied in 2017 by a pair of immature birds (raised and released in 2015). For 6 consecutive years 2017–2022, the territory was occupied by a pair, but in 2023, only a single individual was recorded. We recorded two changes of partners in that period. In 2020, the female was replaced by an individual raised and released in 2016. In 2021, the new female was found with injured wing after collision with a powerline and was replaced by another female in the same year. The pair occupied a Long-legged Buzzard's *(Buteo rufinus)* nest built on an electric pylon *(Figure 1)*.

We recorded 4 breeding attempts in that territory (2018–2021), 14 nestlings (out of 14 eggs – counted by drone) hatched but only eight fledged successfully. In 2021, three nestlings hatched but due to the injury of the female, they all perished as the male was not able to provide sufficient food. In 2022, there was a new female, but the pair did not breed. All individuals that occupied this breeding territory in the period 2017–2021 were ringed and were released as part of the reintroduction program for the species in Bulgaria. In 2022, neither the male nor the female were ringed and the single individual observed in the territory in 2023 was also not wearing a ring. These findings indicate that either these individuals were captive-bred and released but managed to remove their rings or they were hatched in the wild. However, the origin of these individuals remains unknown.

Territory B was discovered in 2022 when the pair was observed in the post-fledging period hunting together with one fledgling. In 2023, four nestlings hatched and all fledged successfully. The pair used a nest built by Long-legged Buzzards on a cliff. Both the female and the male were released as juveniles in 2019 in the frame of the species reintroduction program in Bulgaria.

Table 1. Number of occupied territories and breeding performance of the Saker Falcons in the period 2017–2023

1. táblázat Az elfoglalt territóriumok száma és a kerecsensólymok költési teljesítménye a 2017–2023 közötti időszakban

Year	No of occupied territories	No of pairs	No of nestlings	No of fledglings	Breeding success (fledglings/ incubating pair)
2017	1	1	0	0	0
2018	1	1	3	2	2
2019	1	1	3	2	2
2020	1	1	5	4	4
2021	1	1	3	0	0
2022	2	2	Unknown	1	1
2023	3	2	6	6	3

Figure 1. Saker Falcon occupying a nest built by a Long-legged Buzzard on a pylon
1. ábra A kerecsensólyom egy pusztai ölyv által épített fészket foglal el egy oszlopon

Territory C was discovered in 2023 and most probably it was the first year when this territory was occupied by the pair. A Raven's *(Corvus corax)* nest built on a large cliff was occupied. The pair had two nestlings (out of three eggs) in 2023, and both fledged successfully. At least one of the individuals from that pair was ringed as it was released in 2020 as a juvenile in the frame of the reintroduction program.

Our results indicate that the population of Saker Falcon in Bulgaria is slowly increasing as a result of successful reintroduction program. In the frame of this program, 160 Saker Falcons were raised and released in the wild through the method of hacking over a 12 years' period (2011–2023) (Lazarova *et al.* 2020). All three occupied territories were located 40–60 km from the release site in areas with high abundance of European Ground Squirrels, which probably is the main prey for the species during the breeding season. However, more detailed studies on the diet of this incipient breeding population are needed.

Our observations show that all registered pairs were formed by young and inexperienced individuals which can explain the low number of fledglings in the first breeding attempts. However, with the aging of the partners, the breeding success improved e.g. in **Territory A** 4 fledglings were successfully raised on the third year of breeding. Due to the young age of the breeders and the small sample size, we could not compare our results with other studies from the species range in Europe. More studies are needed in this respect to draw meaningful conclusions about the quality of the territories where the species currently occurs.

Based on the surveys and observations of Saker Falcons during the breeding season, we propose that 1–2 more pairs might be present, therefore, surveys should continue in the future. Furthermore, considering the ongoing reintroduction program for the species, we can assume that new pairs might occupy new breeding territories in the future. Identifying these territories is crucial to ensure that conservation actions will be implemented to safeguard the survival of these pairs and increase their productivity. We encourage detailed surveys of the threats for the species in the occupied breeding territories and the adjacent areas and the implementation of target conservation actions to secure the recovery of the Saker Falcon population in Bulgaria.

Acknowledgements

This work was carried out in the framework of the LIFE project "LIFE for Falcons" (LIFE20 NAT/BG/1162, www.SaveRaptors.org) funded by the EC. The reintroduction of the Saker Falcon in Bulgaria is funded by the Mohamed Bin Zayed Raptor Conservation Fund (UAE) with support funding from Armeec JSC (Bulgaria). The authors express gratitude to Cornel Cotorogea, Dimitar Popov, Emil Enchev, Girgina Daskalova, Petar Shurulinkov, Gradimir Gradev, Gradimir Yovchev, Petar Yankov, Ivelin Ivanov, Ivelina Petkova, Lyubomir Andreev, Dobromir Dobrev, Ivaylo Angelov, Lyubomir Profirov, Nedelcho Nedelchev and Nikolay Kolev.

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Ornis Hungarica 2025. 33(1): 194–201.
DOI: 10.2478/orhu-2025-0012

Update on the status of Saker Falcon *(Falco cherrug)* in Armenia

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Received: January 24, 2024 – Revised: November 11, 2024 – Accepted: November 12, 2024

Aghababyan, K., Manukyan, M., Klem, D. Jr., Stepanyan, H. & Baloyan, S. 2024. Update on the status of Saker Falcon *(Falco cherrug)* in Armenia. – Ornis Hungarica 33(1): 194–201. DOI: 10.2478/orhu-2025-0012

Abstract The update on the status of Saker Falcon in Armenia suggests breeding of seven to nine pairs in the central and southern regions of the country where the birds occupy semi-deserts and mountain steppes. The breeding area of the species is estimated to be 724 km^2, and the extent of occurrence is estimated to be 9,056 km^2. The conservation status of the species in Armenia can be evaluated as Critically Endangered, according to IUCN criteria. The greatest potential threat includes the illegal killing of the species by pigeon breeders. Other threats, such as illegal capture for falconry and illegal killing for trophy do not have a significant influence. The pressure of electrocution requires further investigations. Based on our current results and assessment of the Saker Falcon' conservation status in Armenia, we recommend several conservation suggestions and measures such as the change of the species' conservation status, discovering all the Saker's nests and including them in protected areas, managing the detrimental behavior of the pigeon breeders, training for Environmental Protection and Mining Inspection Body and Armenian Customs Service, raising awareness of hunters, and monitoring raptors' electrocutions.

Keywords: population size, threats, conservation status, poisoning, monitoring

Összefoglalás A kerecsensólyom helyzetének legújabb értékelése alapján Örményországban hét-kilenc pár költése feltételezhető az ország középső és déli régióinak félsivatagos és hegyvidéki sztyeppterületein. A faj fészkelőterületét 724 km^2-re, míg a teljes előfordulási területét 9056 km^2-re becsülik. A faj természetvédelmi helyzete Örményországban az IUCN kritériumai szerint kritikusan veszélyeztetettként értékelhető. A legnagyobb potenciális fenyegetést a faj galambtenyésztők általi illegális pusztítása jelenti. Egyéb veszélyeknek, mint például a solymászati célra történő illegális befogásnak, valamint az illegális trófeavadászatnak nincs jelentős hatásuk. Az áramütés hatása további vizsgálatokat igényel. Az eredményeink, valamint a kerecsensólyom örményországi természetvédelmi helyzetének értékelése alapján több természetvédelmi ajánlást teszünk és intézkedést javaslunk, például a faj védelmi státuszának megváltoztatását, az összes kerecsensólyom-fészek felkutatását, és e területek védetté nyilvánítását, a galambtenyésztők káros tevékenységének kezelését, képzések biztosítását a Környezetvédelmi és Bányászati Felügyeleti Hatóság és az Örmény Vámhivatal számára, a vadászok érzékenyítését, valamint a ragadozómadarakat érő áramütések monitorozását.

Kulcsszavak: állománynagyság, veszélyeztető tényezők, természetvédelmi helyzet, mérgezés, monitoring

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Introduction

Saker Falcon *(Falco cherrug)* is a globally threatened species, included in IUCN Red List as Endangered (BirdLife International 2017), in Resolution 6 of Bern Convention (European Environmental Agency 2011), in Annex II of Convention for Migratory Species (CMS 2020), in Annex II of Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2023), and in Armenian Red Book (Aghasian & Kalashyan 2010) as Endangered.

The species was recorded in Armenia since 1930s (Dahl 1954), and traditionally was considered a migratory and wintering bird for the country (Adamian & Klem 1999), being replaced by Lanner Falcon *(Falco biarmicus)* as was justified by Dementiev and Gladkov (1951).

In 2018 (Korepov & Aghababyan 2020), the first proof of its breeding was recorded in Armenia, and it encouraged us to conduct field investigations to search for other possible breeding locations and to reassess the conservation status of the species in the country.

This paper summarizes the results of our field investigations and provides an assessment of the national conservation status of the Saker Falcon in Armenia.

Material and Methods

Data collection

We collected data on occupied nests, and birds observed in territorial behavior. To guide our search, all documented breeding records of the species were identified in the database of National Bird Monitoring, Observation.Org and eBird. We searched for birds showing territorial behavior and the discovery of occupied nests. We used the guide developed for the European Breeding Bird Atlas 2 (hereinafter EBBA 2) (Voříšek *et al*. 2008) to inform about territorial behavior.

During 2019–2023, we recorded 33 Saker Falcon individuals, and one newly occupied nest.

Data processing

Using QGIS 3.30.2 (QGIS.org 2023), we mapped all species records. We used standard European Terrestrial Reference System 1989 (The Digital National Framework 2013) in a scale of 10 × 10 km. Mapped records and breeding codes were used to identify cells with higher probability of breeding (Voříšek *et al*. 2008). The cells we identified were used to extrapolate to similar areas to estimate the overall breeding population of Saker Falcon in Armenia.

Our breeding records were also used to estimate the Area of Occupancy (AOO) and the Extent of Occurrence (EOO) according to IUCN guidelines (IUCN Standards and Petitions Committee 2019) for the species. To compute the AOO, we divided the existing

10 × 10 km^2 cells into 2 × 2 km^2 cells and overlapped the smaller new grid with areas of individual concentrations, including the cells between the birds, which have been recorded within one concentration. This permitted identifying occupied cells at the 2 × 2 km^2 grid level. We then multiplied the number of occupied cells by the area of an individual cell, taking 4 km^2 (2 × 2 km) cells as the reference scale. To compute the EOO, the rule of minimum convex polygons (the smallest polygon in which no internal angle exceeds 180° and which contains all the sites of occurrence) was applied for the species' AOO, excluding discontinuities and disjunctions of all grid cells within the overall distribution inside the borders of Armenia.

The results of this analysis were used for assessment of the conservation status of the species according to the IUCN guidelines (IUCN Standards and Petitions Committee 2019).

Threat data collection

To determine the threats to the species, we interviewed five inspectors of RA Environmental Protection and Mining Inspection Body, heads of seven Hunting Unions, 23 pigeon breeders, who live around the concentration areas of the Sakers' records, and four custom officers of four customs services of the country: one in Zvartnots International Airport, two services at the northern border with Georgia and one service at the southern border with Iran. Additionally, we obtained records from the Department for Licenses, Permits and Compliances of the RA Ministry of Environment on all authorized permissions to export raptors from Armenia.

Interviews with the first three target groups were conducted in an informal but confidential manner. Our questions to the Environmental Protection and Mining Inspection Body were to assess the poaching of medium-sized raptors, as well as determine Saker Falcon knowledge of the inspectors *(Annex 1)*. Questions to the heads of Hunting Unions were to determine possible poaching cases, and also their knowledge of Saker Falcon *(Annex 1)*. Questions to the pigeon breeders were to assess the harm, they identified with medium-sized raptors, and the hat measures they used to protect their pigeons *(Annex 1)*. Our interview with customs officers was semi-structured, aimed at identification of any illegal trade of different raptor species, and an ability of custom officers to differentiate the raptor species *(Annex 1)*.

Results

Distribution and abundance of Saker Falcon in Armenia

We found two occupied nests, five concentration areas, and two additional areas with isolated records in the breeding season in Armenia *(Figure 1)* and estimated the Saker Falcon population to be seven to nine pairs in the country. Saker Falcons are mostly distributed in the central and southern regions of the country, occupying semi-deserts and dry mountain steppes *(Figure 2)*. Both nests occurred on the cliffs in shallow grottos at the height of 10

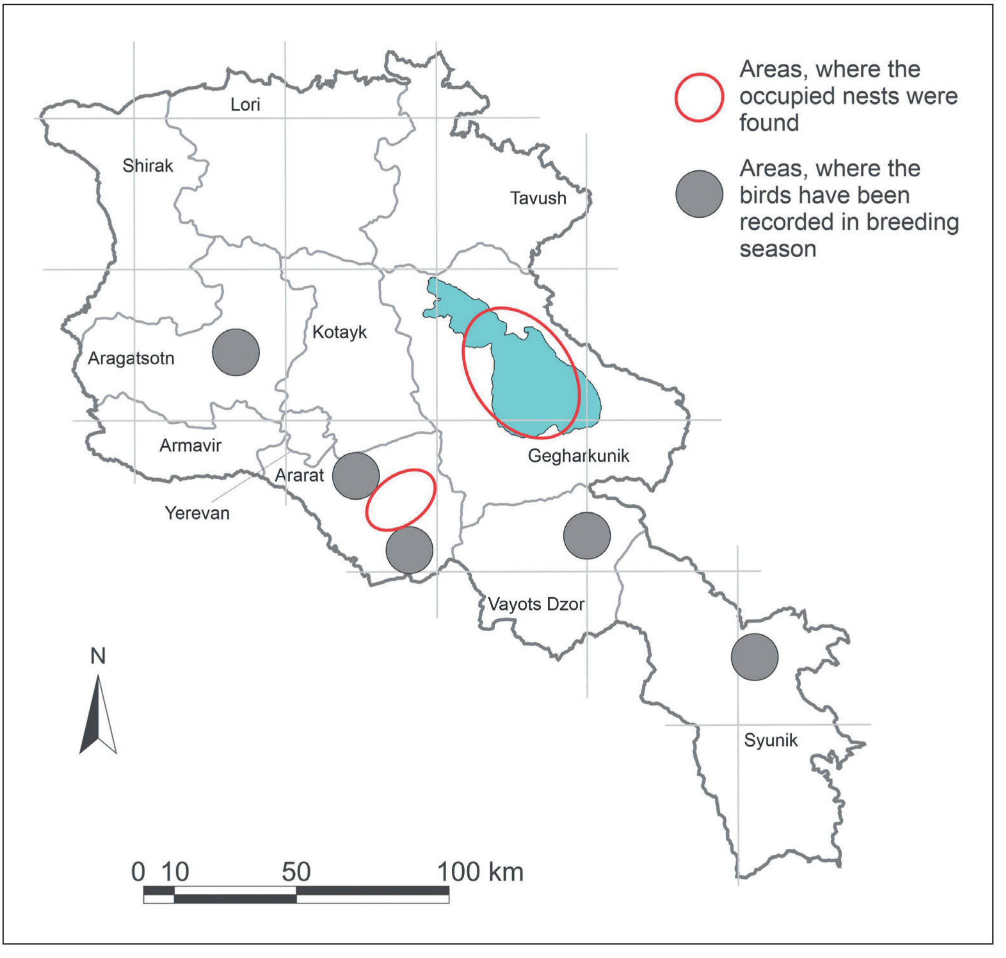

Figure 1. Distribution map of Saker Falcon in Armenia (the geographical details are hidden on purpose, taking the species' sensitivity into consideration)
1. ábra A kerecsensólyom elterjedési térképe Örményországban (a pontos földrajzi adatok szándékosan rejtve maradnak, figyelembe véve a faj érzékenységét)

and 30 meters from the bottom. The length of the cliff face for the first nest was about 70 meters; it was a stick nest constructed by the Egyptian Vulture *(Neophron percnopterus)* and known since 1995. The length of the cliff face for the second nest was about 130 m; it was located on the nude ledge. The area of species occupancy (AOO) is estimated to be 724 km^2, and the extent of occurrence (EOO) is estimated to be 9,056 km^2.

Potential threats for Saker Falcons in Armenia

Our interview with the RA Environmental Protection and Mining Inspection Body (n = 5) revealed that the inspectors do not know the species and its conservation value. During the last 10 years, they documented over 30 cases of poaching of medium-sized raptors

Figure 2. Saker Falcon`s habitat in Armenia. Photo by K. Aghababyan
2. ábra Kerecsensólyom élőhely Örményországban. Fotó: K. Aghababyan

(Annex 2), which were shot for trophies (over 20 cases in 2013–2018 and less than 10 cases in 2019–2023). In all cases, specialists identified the species, most of which were Long-legged Buzzard *(Buteo rufinus)*, Common Buzzard *(Buteo buteo)* and Honey Buzzard *(Pernis apivorus)*. During these ten years, only one case recorded a Goshawk *(Accipiter gentilis)*. Additionally, the Inspection Body informed us about the increased frequency of electrocution of raptors, among them various eagles, buzzards and goshawks.

Interviews with the heads of Hunting Unions (n = 7) identified the existence of more than 200 specimens of medium-sized raptors in the homes of hunters. Of these, two were Saker Falcons, both shot more than 20 years ago in autumn. Only two heads of Hunting Unions knew about Saker Falcon and its conservation status. According to their opinion, members of the hunting union do not know about the species and its conservation value.

Interviews with the pigeon breeders (n = 23) reveal that most of their experiences with avian predators are negative. From pigeon breeders during the past three years, 4 (17%) reported no predation, although they heard about raptor attacks on the pigeons, 7 (30%) reported 1–2 cases, 8 (35%) reported 2–5 cases, and 5 (22%) reported more than 5 cases. Thirteen (57%) pigeon breeders used a gun to scare raptors, and 3 (13%) used poison – a cheap pigeon smeared with poison and then released to be captured and eaten by the raptor. All pigeon breeders expressed a negative attitude towards raptors. Many knew the Peregrine

Falcon *(Falco peregrinus)*, some knew the Eurasian Goshawk, but only one knew the Saker Falcon. None were able to identify raptors on the species level.

The customs officers (n = 4) interviewed revealed that they never recorded any illegal trade of raptors. They had heard about such cases 10 years ago. They were not able to identify the different raptor species. Custom officers also informed us about the lack of procedures to identify exported species. Consequently, although they are required to inspect for authorized legal certificates, they do not check whether the species listed in the certificate is the same as those of the specimens being exported.

The materials obtained from the Department for Licenses, Permits and Compliances reveal that during the last 10 years, there were no cases of issuing a CITES certificate for exporting the wild caught Saker Falcon, but there were six CITES certificates issued for Saker Falcons reared in captivity in 2021. There was no DNA test made to see if young Sakers' DNA matched the DNA of their parents, to exclude the possibility of taking the young birds from the natural nests and selling them as „captive-bred" ones; however, the young Sakers were reported to the Department for Licenses, Permits and Compliances throughout the whole period of their growth as nestlings.

Discussion

We present the most current evidence about the breeding population of Saker Falcon in Armenia. There may be a natural expansion of their breeding range in the country, which may be the result of increased pressure addressing illegal trapping, following such action in neighboring Turkey (Dixon 2007) and Georgia (Kovács *et al*. 2014). Alternatively, breeders may originate from falconry, as escapees from northern Arabic countries may travel to and settle in Armenia as a good breeding destination. It is possible that from the 1990s, some breeding pairs of Saker Falcon occurred in Armenia, but were overlooked, even though extensive surveys were conducted in 1995 during the "Birds of Armenia Project" (Adamian & Klem 1999). Based on the current data, the number of breeding pairs should be estimated at seven to nine, and not three or four, as suggested earlier (Korepov & Aghababyan 2020). There is currently not enough data to estimate a population trend for this species. The conservation status of the species can be based on three criteria (IUCN Standards and Petitions Committee 2019): (1) According to criteria D1 the species qualifies as Critically Endangered having 25 pairs or less; (2) According to criteria B1 the species is Vulnerable, having an EOO of < 20,000 km^2; and (3) According to criteria B2 the species is Vulnerable, having the AOO < 2,000 km^2, although its accompanying point 'a' – qualifies as Endangered, having the number of locations = 5. Considering that this is a species with a large range, its EOO could be misleading; therefore, a more reasonable assessment is to consider the species status in Armenia as Critically Endangered under criteria D1 (IUCN Standards and Petitions Committee 2019) until additional information is available.

Among the threats, illegal trapping for falconry is considered low, although it should not be neglected, as the species becomes more numerous and widespread. To control illegal trapping, the lack of appropriate knowledge and skills of customs inspectors increases this risk for the species.

A greater, even alarming, threat is the attitude of the pigeon-breeders. If guns are used to scare raptors, they are also available to purposefully kill them. The new "poisoned pigeon" technique used by pigeon breeders was also reported for Booted Eagle *(Hieraaetus pennatus),* (Aghababyan & Stepanyan 2020), and is even more alarming. The questioned pigeon breeders (n = 23) make up only 1.2% of Armenian pigeon breeders. Therefore, the figure cannot be considered representative. However, 13% of pigeon breeders that applied this technique indicate that it is likely that pigeon breeders may use poison in this way throughout Armenia. Consequently, the scope and severity of the use of poison should be considered as „high" as a precautionary measure.

The threat of poaching for trophy is believed to be a modest threat to raptor populations. However, the low number of poaching cases can also be resulted by low determination of poaching, and therefore, additional investigation should be conducted.

Losses due to electrocution are unclear and require further investigations.

In sum, we offer the following conservation suggestions: (1) change the conservation status of the species in the upcoming edition of the Red Book of Animals of Armenia; (2) search and discover all other nests of Saker Falcon in the country; (3) include all breeding areas into existing Emerald Sites, protected under Bern Convention; (4) develop a strategy up-listing those areas with the intention of considering them as Nationally Protected Areas; (5) develop a program to manage the detrimental behavior of the pigeon breeders, e.g. alternative methods of scaring avian predators; (6) develop and implement training programs for Environmental Protection and Mining Inspection Body and Armenian Customs Service; (7) develop awareness programs for hunting unions of Armenia; and (8) design and implement a program to monitor raptors electrocutions.

Additionally, we recommend conducting genetic studies to identify the origin of Armenian Saker Falcons, and by so doing determine what, if any, exchanges occur between other border-country populations and their respective vulnerability.

Acknowledgements

The records of the species in Armenia have been conducted by members of the Armenian Ornithological Society (former Armenian Birdwatching Association). Data archiving is supported by the Observation Foundation and eBird. Also, the authors thank the Environmental Protection and Mining Inspection Body, seven Hunting Unions of Armenia, and the Armenian Customs Service for their collaboration.

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Ornis Hungarica 2025. 33(1): 202–212.
DOI: 10.2478/orhu-2025-0013

Comparison of perch deflection, conductor separation and insulation methods at reducing avian electrocutions at an electricity distribution line in Mongolia

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Received: February 05, 2024 – Revised: November 10, 2024 – Accepted: November 12, 2024

Dixon, A., Batbayar, N., Bold, B., Ganbold, M., Gungaa, A., Purev-Ochir, G. & Tsolmonjav, P. 2025. Comparison of perch deflection, conductor separation and insulation methods at reducing avian electrocutions at an electricity distribution line in Mongolia. – Ornis Hungarica 33(1): 202–212. DOI: 10.2478/orhu-2025-0013

Abstract We report persistent high rates of raptor electrocution, particularly of Saker Falcons *(Falco cherrug)*, in the Mongolian steppe grasslands. In 2018–2019, we conducted a trial to compare the efficacy of five mitigation techniques to reduce avian electrocutions at a 15 kV 3-phase power distribution line in Mongolia with a history of consistently high electrocution rates. All five techniques significantly reduced electrocution rates in comparison to controls with no mitigation. At phase 1 on the pole top, we found no significant difference in the efficacy of conductor insulation, arch-type pin-insulator mounts and the use of two pin-insulators as a means of deflecting birds from dangerous perch sites. At phases 2 and 3 on the crossarm, we found no significant difference in the efficacy of conductor insulation and the use of suspended insulators. We discuss the utility of insulation methods and pole hardware reconfiguration for retrospective mitigation of dangerous power poles that pose an avian electrocution risk.

Keywords: Saker Falcon, *Falco cherrug*, electrocution mitigation, retrofitting

Összefoglalás A mongóliai sztyeppéken tartósan magas az áramütést szenvedő ragadozómadarak száma, ezek között különösen a kerecsensólymoké. 2018–2019-ben egy 15 kV-os, háromfázisú elektromos elosztóvezetéken öt különböző módszer hatékonyságát összevető kísérletet végeztünk, olyan szakaszon, ahol korábban folyamatosan magas volt az áramütéses esetek száma. Mind az öt megoldástípus jelentősen csökkentette az áramütéses esetek számát a beavatkozás nélküli kontrollcsoporthoz képest. Az oszlop tetején futó fázis esetén nem találtunk szignifikáns különbséget a hatékonyság terén a porcelánszigetelő és a be-, illetve kilépő sodronyok burkolása (szigetelése), az ív alakú szigetelőtartó konzolok és a kettőzött szigetelők használata esetén, a madarak veszélyes ülőhelyekről való eltérítése, távoltartása szempontjából. A másik fázisoknál, a keresztkarokon, nem találtunk szignifikáns különbséget a szigetelőburkolatok és hosszabbító elemeik segítségével történő utólagos kiegészítés és a függesztett szigetelőkre való csere hatékonysága között. Megvitatjuk az utólagos átalakítási (szigetelési) módszerek, technikák és az oszlopok fejszerkezetének átépítését jelentő megoldások alkalmazhatóságát és hatékonyságát a madár-áramütések kockázatát hordozó hagyományos építésű, veszélyes oszlopok kezelésében.

Kulcsszavak: kerecsensólyom, *Falco cherrug*, áramütés-csökkentés, szigetelés

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Introduction

Avian electrocution at power distribution lines is a long-standing, significant and widespread cause of bird mortality across the world (Lehman *et al.* 2007, Guil & Pérez-García 2022). The problem is well-documented and methods to remediate dangerous infrastructure can be implemented (APLIC 2006, Prinsen *et al.* 2012), but in many countries most existing dangerous power poles have not been remediated and new lines with dangerous pole configurations continue to be installed. One issue that potentially influences remediation rates is the paucity of information available to power line engineers on the efficacy of various items of equipment that are commercially available to reduce electrocution risk for birds. In Mongolia, avian electrocution is widespread and involves large numbers of birds, with the globally endangered Saker Falcon *(Falco cherrug)* being particularly affected (Dixon *et al*. 2013, 2020), while attempts to remediate the problem by electricity distribution companies have often relied on ineffectual or inappropriate methods (Dixon *et al.* 2019).

We previously assessed the efficacy of different mitigation techniques at reducing electrocution risk in a typical Mongolian 3-phase electricity distribution system. These trials indicated that hardware changes and additions that 'deflected' birds away from dangerous perch sites at the top of the pole and on crossarms could reduce electrocution rates by 85%, i.e. by using arch-type pin-insulator mounts at the pole top and additional unconnected pin-insulators at the crossarms (Dixon *et al.* 2018). Two perch deflector methods frequently deployed at crossarms by electricity distribution companies in Mongolia, i.e. grounded perch deflectors and rotating mirrors had contrasting efficacy, with only the latter significantly reducing electrocution risk (Dixon *et al.* 2019). However, arch-type mounts as used in the previous trials are not readily available from electricity distribution equipment manufacturers, so as an alternative way to deflect birds away from dangerous perch sites at the pole top, we established a trial to test to the efficacy of using a standard double-mount upright bracket used for fixing two pin-insulators at the top of the pole. A complimentary approach to reduce electrocution risk through spatial separation of conductors and perch sites at the crossarm, i.e. at phases 2 and 3, is to switch conductor attachment from upright pin-insulators to suspended insulators (Prinsen *et al.* 2012). In addition, we retained conductor insulation covers from our previous trial (Dixon *et al.* 2019) to compare the efficacy of insulation methods at both the pole top and crossarms.

Here, we describe the results of a trial in eastern Mongolia to compare the efficacy of mitigation techniques based on conductor insulation (pole top and crossarm), spatial separation of conductors from perch sites (crossarm only) and deflection from dangerous perch sites (pole top only).

Materials and Methods

Study site

The study was undertaken at a three-phase, 15 kV electricity distribution line running 56 km from the district centre of Uulbayan to the district centre of Monkhkhaan in Sukhbaatar

Province. The predominantly flat and rolling landscape surrounding the line was characterized by grass-dominated steppe habitat and sandy soils. The vegetation was sparse and short, being intensively grazed by livestock and it supported high densities of herbivorous small rodents. The Uulbayan-Monkhkhaan line has a history of avian electrocution (Dixon *et al.* 2013) and has been the subject of previous studies investigating avian electrocution rates (Dixon *et al.* 2017) and trials of mitigation methods (Dixon *et al.* 2019). The line comprises 532 poles, consisting of 36 'anchor or strain' poles and 496 standard 'line or tangent' poles. All poles were made of grounded steel-reinforced concrete, with galvanized steel crossarms. In this 3-phase distribution system, the phase 1 central conductor wire was attached at the top of the poles, while the phase 2 and 3 conductor wires were attached lower down, either side of the crossarms.

Trial design

We describe a trial of avian electrocution mitigation techniques where the unmitigated line pole configuration comprised a single pin insulator fixed to an upright galvanized steel bracket at the top of the pole (Phase 1; P1), and single pin insulators fixed at the ends of a galvanized steel crossarm (Phases 2, 3; P2/3) *(Figure 1)*. At P1, we compared the efficacy of three techniques:

Figure 1. Upland Buzzard *(Buteo hemilasius)* perched at an unmitigated standard line pole (control)
1. ábra Himalájai ölyv *(Buteo hemilasius)* egy szigeteletlen standard oszlopon (kontroll)

(i) insulation of the conductor cable, and physical deflection of birds from dangerous perching sites by (ii) adding an additional pin-insulator and (iii) changing the pin-insulator mount from an upright bracket to an arch-shaped mount, while at P2/3, we compared the efficacy of (i) insulation of the conductor cable, and the physical separation of perching sites from conductor cables by using (ii) suspended insulators at crossarms. For the experimental trial, we divided the line into 24 sections of line poles between anchor poles, excluding 72 and 42 poles at each end of the line. We allocated lines section to five treatment groups, which were determined by a pre-existing configuration based on random allocation for a previous trial (see Dixon *et al.* 2019). On 4 and 5 October 2018, we added additional pin insulators at P1 to 131 poles and suspended insulators at P2/3 to 223 poles in the following five treatment arrangements *(Figure 2)*: (i) P1 Additional Pin Insulator in combination with P2/3 Suspended Insulators (P1Add + P2/3Sus; 66 poles/4 line sections) *(Figure 3)*, (ii) P1 Additional Pin Insulator in combination with P2/3 Insulated Conductor (P1Add + P2/3Ins; 70 poles/4 sections), (iii) P1 Insulated Conductor in combination with P2/3 Suspended Insulators (P1Ins + P2/3Sus; 79 poles/5 sections), (iv) P1 Arch Type Mount in combination with P2/3 Suspended Insulators

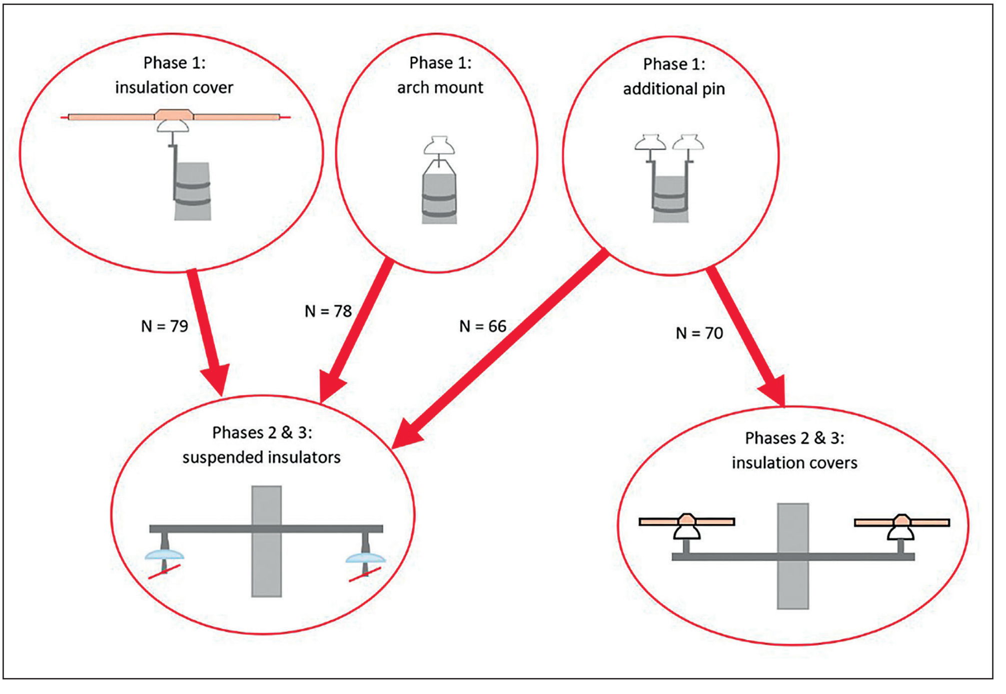

Figure 2. Trial set-up. Efficacy of insulation covers, arch mounts and additional pin-insulator at P1 was compared among poles with suspended insulators at the crossarm. The efficacy of suspended insulators and insulation covers at P2/3 was compared among poles with an additional pin-insulator at the pole top

2. ábra Az oszlopok keresztkarján függesztett szigetelőkkel ellátott oszlopok esetében összehasonlítottuk a szigetelőburkolatok, íves tartók és további csúcsszigetelők hatékonyságát az oszlop tetején (P1). Továbbá az oszlop tetején további csúcsszigetelővel rendelkező oszlopok esetében összehasonlítottuk a függesztett szigetelők és a szigetelőburkolatok hatékonyságát a keresztkarokon (P2/3)

Figure 3. Saker Falcon perched at experimental pole with an additional unconnected pin-insulator fitted to P1 to deflect birds from dangerous perch sites at the concrete pole top, and suspended insulators to separate conductors at P2/3 from perch sites on crossarm

3. ábra A kerecsensólyom egy kísérleti oszlopon ül, amelynek tetején (P1) egy további, nem csatlakoztatott csúcsszigetelőt helyeztek el, hogy elriassza a madarakat a veszélyes beülőhelyektől a betonoszlop tetején. Emellett a keresztkarokon (P2/3) függesztett szigetelők választják el a vezetékeket az esetleges beülőhelyektől, csökkentve ezzel a madarak áramütésének kockázatát

(P1Arc + P2/3Sus; 78 poles/5 sections), and (v) P1 Single Pin Insulator in combination with P2/3 Pin Insulators (Control; 171 poles/9 sections).

At all anchor poles, we reduced mitigation rates by switching the jumper wires at phases 2 and 3 to pass under the crossarm rather than over it (Dixon *et al.* 2019), and for the trial, we replaced the uninsulated jumper wires with insulated cable (n=12) to compare with untreated controls (n=24)

Data collection

In 2018 and 2019, we undertook seven surveys of all poles along the power line on the following dates: 12 and 22 October, 02 and 14 November 2018 and 11 April, 16 May, 23 August 2019. We searched the ground within a radius of 20 m around the base of each pole and recorded the presence of avian remains. The ground below all poles was open and sandy with very sparse grass vegetation, making carcasses highly visible and a low likelihood that any carcasses were not detected.

Statistical analysis

Line sections were allocated sequential numbers and each pole was assigned a section number, depending which section it was in on the line. We used spatial mixed models to test whether electrocution rates significantly differed between mitigation methods and in comparison to unmitigated controls. We used generalized mixed-effect models (GLMMs), with the number of electrocuted birds per pole in line sections being the dependent variable, with treatment type considered a fixed factor. GLMMs were implemented in the spaMM (spatial Mixed Models) package in R (Rousset & Ferdy 2014) based on a Poisson distribution and we accounted for spatial correlated random effects through a Matérn spatial correlation structure. The latitude and longitude of central pole locations in each line section were used as random effects in the models. The pairwise mean comparisons between mitigation methods were carried out using the glht function of multcomp package in R based on Tukey contrasts. We computed all analyses using R (R Development Core Team 2013).

Results

A total of 453 raptors and corvids were electrocuted at poles in our treatment groups, comprising Saker Falcon *Falco cherrug* (n=226), Upland Buzzard *Buteo hemilasius* (n=140), Common Raven *Corvus corax* (n=64), Golden Eagle *Aquila chrysaetos* (n=9),

Table1. Pairwise comparisons at line poles: experimental treatment groups in relation to control, suspended insulators *v* insulation at crossarm and arch mount *v* additional pin-insulator *v* insulation at the pole top

1. táblázat Páros összehasonlítások oszlopokon: kísérleti kezelési csoportok a kontrollhoz viszonyítva, függesztett szigetelők vs. keresztkar szigetelés, valamint íves tartó vs. extra csúcsszigetelő vs. oszlop tetején lévő szigetelés

Treatment comparisons	Estimate	Std. Error	z-value	Pr(>|z|)
Treatment groups v control				
P1 Add + P2/3 Ins *v.* Control	-1.5685	0.2220	-7.064	<0.001***
P1 Add + P2/3 Sus *v.* Control	-1.7511	0.2438	-7.182	<0.001***
P1 Arc + P2/3 Sus *v.* Control	-2.4006	0.2418	-9.927	<0.001***
P1 Ins + P2/3 Sus *v.* Control	-2.6958	0.3066	-8.792	<0.001***
Suspended insulators v conductor insulation at P2/3 on crossarm				
P1 Add + P2/3 Sus *v.* P1 Add + P2/3 Ins	-0.1826	0.3178	-0.574	0.9761
Arch mount v additional pin insulator v conductor insulation at P1 on pole top				
P1 Arc + P2/3 Sus *v.* P1 Add + P2/3 Sus	-0.6494	0.3351	-1.938	0.2770
P1 Add + P2/3 Sus *v.* P1 Ins + P2/3 Sus	-0.9447	0.3831	-2.466	0.0901
P1 Ins + P2/3 Sus *v.* P1 Arc + P2/3 Sus	-0.2952	0.3831	-0.771	0.9321

Eurasian Eagle Owl *Bubo bubo* (n=7), Black Kite *Milvus migrans* (n=2), Common Kestrel *Falco tinnunculus* (n=2), Steppe Eagle *Aquila nipalensis* (n=1), Long-legged Buzzard *Buteo rufinus* (n=1), and Eastern Buzzard *Buteo japonicus* (n=1). Saker Falcons were the most frequently electrocuted species, with most electrocutions occurring during the post-fledging dispersal period. We found 89 carcasses during two breeding season surveys in April and May 2019. Over a 40-day period from 5 October to 14 November 2018, Saker Falcons were electrocuted at a rate of at least 0.45 birds per day at control poles, equivalent to one per day for every 380 unmitigated poles. Of 119 carcasses recovered on a single survey during the post-fledging dispersal period in August 2019, we able to determine the age and sex of 114 birds, 54% of which were male and overall 76% were juveniles electrocuted in the year they hatched (HY; all other birds were recorded as electrocuted 'after hatch year', AHY), with no significant sex-bias among the age classes (Male : Female HY=48 : 39, Fisher's exact test P=0.55; Male : Female AHY=14 : 13, Fisher's exact test P=1.00).

At standard line poles, all treatments significantly reduced electrocutions in comparison to the control *(Table 1, Figure 4)*. Using treatment groups that all had additional pin insulators at the top of the pole to compare the efficacy of different configurations at P2/3

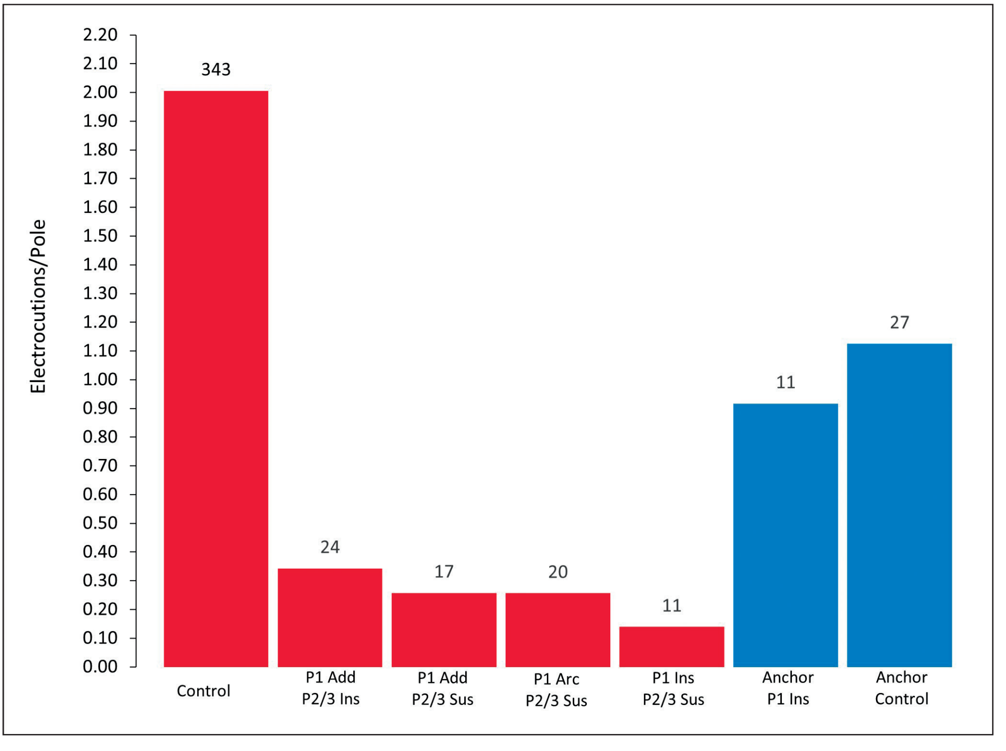

Figure 4. Avian electrocutions per pole in each treatment group of line/tangent poles (red) and anchor/dead-end poles (blue). Values represent the number of carcasses found for each treatment group

4. ábra A madarak áramütéses eseteinek száma oszloponként az egyes kísérleti csoportokban: standard állású/tangens oszlopok (piros) és feszítő/végoszlopok (kék). Az értékek az egyes kezelési csoportokban talált tetemek számát jelzik on the crossarm, we found no significant difference in efficacy between conductor insulation and suspended insulators *(Table 1)*. Additionally, using treatment groups that all had suspended insulators on the crossarms to compare the efficacy of different configurations at P1 on the pole top, we found no significant difference in efficacy at reducing electrocution rates between conductor insulation, arch-type insulator mounts and an additional pin insulator *(Table 1)*.

Table 2. Comparison of avian electrocution rate at anchor poles with insulated jumper wires *v* controls

2. táblázat A madarak áramütéses eseteinek összehasonlítása feszítőoszlopokon szigetelt összekötő vezetékekkel és kontroll csoportokkal

Treatment	**Estimate**	**Cond. SE**	**t-value**
Intercept	-0.1357	0.3317	-0.409
Insulated P1 jumpwire	-0.3178	0.5210	-0.610

At anchor poles, we found no effect of replacing uninsulated jumper wires at phase 1 with insulated cable *(Table 2)*. However, this anomalous result was probably due to incorrect fitting of the insulated jumper cables where the engineers had left an exposed section of uninsulated conductor cable at either end of the cable connecting joints *(Figure 5)*, which posed an electrocution risk for birds perching nearby.

Figure 5. Insulated jumper wires connected to conductors at anchor pole. A: shows correct fitting at P2/3 with cable connection in front of the dead-end clamp. B: shows incorrect fitting at P1 with cable connection on jumper wire after the dead-clamp, leaving exposed conductors above perch sites on the crossarm

5. ábra Szigetelt összekötő vezetékek csatlakoztatása feszítőoszlopon lévő vezetékekhez. A: helyes csatlakoztatás a P2/3 pontokon, ahol a kábelkapcsolat a végzáró bilincs előtt van. B: helytelen csatlakoztatás a P1 ponton, ahol a kábelkapcsolat a végzáró bilincs után van az összekötő vezetéken, így a keresztkaron lévő ülőhelyek felett szabadon maradnak a vezetékek

Discussion

The most frequently electrocuted species was Saker Falcon, accounting for half the raptors recorded in this study. As with previous surveys of this power line in eastern Mongolia, we found that during the post-fledging dispersal period most of the Saker Falcons killed were HY juveniles (Dixon *et al.* 2020). However, we found no evidence of sex bias among age classes, in contrast to previous results obtained during the post-fledging period at the same line (Dixon *et al.* 2020). Persistent high electrocution rates reported for this power line are likely related to asynchronous population cycles among the small mammal community (i.e. Daurian Pika *Ochotona dauurica*, Brandt's Vole *Lasiopodomys brandtii*, and Mongolian Gerbil *Meriones unguiculatus*) maintaining a consistently high abundance of prey in the adjacent grassland.

Our results confirm previous findings based on trials at the same power line in 2013–2014 (Dixon *et al.* 2019), in that arch-type pin-insulator mounts and conductor insulation were effective at reducing electrocution rates at the pole top (P1). The addition of a second pin insulator was also effective at reducing electrocution risk at the pole top. The additional pin insulator reduced the space available for medium- and large-sized raptors and corvids to perch on the concrete pole top, and likely acts by deflecting the birds to perch on top of the insulators, which is relatively safe with a lower risk of contact with the grounded pole. Although there was no significant difference in electrocution rates between these three treatments, the use of conductor insulation at phase 1 on the pole top resulted in the lowest electrocution rates. Conductor insulation at phases 2 and 3 on the crossarm was equally as effective as using suspended insulators that carried the conductor cable under the crossarm.

It is noteworthy that none of the mitigation measures eliminated electrocution risk. Increased separation of live conductor cables from raptor perch sites using suspended insulators at crossarms can significantly reduce electrocution rates, but there is still a risk of electrocution through feacal 'streamers' (Eccleston & Harness 2018). There is also a logistical issue with retrospectively reconfiguring crossarms with suspended insulators in that to achieve minimum regulatory ground clearance heights for conductor cables it may be necessary to move the crossarm higher up the pole, which is not always possible or safe on preexisting poles. New lines utilizing suspended insulators require alternate crossarm designs, taller poles or closer pole-spacing distances, which increases cost. Deflecting raptors from dangerous perch sites at the top of the pole may not always work, especially for smaller species that can still find a place to perch. Larger birds may flap more vigorously when trying to settle on a smaller perch space on the concrete pole top, increasing their risk of simultaneously contacting the conductor cables. When deflected to perch on the top of the pin insulator instead, where their feet are in contact with the live conductor cable, larger raptors may still simultaneously contact the concrete pole or galvanized steel insulator mount with their tail, wing, feacal 'streamer' or even dangling prey (e.g. Dixon *et al.* 2018). Adding insulation to the existing pole hardware is a relatively simple form of retrospective mitigation that can be applied to conductor phases at both the pole top and crossarm and can potentially be fitted without requiring power shutdown. However, depending on the design, insulation covers may have limited durability and require regular replacement and maintenance (e.g. Guil *et al.* 2011), while there can also be risks to conductor integrity (Göcsei *et al.* 2014) and power supply associated with flashover due to ice accretion (Farzanah & Chisholm 2008) and electrical creep caused by dust accumulation (Castillo Sierra *et al.* 2015). In our study, insulation covers were made from durable uPVC and had been in place for 6 years with no losses. We did not investigate any effect of insulation covers on power supply, but we did note that the rigid covers had resulted in many pin insulator mounts tilting from vertical, probably due to increased wind load.

Ongoing electrocution risk can be the result of incorrectly fitted mitigation, described by Dwyer *et al.* (2017) as 'application' errors in retrofitting. Our attempt to mitigate jumper wires at the central phase of anchor poles was unsuccessful due to the insulated jumper cable being too short, leaving a long length of uncovered jumper wire and an uninsulated cable connecter at each end. It is likely this occurred when engineers precut the insulated jumper wires too short at a fixed length prior to installation, and they did not fully appreciate the objective of ensuring that the whole length of the jumper wire from the dead-end clamp was insulated. Consequently, we were not able to examine the efficacy of using fully insulated jumper cables at reducing electrocution risk.

We conclude that retrospective mitigation techniques at dangerous power poles that involve adding additional insulation or changing configurations of pole hardware can be equally effective at reducing electrocution rates. While insulation covers can be quickly and simply applied to all three phases of a dangerous power line, there are potential issues with durability, maintenance and risks to conductor integrity and power supply. Such concerns are not applicable to reconfigured hardware, but it will always require significant input from line engineers and power shutdown, while techniques such as switching to suspended insulators cannot be retrospectively applied in all circumstances.

Acknowledgements

This study was funded by the Mohamed Bin Zayed Raptor Conservation Fund. We thank H. E. Mohammed Al Bowardi for his support.

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Ornis Hungarica 2025. 33(1): 213–227.
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Impact of raptor predation on racing pigeon losses: Insights from Bulgaria and implications for mitigation strategies

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Received: April 26, 2024 – Revised: May 09, 2024 – Accepted: November 13, 2024

Stamenov, A., Arkumarev, V. & Nikolov, S. C. 2025. Impact of raptor predation on racing pigeon losses: Insights from Bulgaria and implications for mitigation strategies. – Ornis Hungarica 33(1): 213–227. DOI: 10.2478/orhu-2025-0014

Abstract Racing pigeons confront predation pressure from birds of prey, resulting in human-wildlife conflict and potential illegal persecution of raptors. Despite perceptions among pigeon fanciers, empirical evidence substantiating raptors as the primary threat remains scant. This study aimed to quantify raptor predation on racing pigeons in Bulgaria, identify high-risk areas, and assess mitigation measures. Data were collected through questionnaires and GPS-tracking of pigeon flights during races. Preventive methods such as bright-colored wing patches and painted eyespots were tested. Results revealed raptor attacks as a major cause of pigeon loss, particularly prevalent during spring and in upland woodlands. Pigeons marked with repellents had higher survival rates than unmarked ones, suggesting partial effectiveness of the prevention methods. Phenology data on raptor attacks and appropriate preventive measures, established in close collaboration with pigeon fanciers, can facilitate mitigating human-raptor conflict. Further research and conservation initiatives are advocated to address this persistent issue. This study underlines the importance of incorporating stakeholder perspectives and deploying targeted conservation strategies to alleviate human-wildlife conflicts involving raptors and racing pigeons.

Keywords: human-wildlife conflict, domestic pigeons, birds of prey, anti-raptor repellent, GPS-tracking

Összefoglalás A versenypostagalambok jelentős predációs nyomásnak vannak kitéve ragadozó madarak részéről, ami ember-állat konfliktushoz és a ragadozók potenciális illegális üldözéséhez vezet. Annak ellenére, hogy a galambkedvelők megítélése szerint a ragadozók jelentik az elsődleges fenyegetést, az ezt alátámasztó tudományos bizonyítékok hiányoznak. Ez a tanulmány arra irányult, hogy meghatározza a ragadozók által okozott veszteségeket a versenypostagalambok között Bulgáriában, azonosítsa a magas kockázatú területeket, és tesztelje a csökkentő intézkedéseket. Az adatokat kérdőívek és a galambok repüléseinek GPS-nyomkövetése révén gyűjtötték össze versenyek alatt. Megelőző módszereket, például élénk színű szárnyakat és festett szemfoltokat teszteltek. Az eredmények azt mutatták, hogy a ragadozók támadásai a legfontosabb okai a galambveszteségnek, különösen tavasszal és hegységi erdős területeken. A taszító jelzésekkel ellátott galamboknak magasabb túlélési arányuk volt, mint azoknak, amelyek nem voltak megjelölve, ez a megelőző módszerek részleges hatékonyságát sugallja. A ragadozók támadásainak fenológiája és az alkalmazott megelőző intézkedések, amelyeket a galambkedvelőkkel szorosan együttműködve állapítottak meg, segíthetnek az ember-ragadozó konfliktus enyhítésében. További kutatásokra és védelmi kezdeményezésekre van szükség e probléma kezeléséhez. Ez a tanulmány hangsúlyozza a résztvevői nézőpontok figyelembevételének fontosságát és a célzott konzervációs stratégiák végrehajtását a ragadozókat és a verseny postagalambokat érintő ember-állat konfliktusok enyhítésére.

Kulcsszavak: ember-állat konfliktus, házi galambok, ragadozó madarak, ragadozó taszító, GPS-nyomkövetés

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Introduction

Birds of prey frequently contribute to human-wildlife conflicts due to predation on economically valuable species, such as domesticated racing pigeons (Henderson *et al.* 2004, Kettel *et al.* 2021). Racing pigeons are utilized for endurance flights lasting from several to 22 hours (tipplers and highflyers), as well as for speed races covering distances ranging from 100 to over 1,000 kilometers (homing pigeons). The global practice of racing pigeons, organized with scoring systems and prizes, is deeply entrenched within a community of enthusiasts who consider it a sport rather than merely a hobby (RPRA 2023). Apart from the emotional bond between fanciers and their birds, high-quality racing pigeons can yield substantial economic returns, sometimes exceeding hundreds of thousands of euros per individual (The New York Times 2020).

While the number of pigeon fanciers may be declining in Europe, interest in the sport is burgeoning in Asia, with significant participation observed in Beijing and Taiwan (Business Insider 2019). Nevertheless, Europe remains a pivotal hub for pigeon racing, particularly in the UK, Belgium, and the Netherlands, boasting tens of thousands of enthusiasts (Kettel *et al.* 2021, France24 2022, The Guardian 2022).

Despite its popularity, the racing pigeon community faces challenges, notably substantial mortality rates during racing seasons, with only approximately 20% of pigeons surviving one-loft races (BENZING 2023). While various factors contribute to pigeon losses, fanciers commonly perceive birds of prey as the primary threat (Armstrong 1991, Henderson *et al.* 2004, Kettel *et al.* 2021), although this perception often lacks scientific evidence (Kettel *et al.* 2021). Additionally, conflicts between pigeon fanciers and raptors can escalate into illegal persecution, including trapping, shooting, poisoning, or nest destruction (RSPB 2014, BSPB unpubl. data). Thus, quantifying raptor predation on racing pigeons and identifying effective prevention measures are vital from a conservation standpoint (Henderson *et al.* 2004, Kettel *et al.* 2021).

In Bulgaria, pigeon sport is quite popular, and pigeon fanciers are organized into local clubs and national-level associations (BFFHEF 2023, BRPA 2023, BRPF 2023). However, there is a lack of quantitative research or published evidence regarding raptor predation on racing pigeons, as well as on the efficiency of any measures to mitigate human-raptor conflict in the country.

This study aims to assess the magnitude of racing pigeon losses due to birds of prey in Bulgaria and test the effectiveness of some mitigation measures.

Materials and Methods

Data collection through questionnaires

Perceptions of pigeon fanciers were surveyed through a structured questionnaire comprising 28 inquiries. These encompassed aspects such as lofts locations, number of pigeons owned, pigeon care practices, timing of trainings and races, ranking of threats (rated on a scale from 1 – very low to 5 – very high), magnitude of pigeon losses, methods applied to mitigate losses, phenology of raptor attacks (timing of the day and season) and the identification of the major groups of raptors most frequently attacking pigeons. The questionnaire was disseminated online via pigeon fancier media platforms and distributed as hard copies during seminars conducted with pigeon clubs. In 2022–2023, a total of 201 completed questionnaires were obtained from pigeon fanciers in 65 municipalities across Bulgaria, which represents 25% of the municipalities in the country (n = 265 municipalities).

Data collection by use of GPS rings during pigeon races

To collect data about location, habitat and frequency of raptors' attacks on homing pigeons, we used SKYLEADER GPS pigeon identification tracker rings (Satellite System – GPS + GLONASS Dual-core System). The GPS rings (n = 18) collected information about geographic position, direction, speed and height of flight. The GPS logging modes were selected based on the flight distance and duration, as follows: (i) GPS location in every two s for flight durations up to two hours (distance 100–150 km); (ii) GPS location in every 35 s

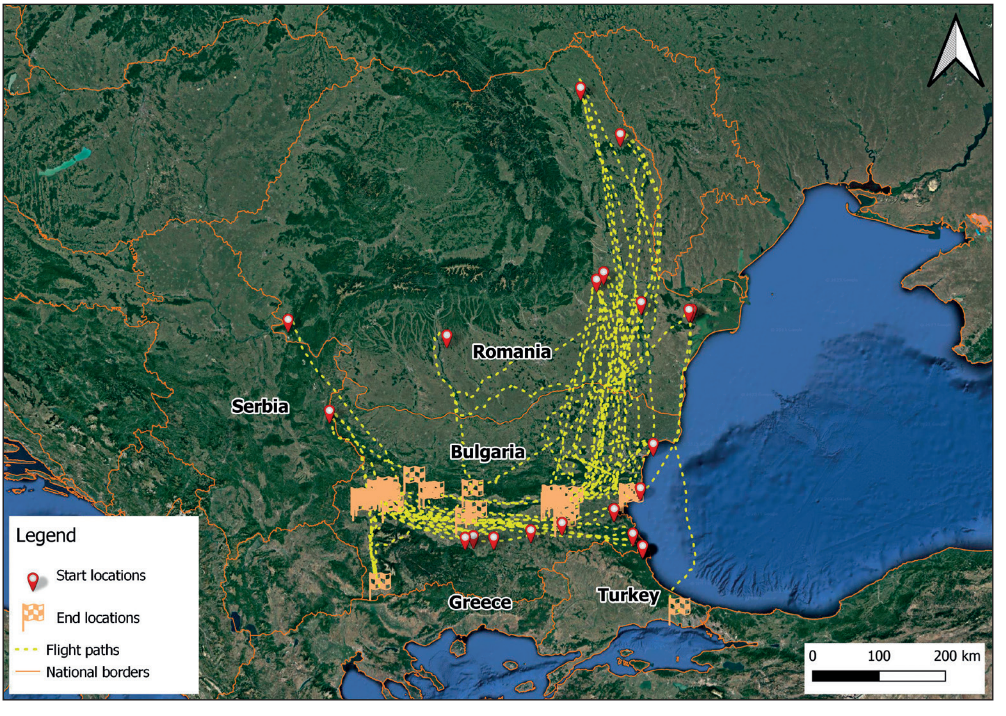

Figure 1. Map with the tracks of GPS marked racing pigeons in 2022–2023 (n = 72 individual pigeon flights tracked during 23 races). Start points were located in ten areas in Bulgaria and six areas in Romania

1. ábra A 2022–2023-ban GPS-jeladóval megjelölt versenygalambok útvonalainak (n = 72 egyedi repülés, 23 verseny során nyomon követve) térképe. Tíz elengedési pont Bulgáriában, hat Romániában volt

– for flights up to six hours (distance up to 400 km); (iii) GPS location in every 180 s – for one day long-distance flights up to 12 hours (600 km); and (iv) GPS location in every 375 s – for over-night long-distance flights up to 35 hours (> 600 km). The weight of GPS rings was 4 g and the devices were attached to the pigeon's legs. To adapt pigeons to the GPS rings and minimize any potential negative impact on their flight ability, the pigeons were marked with dummy rings, with the same weight, dimensions, and shape as the GPS rings, at least two weeks prior to the races. The GPS rings were powered by rechargeable Lithium-ion polymer battery with endurance up to 35 h. Downloading telemetry data was only possible by wired base station upon the return of the pigeon to the loft.

In total, 72 individual pigeon flights were tracked during 23 races where in total 11,740 pigeons took part. In few cases, the same pigeons carried the GPS rings more than once, but the release points, distance, duration and itinerary of the flights were different. All pigeons were raced by fanciers located in South Bulgaria and the racing start points were at 16 locations: ten in Bulgaria and six in Romania *(Figure 1)*.

Test for efficient deterrent methods to mitigate raptor predation on racing pigeons

In 2022, we checked all online platforms in Bulgaria for products advertised to reduce raptors attacks on pigeons and there was just one single product available on the market – the anti-raptor spray. To test for the efficiency of this deterrent method, anti-raptor sprays were distributed to 50 volunteering pigeon fanciers. The method consisted of spraying a bright-colored patch (ca. five cm in diameter) on the upper side of the pigeon's wing *(Figure 2)*. The patch color, unknown in the wild, was supposed to have a deterrent and irritating effect on birds of prey and thus prevent losses (Götmark 1994). The fanciers participating in

Figure 2. Painted eyespots on racing pigeons (homer on the left, highflyer on the right), under the current experiment to test for the efficiency of deterrent effect on raptors

2. ábra Festett szemek a versenygalambokon (balra postagalamb, jobbra magasröptű galamb), a ragadozómadarak elriasztásának hatékonyságát vizsgáló kísérlet során the experiment were instructed to spray only a ratio of their pigeons in the flocks, so that unmarked birds can be used as controls.

We also tested for the efficiency of eyespots method, as a combination between the bright-color wing patch (Götmark 1994) and Codice LIVIA (Federazione Colombofilia Italiana 2014) methods. We painted contrast eyespots on both upper wings of pigeons. As background colors, we used both yellow and pink, but we did not account for the effect of background color due to the small sample size. Eyespots were painted in 72 homers and highflyers (14%) out of 499 raced pigeons in total, belonging to seven fanciers (these birds were independent from the GPS marked individuals). At the end of the racing season, we compared the survival rate of eyespot painted pigeons with non-painted pigeons in the same flocks to assess the raptors deterrent impact.

Data interpretation and analysis

The relative weight of the factors causing pigeon losses was calculated as a ratio of the scoring for a single factor divided to the total sum of scoring points (n = 763) and results were presented as a percentage (Stara *et al.* 2022).

The information collected by the GPS rings was downloaded and displayed via SKYLEADER V2.0 software. A raptor attack was considered probable when rapid shift in the direction, speed and height of flight occurred, often resulting in abrupt landing of the pigeon in unusual habitat (e.g. woodland) for considerable time period – e.g. over an hour (Santos *et al.* 2015). Landing of pigeons in settlements or near water bodies along the tracks were excluded from the analysis. Our analysis is based only on unsuccessful raptor attacks on pigeons, as the data collected from the GPS rings were only from pigeons that successfully returned to their lofts.

The efficiency of bright-colored wing patches method was evaluated based on comparison between survival rates in spray-marked vs unmarked pigeons. The data collected and suitable for analysis came from 66% (n = 33) of the fanciers participating in the survey, who have sprayed a total of 1,080 pigeons (44%), out of 2,473 pigeons they own, both homing pigeons and highflyers.

Results

General features of surveyed pigeon fanciers in Bulgaria (2022–2023)

Of all respondents (n = 201), 87% race their pigeons, whereas 13% keep pigeons purely for their aesthetic appeal, or for external selection and competitions. The interviewed fanciers had on average 125 pigeons per person (ranging from 2 to 1,000 birds) and raced on average 66 pigeons (ranging from 4 to 500 birds). In total, 93% of the fanciers (n = 187) were regularly vaccinating their pigeons and applying other preventive medicine. Most of the fanciers (48%, n = 96) were participating in 1–10 races per year, 30% (n = 60) – in 11–15 races, 11% (n = 22) in 16–20 races, 5% (n = 10) – in over 20 races per year, and 6% (n = 11) do not participate in races at all.

Preventive measures applied

More than half of the pigeon fanciers interviewed (60%, n = 120) do not apply any measures to prevent raptor attacks. In those who apply measures (39%, n = 79), the mitigation methods were not exclusive (i.e. some fanciers were applying multiple methods simultaneously), 1% (n = 2) of the respondents did not answer this question. The most common method to reduce raptor attacks was a strict regime of pigeon release and training according to the time of the day and the season (31%), while in some cases pigeons were kept closed during the winter (10%). Another common method was the bright-colored wing patches made with anti-raptor sprays (21%). Few pigeon fanciers were applying alternative methods, such as making noise (6%), keeping pigeons closed all year round (6%), installing owl decoys on the roof (3%) and breed more individuals to compensate for the losses (3%).

There was no difference in the general pigeon loss rate between the fanciers applying preventive measures (n = 75) and those who do not apply any measures (n = 115) *(Figure 3)*. However, when considering only the pigeon loss rate caused by raptors, it was 14% lower in the fanciers applying measures but it should be noted that these data is based on the perceptions of the fanciers *(Figure 3)*.

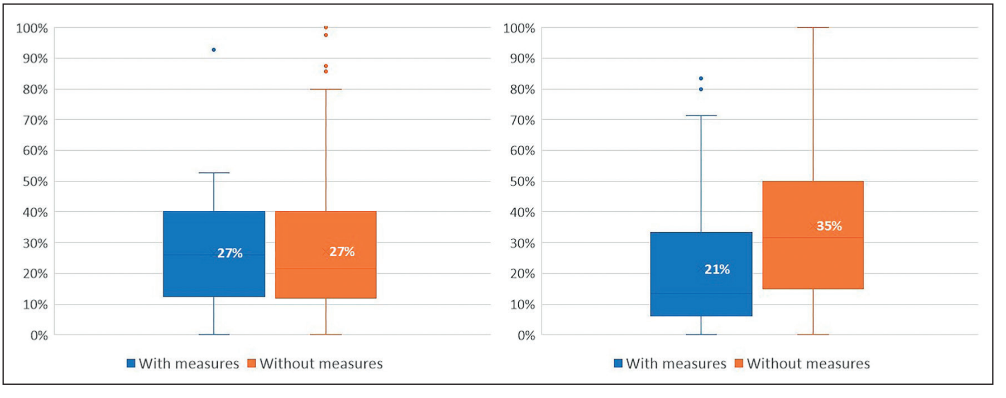

Figure 3. Comparison of general pigeon loss rate (left) and loss rate caused by raptors (right) between the fanciers applying preventive measures and those who do not apply any measures (n = 201 interviewed fanciers)

3. ábra Az összes galambveszteség arányának (balra) és a ragadozók által okozott veszteség arányának (jobbra) összehasonlítása azok között a galambtartók között, akik alkalmaznak megelőző intézkedéseket, és azok között, akik nem alkalmaznak (n = 201 megkérdezett galambtartó)

Factorial weight, phenology and frequency of raptor attacks

Based on the results collected from the questionnaire, raptor attacks were rated as the most significant cause of pigeon loss (25%), followed by bad weather conditions, disorientation, diseases and collisions with power lines (10–16%) *(Figure 4)*. Predation by terrestrial carnivores, theft or shooting were also listed as factors but with very low impact (6–10%). Negligible impact was accounted to unintentional poisoning and collision with other objects

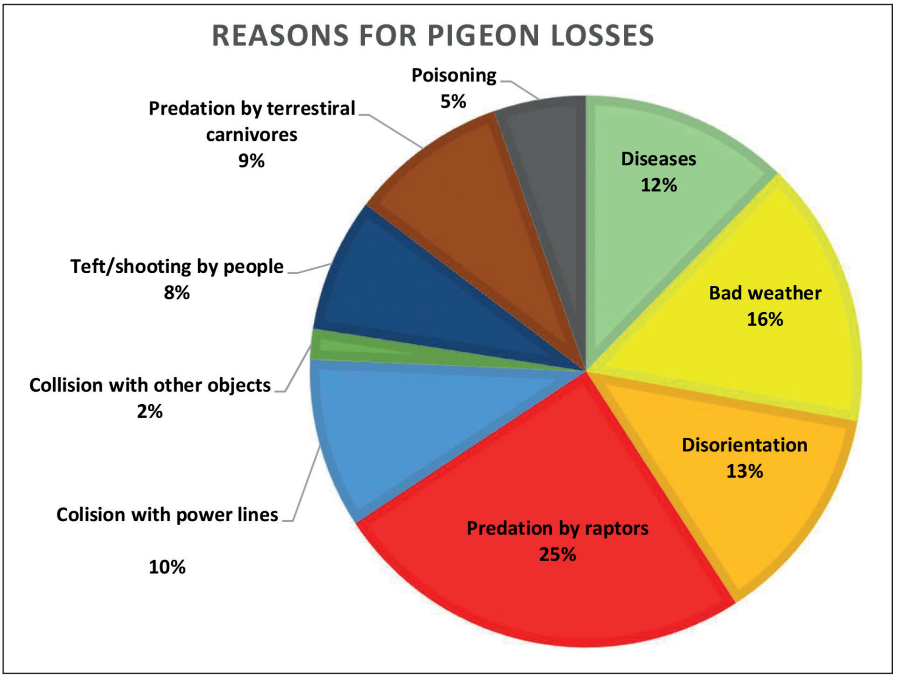

Figure 4. Ranking of the factors causing racing pigeon losses in Bulgaria (n = 201 interviewed fanciers)

4. ábra A versenygalamb-veszteséget okozó tényezők rangsora Bulgáriában (n = 201 megkérdezett galambtartó)

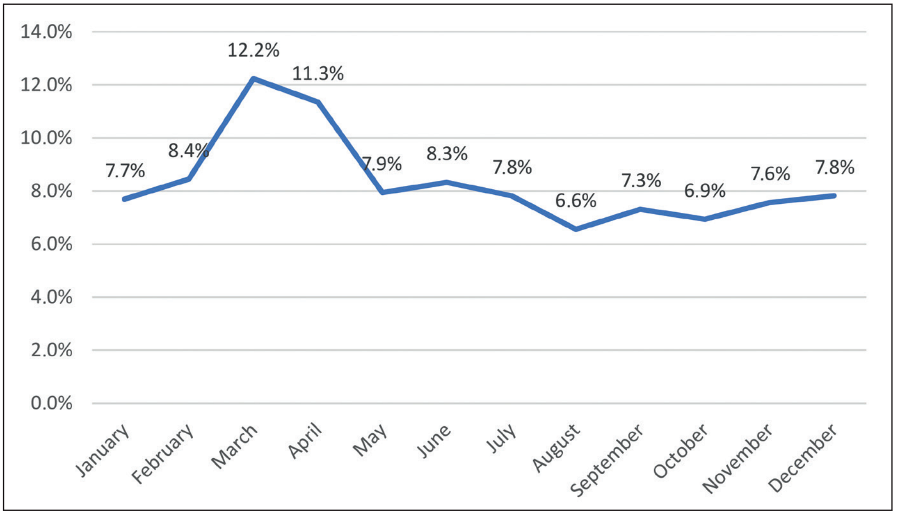

Figure 5. Seasonal phenology of raptor attacks. Percentage values represent the proportion of 201 interviewed fanciers, whose flocks were attacked in the given month

5. ábra A ragadozók támadásainak szezonális alakulása. A százalékos értékek a 201 megkérdezett galambtartó közül azok arányát mutatják, akiknek galambállományát az adott hónapban támadás érte

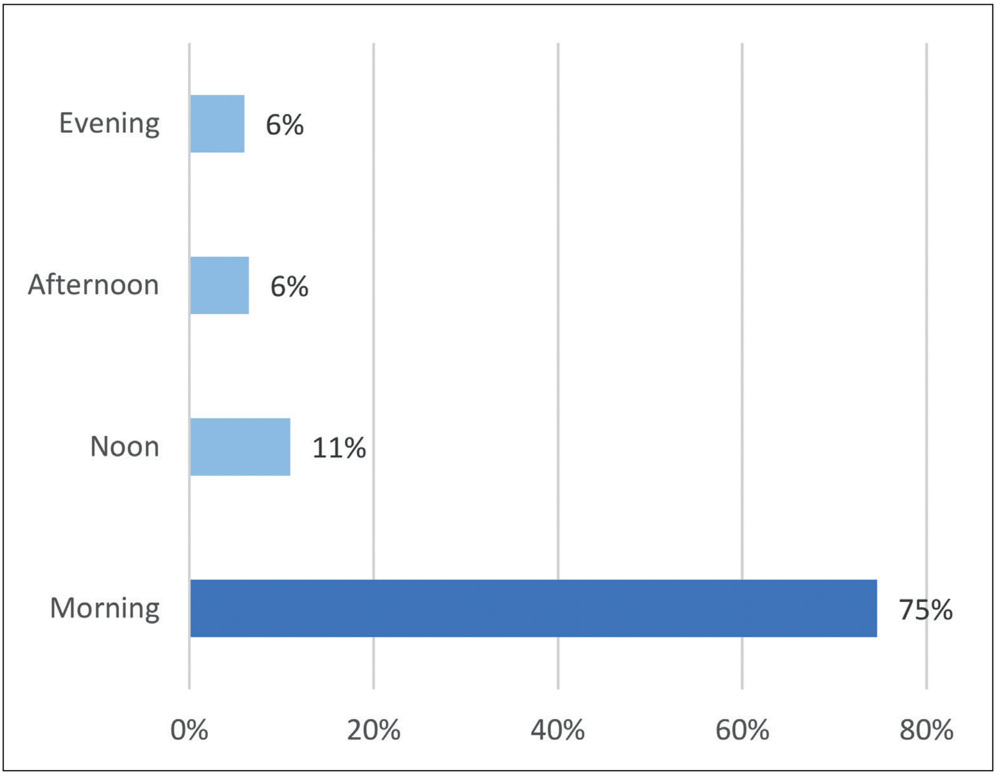

Figure 6. Daily phenology of raptor attacks, based on the answers of those out of the 201 interviewed fanciers, who suffered raptor attacks. Daytime periods: Morning (7:00–10:00), Noon (10:00–14:00), Afternoon (14:00–18:00), Evening (after 18:00)

6. ábra A ragadozómadár-támadások napi fenológiája, a 201 megkérdezett galambtartó közül azok válaszai alapján, akik ragadozó-támadásokat tapasztaltak. Napszakok: reggel (7:00–10:00), délelőtt (10:00–14:00), délután (14:00–18:00), este (18:00 után)

(≤ 5%). The reported average annual rate of pigeon loss during races was 30% (n = 6,007 pigeons lost) and for 13% (or 42% of all pigeons lost) of these, the fanciers blamed raptors. Most of raptor attacks were reported to take place in spring (March – April) *(Figure 5)*, in the morning hours *(Figure 6)* and were caused by hawks (*Accipiter* sp.) and falcons (*Falco* sp.) *(Figure 7)*.

Data from the GPS rings revealed that in 18% (n = 13) of the GPS-tracked flights pigeons were target of a raptor attack. In one of those cases, the pigeon was attacked at three different locations along 245 km long race flight, while in another case the pigeon was attacked twice along 217 km long race flight. In four cases (n = 72 tracked flights in total), the GPS ringed pigeons were lost, but there is no evidence this resulted from raptor attacks.

The GPS marked pigeons flew through three main regions in Bulgaria *(Figure 1)*, with predominance to Eastern (54% of the tracked flights), compared to Southern (37%) and Western Bulgaria (10%). However, just one of all raptor attacks took place in the east (in Romania), while all other attacks (12 attacks or 94%) took place in Western Bulgaria. The

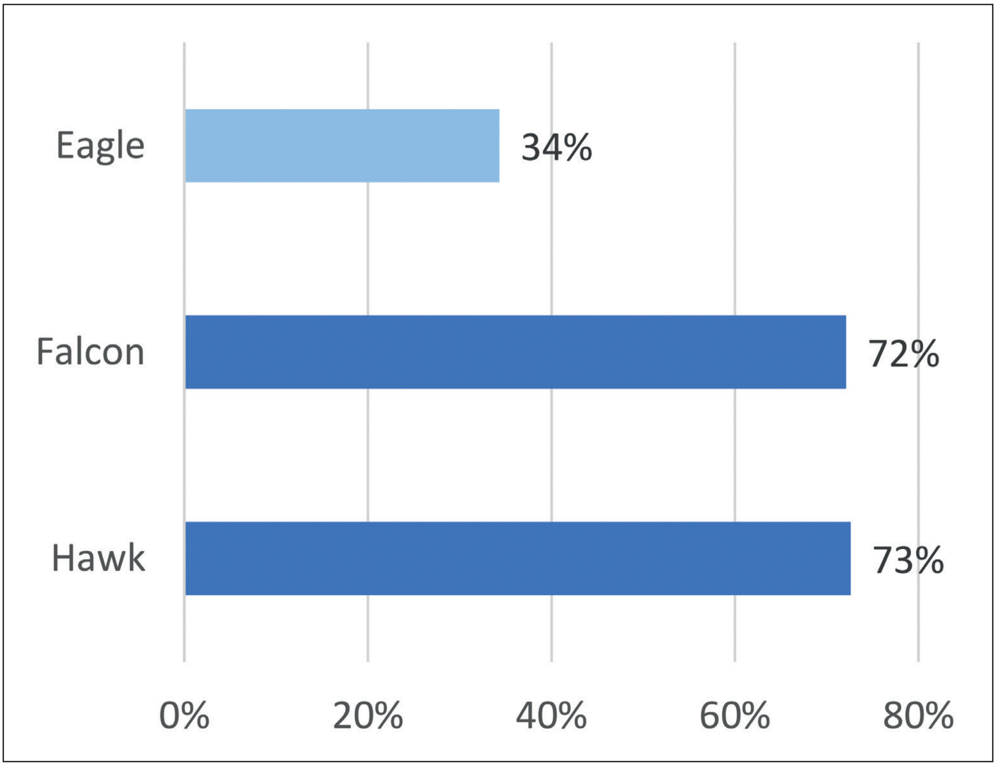

Figure 7. Ranking of raptor groups attacking the racing pigeons the most often, based on the answers of those out of the 201 interviewed fanciers, who suffered raptor attacks

7. ábra A versenygalambokat leggyakrabban támadó ragadozómadár-csoportok rangsora, a 201 megkérdezett galambtartó közül azok válaszai alapján, akik ragadozó-támadásokat tapasztaltak

elevation of attacks varied between 256 m a.s.l. and 1,534 m a.s.l. (962 m a.s.l. on average). Most raptor attacks took place along the final 1/3 of the race itinerary (11 attacks or 88%), in the upland (above 800 m a.s.l.) and in woodlands (81%).

Efficiency of preventive measures

For Bright-Colored Wing Patches method, the survival of anti-raptor spray-marked pigeons (77% survival; n = 1,080) was 16% higher compared to unmarked pigeons (61% survival; n = 1,393) *(Figure 8a)*. While this method showed some effectiveness, it cannot fully deter raptor attacks on pigeons, as 18 of the spray-marked pigeons (1.7%) returned home with injuries caused by raptors. These results were supported by fanciers' perceptions about the spray's effect: overall, 79% (n = 26) were satisfied, 36% (n = 12) expressing full confidence in the method; 18% (n = 6) could not judge if the method was efficient or not, and 3% (n = 1) considered the spray ineffective. For the Painted Eyespots method, fanciers reported an average 20% higher survival rate in eyespot-painted pigeons compared to the control *(Figure 8b)*.

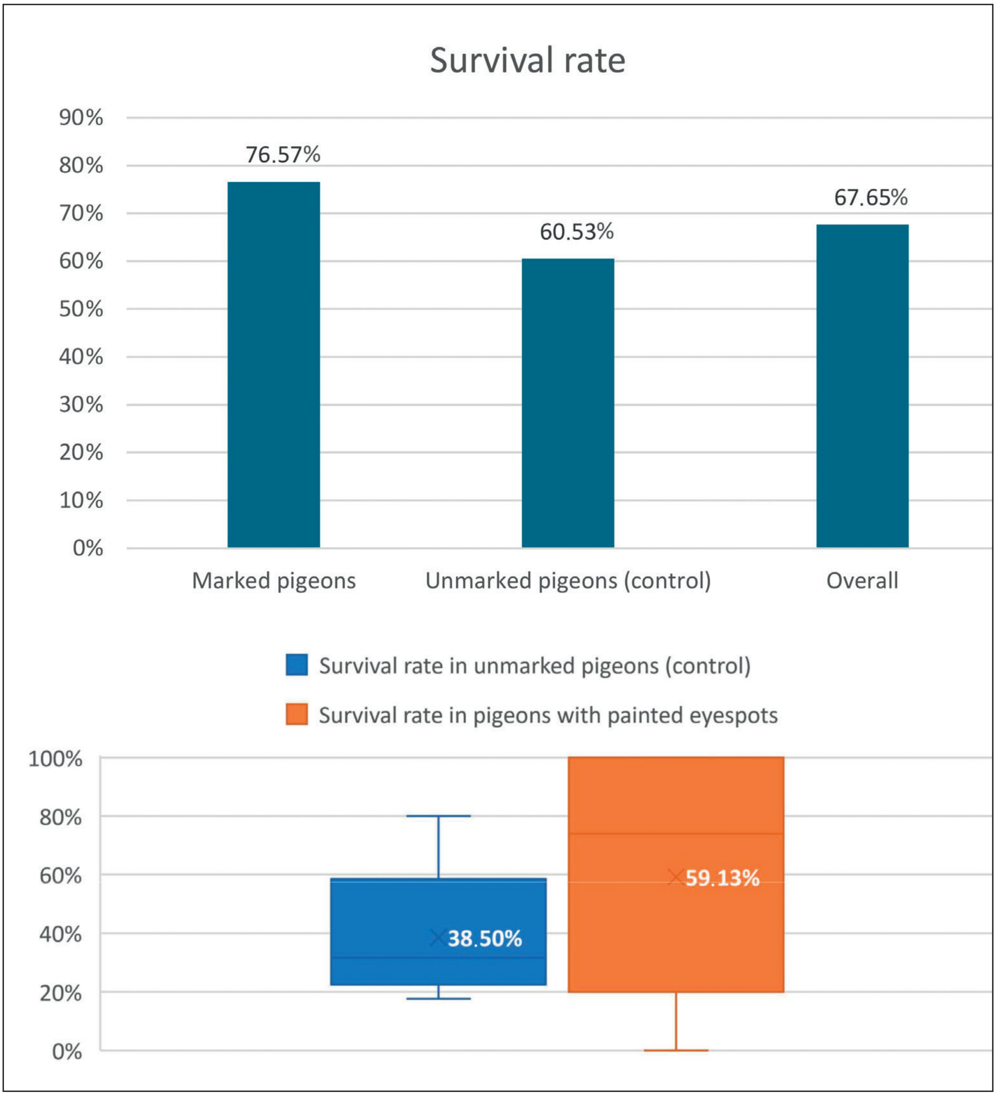

Figure 8. Comparison of the survival rates between: (a) *above*: marked pigeons (n = 1,080) with anti-raptor repellent spray and unmarked pigeons (n = 1,393) in the same flocks; (b) *bellow*: pigeons with painted eyespots (n = 72) and unmarked pigeons (n = 427) in the same flocks

8. ábra A túlélési arányok összehasonlítása: (a) Fent: ragadozómadár-riasztó spray-vel kezelt jelölt galambok (n = 1080) és ugyanazon csapatokban lévő, nem jelölt galambok (n = 1393); (b) lent: festett szemes galambok (n = 72) és ugyanazon csapatokban lévő, nem jelölt galambok (n = 427)

Discussion

Timing and location of raptor attacks

Our study shed light on the location and timing of raptor attacks on racing pigeons. The main known raptor predators for racing pigeons in Europe are the Peregrine Falcon *(Falco peregrinus)*, the Saker Falcon *(F. cherrug)*, the Eurasian Sparrowhawk *(Accipiter nisus)* and the Northern Goshawk *(A. gentilis)* (e.g. Shawyer *et al.* 2000, Henderson *et al.* 2004, Rutz 2004, Dixon *et al.* 2018, Panter & Amar 2021). According to Iankov *et al.* (2007), the European Sparrowhawk and the Northern Goshawk are more densely distributed in forested mountain and hilly areas, while the Peregrine population inhabits mainly mountain and semi-mountain regions in the country. This can explain the observed higher frequency of raptors attacks on pigeons in upland forested areas during our study. Although the re-introduction efforts since 2015, the Saker Falcon is still very rare in Bulgaria (Lazarova *et al.* 2021, Arkumarev *et al.* 2025), and thus, discussing any potential impact on domestic pigeons would be speculative. The higher frequency of raptor attacks on domestic pigeons in spring coincide with the breeding season of the raptors (Newton 1979). Likely, it is also related to the start of intensive training of homing pigeons in Bulgaria and in the most European countries *(pers. comm.)*, when large numbers of tossed pigeons start to cross the countryside offering „complementary" prey for raptors. The morning and evening peaks of falcons hunting activity are described by (Rejt 2001). The observation that the majority (88%) of attacks occurred along the last 30% of the race itinerary, when pigeons are likely more exhausted, highlights the vulnerability of racing pigeons during this critical phase of the flight. This finding emphasizes the need for targeted mitigation strategies to protect pigeons during the final stages of races, when they may be particularly susceptible to predation.

Effectiveness of preventive measures

The results of our study provide insights into the effectiveness of preventive measures aimed at mitigating raptor predation on racing pigeons. Bright-colored wing patches, applied using anti-raptor spray, showed some degree of effectiveness in increasing pigeon survival rates. The survival of spray-marked pigeons was 16% higher compared to unmarked pigeons, indicating a potential deterrent effect against raptor attacks. However, it is important to note that this method did not fully eliminate raptor predation, as some spray-marked pigeons returned home with injuries caused by raptors. Fanciers' perceptions of the spray's effectiveness varied, with a majority expressing satisfaction, though some remained uncertain or considered the spray ineffective.

Similarly, painted eyespots were found to contribute to increased survival rates among pigeons, with an average 20% higher survival rate reported compared to controls. While this method seemed more promising, variability in survival rates among fanciers and individual pigeon flocks suggests the need for further optimization and refinement. In a previous study conducted by Götmark (1994), creating bright-color patches on Common Blackbird *(Turdus merula)* wings has been proved to reduce predation risk by Northern Goshawks. However, during the preliminary meetings with pigeon fanciers, we found quite contradictory opinions about the efficiency of anti-raptor spray: some fanciers believed it is very useful to minimize the losses, while others claimed it has no effect on raptor attacks. Few people even speculated it has an opposite effect by attracting raptors to pigeons. In contrast, the Codice LIVIA method, being used in Italian lofts to ward off hawks, has been documented to significantly reduce the fatal attacks (Federazione Colombofilia Italiana 2014). The natural eyespots markings evolved independently in many taxa as anti-predator signals (Ruxton *et al.* 2004). A classic example of anti-predator markings are eyespots on moth and butterfly wings (De Bona *et al.* 2015), but many other animal groups including other insects, fishes, mollusks, amphibians and birds use concentric circles to deter predators (Ruxton *et al.* 2004). The suggested mechanism behind the anti-predator effect for raptors (Balgooyen 1975, Negro *et al.* 2007) is that eyespots may deceive predators or 'mobbers' into perceiving they have been detected, thereby preventing an attack (the "detection hypothesis"). A successful experiment has been conducted in Africa, where artificial eyespots painted on cattle rumps have been evidenced to reduce attacks by large carnivores (Radford *et al.* 2020). In Scotland, the eyespots were used only as loft-based deterrent, but not as pigeon-based deterrent, with relatively high rate of positive feedback from pigeon fanciers (Henderson *et al.* 2004). All this is to say that factors such as color choice, placement, and individual variation in raptor response may influence the efficacy of this deterrent method.

Overall, these findings underscore the importance of evaluating and further refining preventive measures to effectively mitigate human-raptor conflicts in the context of racing pigeon sport. Further research is needed to optimize the application and effectiveness of these methods, taking into consideration factors such as color choice, placement, different combinations of methods, and individual variation in raptor response to enhance efficacy.

Potential biases and gaps in interpretation

Several potential biases and limitations should be considered in the interpretation of our results. Firstly, the results from the questionnaires represent the perceptions of pigeon fanciers which should be further tested to understand at what extend they meet the objective circumstances. However, from the more general perspective of the topic, we are discussing (i.e. human-raptor conflict), and specifically from the fancier's view-point, the presence or absence of scientific evidence as a background for their perceptions does not always reflect on the severity of the conflict (Benett & Dearden 2014, Benett 2016). Moreover, through grasping perceptions we can acquire insights into the rationales behind local endorsement or opposition to wildlife governance and management (Engen *et al.* 2019). Moreover, the effectiveness of preventive measures may also vary depending on factors such as local raptor populations, environmental conditions, and individual pigeon fancier practices. Additionally, the sample size and geographic scope of our study may limit the generalizability of results to other regions or contexts. Furthermore, the perception of effectiveness among pigeon fanciers may be influenced by factors such as individual experiences, biases, and preferences, which could introduce subjective biases into the data. Future research should aim to address these limitations by incorporating larger sample sizes (also allowing to analyze the impacts considering different types of pigeons), wider geographic scope, and interdisciplinary approaches to better understand the dynamics of human-raptor conflicts from the perspective of pigeon racing and inform conservation strategies.

Inferences for conservation

Our study underscores the importance of engaging with the pigeon fancier's community as a key stakeholder group in successful raptor conservation programs. The effective collaboration with the Bulgarian pigeon fanciers' community played a pivotal role in acquiring data on pigeon losses attributed to birds of prey. By engaging with various racing pigeon organizations at local and national levels, BSPB (BirdLife Bulgaria) fostered collaborative partnerships and conducted multiple working sessions with local clubs, associations, and federations. This approach facilitated the collection of valuable data and ensured that the perspectives and expertise of pigeon fanciers were integrated into the study design and implementation process.

The findings of our study have important implications for understanding and addressing human-wildlife conflicts, particularly in the context of racing pigeon sport. By quantifying the impact of raptor predation on racing pigeons and testing preventive measures, our study highlights the complex interplay between human interests and wildlife conservation. While raptors are protected under various conservation laws and regulations, conflicts with human activities, such as racing pigeon sport, continue to pose challenges for conservationists. Effective mitigation strategies, informed by scientific research and stakeholder engagement, are essential for promoting coexistence between humans and raptors.

Understanding the phenology of raptor attacks provides valuable insights for adapting pigeon training regimes to minimize losses. Our findings provide novel insights into the effectiveness of preventive measures aimed at mitigating raptor predation on racing pigeons in Bulgaria. Additionally, we evidenced that the use of painted eyespots has good potential as a deterrent against raptor attacks in the context of racing pigeon sport. Our study revealed higher pigeon survival rates among fanciers who apply prevention measures compared to those who do not, but it is essential to acknowledge that mitigation measures such as anti-raptor spray and painted eyespots are not panaceas. While they show promise in decreasing raptor predation, they cannot eliminate it entirely. Therefore, promoting the application of these measures among pigeon fanciers should be encouraged, with realistic expectations communicated to avoid exacerbating human-raptor conflicts. Further research is warranted to deepen our understanding of raptor predation on racing pigeons. Direct assessment of mortality rates and more extensive experimental studies on the efficacy of different mitigation measures are needed to inform evidence-based conservation strategies. Specifically, repeating experiments on painted eyespots with larger sample sizes and broader participation of pigeon fanciers could yield valuable insights into the effectiveness of this method. Additionally, fostering better awareness, communication, and collaboration between authorities, environmental NGOs and pigeon fancier organizations is imperative for softening human-raptor conflicts. Producing guidelines for pigeon fanciers, outlining the best-known mitigation practices, can serve as a useful tool in this regard. By working together and sharing knowledge and resources, we can strive towards a more harmonious coexistence between racing pigeons and raptors, ensuring the sustainability of both wildlife and human activities.

Acknowledgements

This study was conducted in the framework of the project LIFE for Falcons (LIFE20 NAT/BG/001162) funded by the LIFE program of the European Union. The authors highly acknowledge the assistance and good collaboration with the Bulgarian Association for Racing Pigeons and the Bulgarian Federation for Racing Pigeons which are the overarching bodies representing over 62 local clubs in the country, and specifically with the local pigeon clubs and fanciers from the regions of Sofia, Pernik, Pirdop, Sandanski, Sliven, Yambol, Nessebar, Pazardjik and Karlovo. This work would not be possible without the precious feedback of over 200 anonymous fanciers from all around Bulgaria who filled the questionnaire. Constructive comments by the Editor and anonymous reviewers helped to increase significantly the quality of the manuscript.

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Ornis Hungarica 2025. 33(1): 228–236.
DOI: 10.2478/orhu-2025-0015

Spatial patterns of territorial large falcons influence mixed pair formation in an arid environment

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Received: February 23, 2023 – Revised: November 08, 2024 – Accepted: November 10, 2024

Leonardi, G., Binothman, A., Alabdulhafith, B., Alwahiby, A., Haig, S. M. & Prommer, M. 2025. Spatial patterns of territorial large falcons influence mixed pair formation in arid environment. – Ornis Hungarica 33(1): 228–236. DOI: 10.2478/orhu-2025-0015

Abstract Interspecific crossbreeding among breeding populations can lead to outbreeding depression and reduce individual fitness. Mixed pairs occur more frequently in areas with fragmented habitat where individual species often have low population densities. Due to the genetic affinities among falcons, hybrids from within this group exhibit full or partial fertility, presumably over indefinite generations. This study aims to ascertain the influence of spatial patterns of territory holders (pairs and non-paired individuals) on the occurrence of mixed pairs among large falcons (Barbary *Falco peregrinus pelegrinoides* and Lanner Falcons *F. biarmicus tanypterus*) in Saudi Arabia. We found that mixed pairs occurred in study areas (5.4% of territories) with higher nearest neighbour distances (NND). Densities per se had no effect on the occurrence of mixed pairs, and neither did the quality of territories. Favourable but restricted core areas maintain a healthy breeding population but separated by very large unfavourable terrains. Distances from core areas affect the presence of pairs and unpaired falcons. Higher distances (>200 km) force potential breeders to mate and breed interspecifically. Probably a modest risk of outbreeding depression occurred, but the desirable re-establishment of gene flow between population fragments, also using reintroduction techniques will minimize the risk by decreasing the chance for the occurrence of mixed pairs.

Keywords: *Falco biarmicus tanypterus*, *Falco peregrinus pelegrinoides*, hybridization, Saudi Arabia

Összefoglalás Az egyes fészkelőfajok állományainak kereszteződése „outbreeding depression” -hez vezethet, ami végső soron csökkenti az egyedi fitneszt. Eltérő fajokhoz tartozó párok gyakrabban fordulnak elő fragmentált élőhelyeken, ahol az egyes fajok állománysűrűsége alacsony. Genetikai közelségük miatt a sólyomfajok közötti hibridek teljes vagy részleges termékenységet mutatnak, feltehetően végtelen számú generáción át. Jelen vizsgálat célja a foglalt revírek (párok és egyedül foglaló példányok) területi mintázatának a kevert, nagytestű sólyom (sivatagi sólyom *Falco peregrinus pelegrinoides* és Feldegg-sólyom *F. biarmicus tanypterus*) párok előfordulására gyakorolt hatását törekszik bemutatni szaúd-arábiai adatok alapján. Azt találtuk, hogy a kevert párok (a revírek 5,4%-a) a vizsgált területen belül ott fordultak elő, ahol a legközelebbi szomszédok nagyobb távolságra voltak (nearest neighbor distance, NND). Az állománysűrűségnek közvetlenül nem volt hatása a kevert párok előfordulására, ahogy a revírek minőségének sem. Az előnyben részesített, de korlátozott kiterjedésű magterületek egészséges fészkelőállománynak adtak otthont, azonban ezek nagy kiterjedésű, a sólymok számára alkalmatlan területekkel voltak elválasztva. A magterületektől való távolság meghatározza a párok és a pár nélküli, revírt foglaló madarak jelenlétét. A nagyobb távolság (>200 km) pedig arra kényszeríti az ivarérett madarakat, hogy más fajjal álljanak párba és kezdjenek költésbe. Az outbreeding depression megjelenésének feltehetően van némi esélye, de a töredékállományok közötti génáramlás helyreállítása, akár visszatelepítési technikák alkalmazásával is, mérsékelni fogja ezt a kockázatot, csökkentve a valószínűségét a kevert párok megjelenésének.

Kulcsszavak: *Falco biarmicus tanypterus, Falco peregrinus pelegrinoides*, hibridizáció, Szaúd-Arábia

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Introduction

Interspecific crossbreeding may be an evolutionary mechanism that allows increased genetic diversity and can be a relatively common phenomenon in some avian sister taxa (Pierotti & Annett 1993, Randler 2006, Gholamhosseini *et al.* 2013). Genetic differences among partners can lead to outbreeding depression, and consequently, to a reduction of their breeding fitness (Frankham *et al.* 2011, Ralls *et al.* 2013). The establishment of mixed pairs within avian genera occurs more frequently in areas with fragmented habitat and/or at the border of two species' ranges (Panov 1989, Harrison 1991, Pierotti & Annett 1993). In these marginal zones, ecologically distinct forms often have low population densities, and they are more prone to genetic erosion (Barton & Hewitt 1985, Frankham *et al.* 2011). Thus, lack of conspecific forces potential breeders to mate and breed interspecifically (Wilson & Hedrick 1982, McCarthy 2006). Usually, reproductive isolation mechanisms and behavioural barriers should prevent interbreeding between species potentially resulting in outbreeding depression (Angelov *et al.* 2006, Gjershaug *et al.* 2006).

Several records of mixed pairs and hybridization events regarding raptors in the wild (Panov 1998, Gjershaug *et al.* 2006, Cugnasse *et al.* 2017, Literák *et al.* 2019). Due to the genetic affinities among falcons (genus *Falco*), hybrids from within this group exhibit full or partial fertility, presumably over indefinite generations (Heidenreich *et al.* 1993, Nittinger *et al.* 2005, McCarthy 2006). In fact, evolutionarily they are a rather young species with a high propensity to hybridize (Prager & Wilson 1975, Nittinger *et al.* 2005). There are reports about interbreeding among mixed pairs of Saker *(F. cherrug)* and Barbary Falcons *(F. p. pelegrinoides)*, Peregrine *(F. peregrinus)* and Gyrfalcons *(F. rusticolus)*, Saker and Lanner Falcons *(F. biarmicus)*, as well with all hybrids escaped from falconry (Boev & Dimitrov 1995, Gjershaug *et al.* 2006, Everitt & Franklin 2009, Dixon 2012, Cugnasse *et al.* 2017). The *Hierofalco* sub-genus (Saker, Gyr- and Lanner Falcons) indicate a very low genetic distance (>2%) but crossing with Peregrine Falcons usually produce sterile female offspring (Pomichal *et al.* 2014). Overall, genetic introgression to local falcon populations and the relative presence of hybrids are the main effects of direct and indirectly human activities (Fleming *et al.* 2011, Dixon 2012).

The Barbary Falcon *(F. p. pelegrinoides)* is a subspecies of the Peregrine Falcon inhabiting a vast geographical area from the Canary Islands to the Arabian Peninsula including all North African countries (Brosset 1986, White *et al.* 2013, Rodríguez *et al.* 2019). Interbreeding occurs among Barbary Falcons and other Peregrine subspecies (i.e. *F. p. brookei*) but rarely with *hierofalcons* such as Saker and Lanner Falcons (Brosset 1986, Angelov *et al.*

2006, McCarthy 2006, Rodríguez *et al*. 2019). For the latter species although its breeding range largely overlaps with Barbary Falcons, interspecific crossbreeding records have only occurred among captive birds (McCarthy 2006). The Lanner Falcon could be in competition for nest sites with the Barbary Falcon in several areas in North Africa and the Middle East (Leonardi 2015). Overall, habitat segregation separates these large falcons with the Barbary Falcon as the dominant species, probably due to its use of safe high cliffs avoided by the Lanner Falcon (Ledant *et al.* 1981, Amato *et al.* 2014, Binothman 2016). Thus, it is reasonable that habitat requirements and behavioural patterns (i.e. dietary difference) can limit mixed-species pairings between the two species (Gjershaug *et al.* 2006).

The main aim of this study was to ascertain the influence of spatial patterns of territory holders (pairs and non-paired individuals) on the occurrence of mixed pairs among large falcons in Saudi Arabia. Results are discussed in terms of the potential conservation implications for these threatened species.

Methods

In Saudi Arabia, intensive field studies in the whole country have been conducted since 2015 to investigate 1,255 putative Lanner and Barbary Falcons nest sites (Binothman 2016). Preliminary analyses indicate a low rate of active Barbary Falcon nests (>15%, n = 725), with unpaired males occupying 4% of inactive nests (Binothman 2016).

In-depth field surveys were conducted in three sample areas identified across the breeding range of the Barbary Falcon in Western and Central Saudi Arabia in 2021 *(Figure 1)*. The first area (A – 158,125 km^2, perimeter = 1,953 km) was within the Medina province, the second (B – 128,771 km^2, perimeter = 1,403 km) in the Riyadh region (Central Arabia) and the third (C – 70,907 km^2, perimeter = 1,285 km) across Al-Bahah/'Asir provinces. Sample area A is characterized by a cold-dry climate with a desert subzone, area B is a hot-dry desert subzone and area C is a subtropical and Mediterranean subzone (Alrasheda & Asif 2015). For the statistical analysis, sample areas were grouped based on the presence (MIX) or absence (ABS) of mixed pairs. In the early part of the breeding season, each nesting site was categorized based on presence of a pair or an un-paired territory holder.

Barbary Falcon nest locations were plotted on a map using QGIS software (ver. 3.14). Nearest neighbour distances (NND) for all located Barbary Falcon nests were measured on the map from centre of an occupied territory to the centre of the nearest neighbour's territory (Solonen 1993, Martínez-Hesterkamp *et al.* 2018). Following Brown (1975), the regularity of nest spacing (G-statistic) was calculated as the ratio between geometric and arithmetic means of the squared nearest-neighbour distances. Values ranged from 0 to 1 with those >0.65 indicating a regular dispersion of nest sites and those close to 0 randomness (Brown 1975). The Clark and Evans (1954) aggregation index (R) was used to assess whether the spatial distribution of nests differed significantly from the null hypothesis of complete spatial randomness. A value of R =1.0 represents randomness, R >1.0 regularity and R <1.0 aggregation (Clark & Evans 1954). Nevertheless, the exact null distribution for randomly dispersed points depends upon the geometry of the studied population (areas

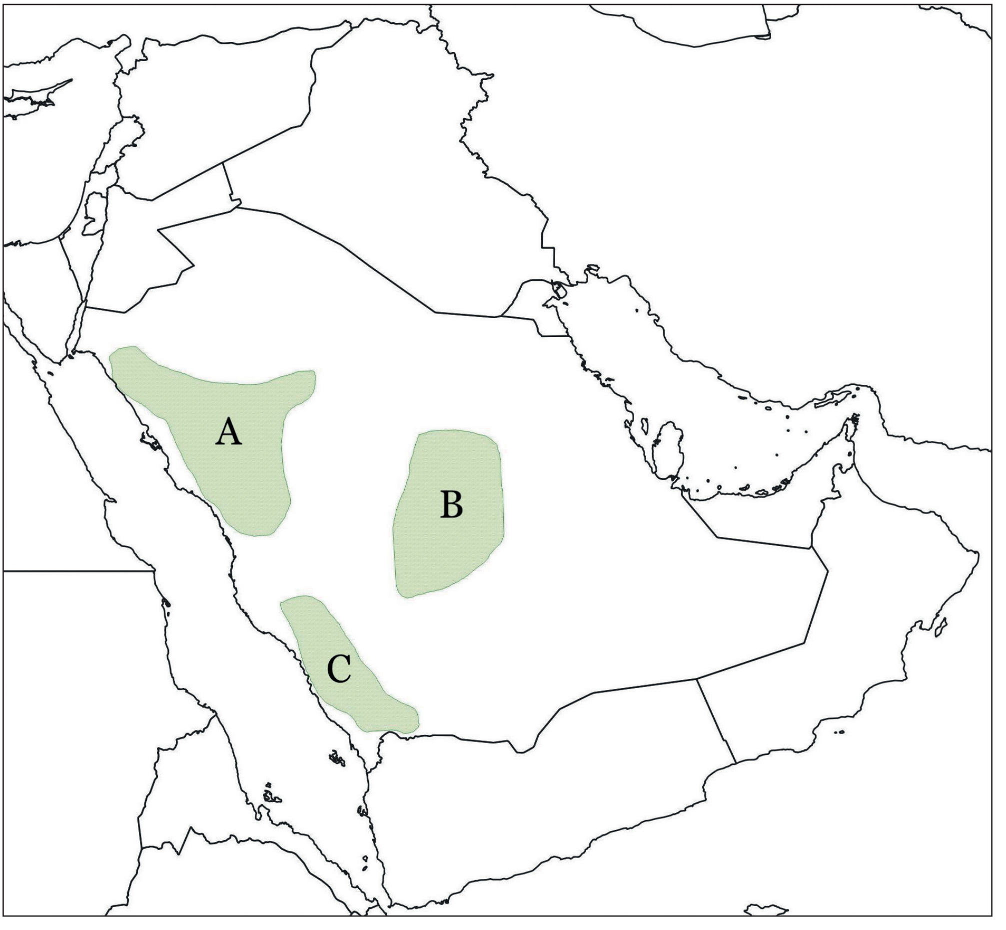

Figure 1. Map showing the three study areas for the Barbary Falcons: Medina province (A), Riyadh region (B), and in Al-Bahah and Asir provinces (C) of Saudi Arabia

1. ábra Térkép a sivatagi sólyom kutatásának három mintaterületéről: Medina tartomány (A), Rijád régió (B), valamint Al-Bahah és Asir tartományok (C) Szaúd-Arábiában

and perimeters) (Connor & Bowers 1987). Thus, as suggested by Donnelly (1978) a modification for bias was made following the mathematical procedure in Krebs (1989). In addition, this correction become necessary when working with small sample sizes (n = <100) as in the present study (Donnelly 1978, Krebs 1999). As suggested by Morandini *et al.* (2020), the average number of fledglings in each territory was used as surrogate of territory quality.

A one-way analysis of variance (ANOVA) was used to analyse differences in the mean-nearest distances between the MIX and ABS groups, while the Kruskal-Wallis test was applied to assess differences in the number of fledged chicks between the same groups (Sokal & Rohlf, 1981). Median densities were compared between groups by means of Mann-Whitney U-tests (Siegel & Castellan 1988). Statistical analyses were performed using SPSS 21.0 (IBM Corp., Armonk, NY) and significance was set at $P < 0.05$.

Table 1. Mean nearest neighbour distances (NND) in km, and observed *G* values for the two study groups (with (M), and without (A) mixed pairs). The probability (P) that the G value was larger than expected from a random distribution was calculated using Clark and Evans (1954) aggregation index (R) modified by Krebs (1989)

1. táblázat Az átlagos legközelebbi szomszéd távolság (nearest neighbor distance, NND) kilométerben, és a G érték a két vizsgált csoportra (M – kevert pár, A – nem kevert pár). A valószínűség (P), hogy G értéke magasabb lesz a véletlenszerű eloszlásból számított értéknél, Clark és Evans (1954) aggregációs R-indexe alapján került kiszámításra, Krebs (1989) által módosított formulával

Study group	**Occupied territories/ 100 km² (*n*)**	**Un-paired falcons (*n*/*N*)**	**Productivity**	**NND (km)**	*G*	*R*	*z*	*p*
MIX	0.007 (21)	0.82	1.92	284.8±158.8	0.59	4.87	25.5	<0.001
ABS	0.020 (14)	0.57	2.45	131.5±84.7	0.41	3.54	14.4	<0.001

Results

No active nests of the Lanner Falcon were located during the entire duration of the preliminary survey (2015–2020) and the in-depth survey of 2021 (n=530). In 2021, from 72 checked nest sites of Barbary Falcons in the three study areas, only 35 (ca. 50%) were occupied (A=16, B=7, C=13).

Two mixed pairs, both composed of a Lanner female and Barbary Falcon male, were found in A and B sample areas, respectively. This is the first time that mixed pairs among these two species were reported in the wild. Overall, they represent 5.4% of all occupied territories by Barbary Falcons (n=35). The mixed nest in sample area B was unsuccessful whereas two chicks were raised by the mixed pair in sample area A. Nevertheless, only one fledged from this nest and it was then captured.

The percentage of unpaired territory holders was ca. 71% and they were all males (n=35) *(Table 1)*. Nevertheless, mean densities did not vary between the two (MIX and ABS) study groups Mann-Whitney U-test, n=2, z=−1.225, P=0.221) as well productivity (Kruskal-Wallis test, H=1.672, df=1, P=0.196, n=33). Site dispersion showed a non-regular distribution in both study groups, especially for sample areas without mixed pairs (G=0.41) *(Table 1)*. Nevertheless, the spacing pattern deviated significantly from random toward regularity in both study groups *(Table 1)*. Mixed pairs occurred in study areas with higher NNDs *(Table 1, Figure 2)*. Distances between territories occupied by unpaired falcons and pairs ($F_{1,88}$ =36.164, P=0.0001) and between them ($F_{1,102}$ =11.465, P=0.001) were significantly different among study groups.

Discussion

Results support the hypothesis that spatial patterns of nesting sites have a fundamental role on the occurrence of mixed pairs among Barbary and Lanner Falcons in these arid environments *(Figure 2)*. Overall, the Lanner Falcon could be in competition with the Barbary Falcon in

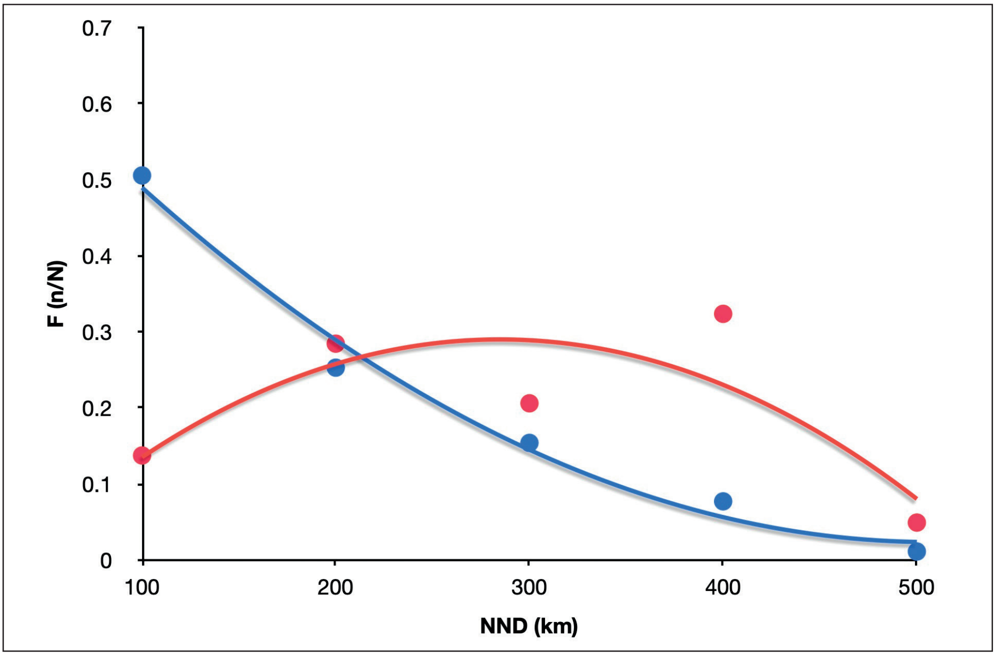

Figure 2. Frequencies of NNDs among study groups consisting of n pairs (n=210) with absence (blue line) or presence (red line) of mixed pairs. Mean NNDs did vary significantly ($F_{1,210}$ =64.301, P=0.0001). Values have been fitted to a second-degree polynomial function

2. ábra Az NND gyakorisága az összes n párból (n=210) álló vizsgált csoportokban, a vegyes párok nélkül (kék vonal) és a vegyes párokkal (piros vonal). Az átlagos NND szignifikánsan változott ($F_{1,210}$= 64,301, P=00001). Az értékekhez egy másodfokú polinomfüggvény lett illesztve

several areas in North Africa and the Middle East (Leonardi 2015). Historical observations in NW Algeria reported a ratio of 3:1 breeding pairs among Barbary and Lanner Falcons (Ledant *et al.* 1981). Unfortunately, no comparative data exists about this possible interaction also in relation species-specific abilities to cope limiting factors other than nest site availability (i.e. food shortage, human pressures). In Saudi Arabia, it is possible that habitat segregation separates these large falcons, but nest sites of both species could be established also at short distance apart (Brosset 1986, Leonardi 2015, Binothman 2016).

Unfortunately, there are few papers devoted to Barbary Falcon breeding biology and even those focus on the Canary Island and North African populations (see White *et al.* 2013 for a review). Although observed NNDs for the Barbary Falcon in Saudi Arabia were significantly higher than in Canary Islands, they correspond to those observed in similar open habitats in Iran (Rodríguez *et al.* 2007, Shafaeipour *et al.* 2016). Study areas without mixed pairs shows an aggregation of territories with NNDs range of ≤100 km and a decrease in numbers at increasing distances *(Figure 2)*. On the contrary, distances in study areas with mixed pairs were higher with a peak of frequency at 300 km far from the core area *(Figure 2)*. The non-regular dispersion of breeding territories deviated from randomness toward regularity in both study groups and was similar to that observed in the Canary Island population (G=0.52) *(Table 1)* (Rodríguez *et al.* 2007).

Although both studied groups include a large number of unpaired territory holders, effects of densities *per se* are negligible as well as the quality of territories *(Table 1)*. These results suggest that favourable but restricted core areas maintain a healthy breeding population but are separated by very large unfavourable terrains. In fact, habitat fragmentation can create a system of discrete patches, inhabited or uninhabited by the local population (Fahrig 2003). Furthermore, habitat fragmentation may significantly impact the number of floated falcons in a meta-population (Lenda *et al.* 2012). In the ABS group, un-paired falcons presumably remain close to the area and wait until a breeding vacancy becomes available (Hunt 1998, Kenward *et al.* 2000). Ultimately, distances from core areas affects the presence of pairs and un-paired falcons but not favour mixed pair formation *(Figure 2)*. Inversely in the MIX group, there is not a core area within 100 km of distance but the whole population (pairs and un-paired falcons) is sparsely spaced by higher distances (>200 km) *(Figure 2)*. Accordingly, un-paired falcons in the study group MIX were far from established breeding pairs but also from other potential partners. Thus, the lack of close conspecific neighbours could force potential breeders to mate and breed interspecifically (Wilson & Hedrick 1982, McCarthy 2006).

The percentage of un-paired Barbary Falcons found inside the three sample areas (A=80%, n=16; B=83%, n=7; C=57%, n=13) is according with 30–70% range reported in comprehensive reviews on raptor populations (Newton 1998, Kenward *et al.* 2000). These territorial males not only increase the intraspecific competition but can try to seduce paired females (Lenda *et al*. 2012). In the MIX group with fewer breeding pairs, poor quality habitats and far from better core areas, males can exhibit an active (non-random) and forced choice towards co-genre female partners.

Overall, the presence and mobility of un-paired falcons should play a crucial role in metapopulation persistence and may constitute a ‘buffer zone’ against population size changes (Lenda *et al.* 2012). In fact, the higher mobility of floaters impact on recruitment rates, the pattern of patch occupancy, and movement between habitat patches (Lenda *et al.* 2012). Nevertheless, in this case of restricted available habitat with a large proportion of un-paired falcons, the higher competition for territories may also increase the probability of local extinction (Penteriani *et al.* 2011, Lenda *et al.* 2012). The occurrence of mixed pairs should be a sign of the same problem but in populations inhabiting unfavourable and fragmented habitats. For genetical different breeding populations such as in our study, the decision tree developed by Frankham *et al.* (2011) suggest a modest risk of outbreeding depression where F_1 individuals are sterile or have very low fitness. Nevertheless, the re-establishment of the gene flow between population fragments is desirable, also by using reintroduction techniques.

Acknowledgements

This research was supported by the Saudi Falcon Club, the Special Forces for Environmental Safety, the National Wildlife Center, the Ministry of Environment, Water and Agriculture, Tilad Environmental Consultancy and IUCN.

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Ornis Hungarica 2025. 33(1): 237–245.
DOI: 10.2478/orhu-2025-0016

First-time use of metal construction for mounting artificial nests on trees for Saker Falcons *(Falco cherrug)* in Bulgaria

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Received: February 03, 2022 – Revised: November 12, 2024 – Accepted: November 14, 2024

Petrov, R., Costain, R., Andonova, Y. & Klisurov, I. 2025. First-time use of metal construction for mounting artificial nests on trees for Saker Falcons *(Falco cherrug)* in Bulgaria. – Ornis Hungarica 33(1): 237–245. DOI: 10.2478/orhu-2025-016

Abstract Artificial nests offer a promising solution to nest shortage, stemming from decreased breeding habitat for raptor populations. In Bulgaria, an area with declined raptor populations and increasing habitat loss, artificial nests offer an opportunity to re-establish breeding pairs of Saker Falcons *(Falco cherrug)*. As a part of the nonprofit Green Balkans' captive breeding and release programme for Saker Falcons, 20 artificial nests were installed in the Stara Zagora region from 2020–2021. Nests were made from a steel metal frame filled with dried sticks and vegetation and installed in old-growth trees. Each nest site was evaluated for characteristics such as habitat type and prey availability. None of the 20 artificial nests have been used by Saker Falcons yet, but they have been regularly monitored for activity since their installation. As Saker reintroduction efforts continue, ongoing monitoring of artificial nests will be essential in determining their effectiveness for future reintroduction projects. The specifications of construction and placement of artificial nests in this project can be used to inform other raptor reintroduction projects, considering location differences and individual species needs.

Keywords: raptors, birds of prey, conservation, reintroduction, biodiversity

Összefoglalás A mesterséges fészkek ígéretes megoldást kínálnak a ragadozómadarak élőhelyeinek zsugorodásából fakadó fészekhiány problémájára. Bulgáriában, ahol a ragadozómadár-állományok csökkennek, és egyre erőteljesebb az élőhelyvesztés, a mesterséges fészkek esélyt adnak a kerecsensólyom-párok újbóli megtelepítésére. A Green Balkans nonprofit szervezet tenyésztési és visszatelepítési programjának részeként 2020 és 2021 között 20 mesterséges fészek került kihelyezésre a Stara Zagora régióban. A fészkeket acélkeretből építették, amelyet száraz ágakkal és növényzettel töltöttek meg, és idős fákra helyeztek ki. Minden fészkelőhely értékelésre került olyan jellemzők alapján, mint az élőhely típusa és a zsákmányállatok elérhetősége. A 20 mesterséges fészek egyikét sem használta még kerecsensólyom, de kihelyezésük óta rendszeresen ellenőrzik a körülöttük zajló aktivitást. Ahogy halad előre a kerecsensólymok visszatelepítése, a mesterséges fészkek folyamatos monitorozása elengedhetetlen lesz a projektek hatékonyságának meghatározásához. A mesterséges fészkek ezen projektben alkalmazott konstrukciós megoldásai és a fészkek kihelyezésének jellemzői más ragadozómadarak visszatelepítési projektjeiben is hasznosak lehetnek, figyelembe véve a helyi különbségeket és az egyes fajok egyedi igényeit.

Kulcsszavak: ragadozómadarak, természetvédelem, visszatelepítés, biodiverzitás

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Introduction

Since the 19th century, raptor populations across Europe have declined, largely due to negative human-based interactions (Stroud 2003). Human impacts surrounding land-use changes present a major issue for raptors. Stroud (2003) found that 27 of the 29 most vulnerable European diurnal raptor species are adversely affected by habitat changes, often due to agricultural intensification. While habitat loss is likely to have a negative effect on any part of a population, land-use changes are particularly impactful on breeding populations of raptors. Tapia and Zuberogoitia (2018) note that raptor populations are highly constrained by available breeding habitat. Each species has unique specifications for the size, height, orientation, and overall location of a nest, and shortages of nest sites can limit the density of a species (Tapia & Zuberogoitia 2018). As habitat loss continues to negatively impact raptor populations across Europe (BirdLife International 2021), adequate raptor nest sites are also likely to decrease. In areas where nest sites are limited, the installation of artificial nests offers promise for retaining or increasing raptor populations. These human-made nests vary in construction depending on location and focus species, from placing nests on metal poles versus in trees (Björklund *et al.* 2013) to using flat platforms versus boxes (Dixon *et al.* 2008). Across Europe, artificial nests in various environments for various species have been shown to be an effective method for increasing breeding populations (Ivanovski 2000, Bakka *et al.* 2020). Not only do artificial nests provide space for breeding birds, but they may also provide areas away from electricity poles and other unsuitable nesting locations (Ragyov *et al.* 2012), pending a full analysis of selected nesting location safety (Björklund *et al.* 2013).

The variations in artificial nest construction and placement across regions and species exemplify the required specificity of artificial nest use to an individual raptor conservation project. Up to this point, there has been no published information on artificial nest use for Saker Falcons *(Falco cherrug)* in Bulgaria despite ongoing conservation efforts (Lazarova 2021). To avoid reliance on meta-analyses from across Europe and Asia, individual case studies of Saker Falcons and their artificial nest use are necessary in strengthening reintroduction biology (Armstrong *et al.* 2008). Another notable gap of information exists surrounding the specifications of artificial nests, notably in details on construction and design (Lambrechts *et al.* 2011). The remainder of this paper focuses heavily on artificial nest use by Saker Falcons in Bulgaria to act as a case study, sharing details on the species' conservation status, the construction and installation of artificial nests for Saker Falcon use in Bulgaria, and the monitoring of these nests as a part of Saker Falcon reintroduction.

The IUCN currently lists the Saker Falcon as an endangered species (BirdLife International 2017). During the 20th century, heavy pesticide use, nest robbing, hunting, poisoning, and land-use changes due to agricultural intensification led to the loss of Saker Falcons as a breeding species in Bulgaria (Ragyov *et al.* 2014). Even today, habitat loss from agricultural intensification, fuelled by Bulgaria's accession into the EU, continues to cause declines in bird populations (Spasov *et al.* 2017). The effort to reintroduce Saker Falcons to Bulgaria is a multistep process. In 2015, the nonprofit Green Balkans began a breed-and-release programme to try and establish a breeding population of Saker Falcons in the country. As of

2023, two confirmed breeding pairs formed of birds from the reintroduction programme are living in the wild in Bulgaria.

An important component of Green Balkans' reintroduction effort is the use of adaptation aviaries called hacks. Between 2015–2023, 143 Saker Falcons were released near Stara Zagora using the hacking method, and 160 were released in total in Bulgaria from 2011–2023. Saker Falcon chicks hatched at the Green Balkans Wildlife Rehabilitation and Breeding Centre were moved to closed hacks at around 30 days old (Petrov *et al.* 2021). After 10 days, the lids of the hacks were opened, and the chicks were able to independently move in and out of the nest. Food was provided in the hacks and on nearby feeding tables. The longer fledglings stayed in the area, the more likely they were to survive into adulthood (Lazarova 2021) – one and a half month being the average estimated post-fledging dependence period (PFDP) for Saker Falcons (Prommer *et al.* 2012). Juvenile Saker Falcons often disperse from the area after the PFDP but will return to breeding territories in early spring (CITES 2008). Helping Saker Falcons establish a territory with a reliable food source at a young age through the hacking method can encourage them to return to the area when they reach breeding age.

Even with having successfully released Saker Falcons, a lack of enough available nests for breeding pairs poses another challenge. Saker Falcons do not build their own nests. Instead, they use nests made by other large birds or raptors (Rahman *et al*. 2014) – (Common Raven *Corvus corax*, Long-legged Buzzard *Buteo rufinus*, Eastern Imperial Eagle *Aquila heliaca*, Common Buzzard *Buteo buteo*, Hooded Crow *Corvus cornix*). Because of a decline in overall raptor populations over the last century (Stroud 2003, Donázar *et al.* 2016), fewer nests are available. Furthermore, many of the old-growth trees in which these raptors would build nests have since been removed because of agricultural intensification (Spasov *et al.* 2017), leaving only cliff edges which may not be abundant in habitats with the most optimal food base.

The effectiveness of artificial nesting sites such as nest platforms and nest boxes in facilitating the growth and expansion of Saker populations in otherwise suitable areas has been demonstrated in Austria, Hungary, Slovakia, and Mongolia (Chavko *et al.* 2014, 2019, Fidlóczky *et al.* 2014, Rahman *et al.* 2014, 2016, Zink *et al.* 2025). As part of a 5-year project that began in 2020, Green Balkans is continuing its Saker Falcon reintroduction efforts, which include installing artificial nests based on international experience. Their goal is to install 80 nests in the Stara Zagora, Yambol and Sliven regions by 2025. Funding for 20 nests is from the Mohamed bin Zayed Raptor Conservation Fund (United Arab Emirates) and Armeec JSC (Bulgaria), and funding for the next 60 is from the LIFE for Falcons project LIFE20 NAT/BG/001162. Research by Palma *et al.* (2019) offers evidence that installing artificial nests in combination with species reintroduction through captive-breeding can increase reintroduction success. The aim of this article is to report the part of preparation process for the reintroduction of Saker Falcon in Bulgaria, where appropriate nest sites are constructed for future breeding pairs. The study provides details about the technical parameters of artificial nests and describes the considerations towards their instalment in potential Saker Falcon breeding areas.

Materials and Methods

Artificial nest construction

Between 2020 and 2021, 20 artificial nests were built *(Table 1)*. Each nest was constructed of a 10-sided steel frame that was filled with vegetation. Steel was used as it was easily accessible, relatively lightweight, and would likely last longer than wood, a material used in previous artificial nests built by Green Balkans. The measurements shown in *Figure 1* are based on a single nest frame but are representative of a typical artificial nest. The exact measurements of each nest vary, similar to natural, bird-built nests. Nests were made with steel mesh bottoms that could hold nesting material while allowing for water drainage. Colours of the frame were chosen based on what was likely to blend in with the nest's surroundings once installed (typically brown, green or grey). Dried vines were woven between the rods along the sides of the nests. Once placed in a tree, material was added into the nest, starting with a layer of small sticks (approximately 1 cm in diameter and 0.3 m in length). Each layer used increasingly smaller sticks, followed by dried leaves. Material from walnut trees *(Juglans regia)* was ideal for nesting material due to its antimicrobial properties (Vieira *et al.* 2019). As walnut is a protected species in Bulgaria, it was only used for nesting material if trees were legally felled.

Table 1. Specifics about the installed nesting platforms
1. táblázat A kihelyezett fészektálcák paraméterei

	Nests (*n*)
Region	
10 km from hack site	10
30–60 km from hack site	10
Tree species	
Field elm *(Ulmus minor)*	1
Black poplar *(Populus nigra)*	11
English oak *(Quercus robur)*	8
Nest height	
10–16 m	10
17–23 m	10
Nesting material	
Dried ivy *(Hedera helix)*	20
Grapevines *(Vitis vinifera)*	20
Old man's beard *(Clematis vitalba)*	20
Poplar *(Populus nigra)* twigs and leaves	20
Mulberry *(Morus alba)* twigs and leaves	20

Placing artificial nests

Nest locations were chosen primarily based on tree availability and surrounding habitat, followed by vehicle accessibility. Choosing sites accessible by car (namely farm and orchard dirt roads) allowed for materials to be brought in when installing nests and will increase the ease of future monitoring. Nests were installed approximately 5 km apart, with some nests being 1 km apart based on tree availability. Trees were selected based on their height, overall health, and species. Nests were placed as high as possible, dependent on the branches' ability to support the weight of the nest. Habitat surrounding the trees was also assessed. When available, areas near grazed pastures were chosen as suslisks are often found in these habitats. Suslisks make up the largest part of Saker Falcon diets (Watson & Clarke 2000). Chosen nest sites were adjacent to agricultural land, as this is a common land use in the study area. Crops in these fields included rice *(Oryza sativa)*, sunflowers *(Helianthus annuus)*, wheat *(Triticum)*, rapeseed *(Brassica napus)*, barley *(Hordeum vulgare)*, and orchards of cherries *(Prunus avium)*, apricots *(Prunus armeniaca)*, peaches *(Prunus persica)*, and blue plums *(Prunus domestica)*. Vegetative buffers separate crop fields. The available habitat indicated other prey species of small rodents and birds could be found in these areas (Watson & Clarke 2000). To provide any nesting Saker Falcons with a view of the surrounding habitat, single standing trees or trees at the edge of tree stands and fields were chosen.

Nest installation took place in late fall and early spring when trees were bare and easier to climb. The period when crops were more than 10 cm tall was avoided. Once a site and a tree was selected, a rope was used to lift the nest and nesting materials into the tree. Two triangular metal supports were screwed into the tree trunk. The artificial nest was placed on top of these supports and screwed down. If tree branches were positioned in a way that provided adequate support, only one or no metal support was used. Once secured to the tree, nesting material was added. As a final step, calcium oxide was added in the nest to imitate bird droppings. Doing so was meant to indicate that the nest was previously used, implying the existence of a food source and safe location.

Saker Falcons courtship starts in mid-February and egg laying is in early March (The Peregrine Fund 2021). Artificial nests

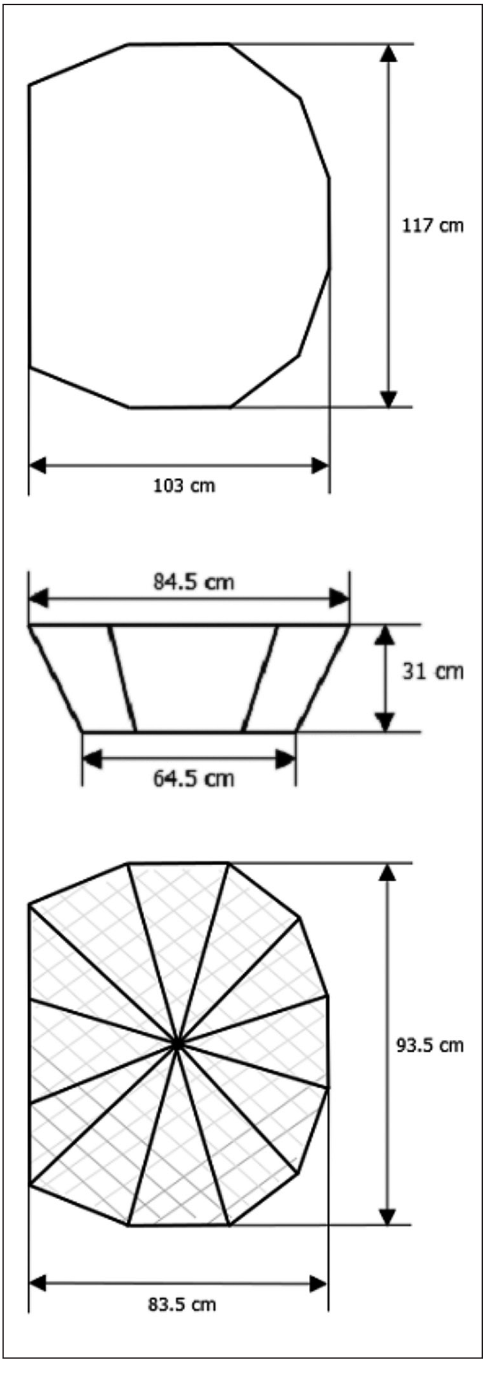

Figure 1 Upper, side, and the bottom view of an artificial nest

1. ábra A mesterséges fészek felül-, oldal- és alulnézete are visited a minimum of twice a month in February, March, and April to look for breeding pairs. If Saker Falcons begin using a nest, monitoring will be extended into May and June, when chicks would occupy the nest (The Peregrine Fund 2021).

Results and Discussion

Although the Saker Falcon was historically reported as common, the breeding population in Bulgaria became extinct in the late 1990s (Ragyov *et al.* 2014). The Bulgarian population was part of the Eastern European population and had no direct connection to the Central European population, even though satellite-tracked Central European Saker Falcons regularly visit the region (Prommer *et al.* 2025). Given the long-standing decline of the Eastern European population (Ajder *et al.* 2025, Fântânâ *et al.* 2025, Prommer *et al.* 2025), natural recolonisation from that population was not expected. Recognising this, Green Balkans launched a captive-breeding and release programme in 2015. Since falcons do not build nests and suitable nesting sites near high-quality foraging areas are limited, it was essential to include the construction and installation of artificial nests in the programme.

As of December 2023, none of the 20 artificial nests installed near Stara Zagora were used by Saker Falcons. Field experts have observed unconfirmed nesting by Common Buzzards and Common Kestrels *(Falco tinnunculus)* in a number of the nests. The lack of use by Saker Falcons was expected, as the installation of these nests was a proactive portion of the latest stage of reintroduction that began in 2020. In 2020, 12 Saker Falcons were released using hacks in the study area, in 2021 – 17, in 2022 – 25, and in 2023 – 19. Saker Falcons reach sexual maturity after 2–3 years (CITES 2008), before which they may migrate throughout Eastern Europe, Asia, and Northern Africa (Prommer *et al.* 2012). As artificial nests were present when Saker Falcons were released in 2020–2023, they may be more willing to return to the area in which they know there are viable nests and available food sources. However, juvenile mortality is high for Saker Falcons (Ragyov *et al.* 2009, Kovács *et al*. 2014), thus many birds are needed to be released to account for the natural losses and for a local population to form, which would potentially utilise the nests. As installing artificial nests is a preliminary step in establishing breeding pairs of Saker Falcons in Bulgaria, the weight of determining reintroduction success is on future monitoring. So far, monitoring of the first installed nests – from 2020, revealed that more nesting material should be added when installing nests, as some of the material was displaced over the two winters.

Observing the lifespan of the nest frames will also be important, as Green Balkans has not previously used metal in artificial nest construction. Analyses in Spain found that raptor-built nesting platforms lasted an average of 12 years, depending on use and location (Jiménez-Franco *et al.* 2014). Previous attempts by Green Balkans to install artificial nests for other species indicated that wooden frames and platforms would last approximately 3 years. This short lifespan was attributed to rot from exposure to water and weather. Other attempts at building artificial nests for raptors have also found wooden platforms have a short lifespan, and saw more success using a metal construction (Fidlóczky *et al.* 2014). Specific to Saker Falcons, metal artificial nests are promising for encouraging use (Iankov &

Gradinarov 2012). Wanting a longer lifespan was a major factor in choosing to use metal for the frame construction in this project. It is estimated the metal nests will last 20–25 years. Green Balkans plans to install a total of 80 artificial nests in the 60 km radius of the Saker Falcon release site by 2025. After mounting the first 20, however, noted was the lack of tree availability, resulting in considerations of placing nest boxes on electricity pylons instead, in the same area, similarly to the ones placed as part of LIFE project *Falco cherrug* B-H-R-S LIFE09 NAT/HU/000384 (Chavko *et al.* 2014, Fidlóczky *et al.* 2014).

Finally, monitoring of artificial nest use will be important in estimating Saker Falcon populations. The current 5-year reintroduction plan estimates that 6 breeding pairs will form in Bulgaria by 2026, which would create the basis of a self-sustaining population and indicate reintroduction success (Lazarova *et al.* 2021). This population model is based solely on released chicks, meaning adequate available breeding territories with nests are necessary to maintain breeding pairs. Artificial nest use has been shown to have a positive impact on Saker Falcon breeding populations in surrounding countries (Rahman *et al.* 2014). Yet, individual site considerations remain critical to establishing the efficacy of artificial nests (Björklund *et al.* 2014). Continued monitoring of the artificial nests near Stara Zagora, as well as any natural nests, will be essential for determining reintroduction success of Saker Falcons in Bulgaria.

The details laid out in this paper can be used to inform tactics around artificial nests in future reintroduction projects both for Saker Falcons and for other species. While it is important to avoid reliance on meta-analyses (Armstrong *et al.* 2008), details from this project may be useful in determining construction, placement, and monitoring specifications for artificial nest use and captive-breeding-based reintroduction. Similarities between threats to Saker Falcons and other raptors across Europe suggest the transferability of the methods in this paper to other projects if possible. For example, habitat loss due to agricultural intensification is a problem across Europe, and specifically in Bulgaria (Spasov *et al.* 2017). A decrease in habitat leads to a loss of available nest sites for many raptors (Tapia & Zuberogoitia 2018), indicating a need for habitat restoration and nest creation. Another promising indicator for transferability stems from the fact that many of the studies concerning artificial nests referenced in this paper based their construction and placement of nests on research that differed in species focus or region (Ivanovski 2000, Björklund *et al.* 2013, Bakka *et al.* 2020). The success, and therefore reproducibility and transferability, of the materials and methods used in Bulgaria's Saker Falcon reintroduction project will become more apparent with continued monitoring.

Acknowledgements

The work for installing metal artificial nests on trees for Saker Falcons in Bulgaria is made possible by the funders of the "Saker Falcon Reintroduction in Bulgaria" project – the Mohamed Bin Zayed Raptor Conservation Fund (UAE), with support funding provided by Armeec JSC (Bulgaria). The activities described were implemented by a team of the Wildlife Rehabilitation and Breeding Centre – Green Balkans.

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