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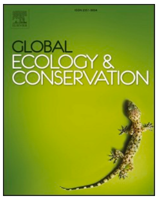

Original research article

Challenges and opportunities in the translocation of grassland-dwelling subterranean mammals: The case of blind mole rats

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ABSTRACT

Grasslands have been transformed into anthropogenic habitats worldwide and consequently have lost many species, including their ecosystem engineer species. European blind mole rats (Rodentia: Spalacidae) are an important biological component of grassland ecosystems, as their digging creates mounds of bare soil surfaces available for plant colonisation, they maintain soil structure, and provide a subterranean niche for other animals. Blind mole rats have long been persecuted, and many species are threatened by extinction as they only exist in a few small and isolated populations.

The translocation of individuals for reintroduction or establishment of new populations is a promising tool for the conservation of rare and endangered species. As data regarding the translocation of blind mole rats or other strictly subterranean mammals has not yet been published, here we discuss the proposed methods and evaluate the results of seven translocation projects in Hungary between 2013 and 2024. We found that these projects varied greatly in their efficacy, and that habitat quality, the number and sex ratio of translocated animals, as well as survival during the first winter, were the decisive factors for success and failure. Translocations require the strict application of a detailed protocol, which covers the thorough assessment of the soil and vegetation quality of the target habitats, careful selection of source populations and individuals, timing of the capture and release, and the regular monitoring of translocation

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Abbreviations: BMR, blind mole rat; PBR, Pannonian Biogeographic Region.

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success. We developed recommendations for future translocation projects of subterranean mammals, a guild which is present in all open grassland ecosystems and is often threatened globally.

1. Introduction

1.1. Threatened subterranean mammals

Many mammal species inhabit underground habitats and show a broad range of adaptations to living underground (Andersen, 1987; Nevo, 1979). Fossorial or burrowing species only seek temporary shelter in their burrows but forage mainly on the surface, whereas subterranean species build tunnel systems, feed underground and only rarely come to the surface. There is a continuum between the fossorial and subterranean lifestyles (Begall et al., 2007).

Subterranean lifestyle is found in four orders (Notoryctemorphia, Afrosoricida, Eulipotyphla and Rodentia) and 12 families of mammals (Notoryctidae, Chrysochloridae, Talpidae, Geomyidae, Aplodontiidae, Cricetidae, Spalacidae, Bathyergidae, Heterocephalidae, Octodontidae, Echimyidae, and Ctenomyidae) existing on every continent except Antarctica (Begall et al., 2007; Nevo, 1999). The estimated number of subterranean species varies between 259 (Lynx Nature Books, 2023) and 274 species (American Society of Mammalogists, 2024) due to taxonomic uncertainties. IUCN Red List categorisation has been assessed for 223 subterranean species. Of these, 36 (16 % of all subterranean mammal species) are threatened by extinction: eight species are vulnerable (VU), 22 are endangered (EN), and six species are critically endangered (CR). It has to be noted that the IUCN Red List lags behind recent progress in taxonomy and systematics. Additionally, 25 lesser-known species are classified as data deficient (DD), meaning the actual number of threatened species may be higher.

1.2. Subterranean mammals as ecosystem engineers in grasslands

Ecosystem engineers create, modify, maintain or destroy habitats for other species. They often form patches that differ from the surrounding matrix in structure or ecological processes (Jones et al., 1994) and modify the distribution of resources that other species use (Mallen-Cooper al. 2019; Neilly et al., 2022; Valkó et al., 2022). Such modified resources include habitat conditions, microclimate, and soil type (Mallen-Cooper et al., 2019; Root-Bernstein and Ebensperger, 2013).

Burrowing mammals such as prairie dogs or marmots are well-known ecosystem engineers (Beca et al., 2022; Davidson et al., 2012; Reichman and Seabloom, 2002, Valkó et al. 2021; Whitford and Kay, 1999; Winter et al., 2002). These species move masses of soil by digging burrows and building mounds, creating sparsely vegetated patches or vegetation patches that greatly differ from the surrounding habitats (Coggan et al., 2018; Mallen-Cooper et al., 2019).

In contrast, we know much less about the ecosystem engineer activity of subterranean mammals. Subterranean rodents most typically inhabit dry open landscapes; examples include African mole rats (Bathyergidae) in the African open savanna (Nevo, 1999; Visser et al., 2019), blind mole rats (Spalacinae) in Mediterranean and continental steppes of Europe (Németh et al., 2024; Savić and Nevo, 1990) or zokors (Myotalpinae) in the Asian continental and alpine steppes (Zhang et al., 2003). Subterranean rodents can modify the vegetation composition of dry open landscapes through several mechanisms: (i) soil structure modification: underground tunnelling alters the structure and other properties of the soil (Bodnár, 1928), which indirectly impacts vegetation (Platt et al., 2016; Reichman and Seabloom, 2002; Zhang et al., 2003); (ii) disturbance: mound-building creates open, bare soil surfaces, which serve as establishment gaps for plants and can thus influence vegetation dynamics (Reichman and Jarvis, 1989); (iii) herbivory: the consumption of belowground plant parts such as roots and bulbs potentially controls the abundance of certain plant species (Šklíba et al., 2017); (iv) indirect dispersal: many species store food by hoarding plant organs such as bulbs, rhizomes, and tubers, and unconsumed propagules can subsequently sprout, increasing the abundance of some plants (Szabó and Zimmermann, 2012).

Several studies have provided evidence of ecosystem engineering impacts of subterranean rodents. They often produce clearly visible mounds with sharp boundaries that separate them from the grassland matrix (Boldog, 2010; Moldován et al., 2021). The mounds of African mole rats are characterised by reduced vegetation cover and increased species richness relative to the surrounding habitat matrix (Davies and Jarvis, 1986; Hagenah and Bennett, 2013; Reichman and Jarvis, 1989). In temperate dry grasslands in Hungary, plant species composition differed significantly between the mounds built by blind mole rats and the surrounding undisturbed grasslands (Valkó et al. 2022b; Zimmermann et al., 2014). The mounds had lower vegetation cover, lower cover of perennial graminoids, and higher diversity and evenness compared to the grassland matrix. The mounds improved establishment conditions for subordinate plant species, probably by reducing belowground competition, and this effect was the largest in more closed grasslands (Valkó et al. 2022b).

1.3. Eurasian blind mole rats and their conservation

Eurasian blind mole rats (Spalacidae: Spalacinae) are unique subterranean rodents that developed extreme adaptations to living underground. They are the only entirely blind rodents, having cylindrical bodies with very short legs, a vestigial tail, and no external ears (Topachevskii, 1969; Norris, 2017). They use their large incisors to dig complex and extensive tunnel systems, where they spend their entire life. Blind mole rats typically inhabit open dry ecosystems (steppe grasslands, mountain steppes and open Mediterranean scrublands) of the Western Palaearctic including the Pannonian Basin, Eastern Europe, the Balkan Peninsula, Asia Minor, the Middle East, and a narrow coastal strip in North-eastern Africa (Topachevskii, 1969; Savić and Nevo, 1990). Because of their special lifestyle, they have very restricted morphological variability and, consequently, high taxonomic uncertainty (Nevo, 1999). Taxonomic uncertainty, particularly regarding cryptic/overlooked species with limited ranges, represents a risk that these species slip into critical conservation status or even go extinct in the absence of adequate conservation measures.

Recent phylogenetic analyses and species delimitation studies classified European members of the genus *Nannospalax* into 11 well-separated distinct species; all are endemic to Europe (Németh et al., 2024). Many of the newly recognised taxa exhibit highly restricted geographical ranges and declining populations, which presents a significant conservation challenge. Some of the recently identified species, especially in the northern part of the range, already have critical conservation status (Csorba et al., 2023). The threatened status of blind mole rats native to the Pannonian Basin has been known for decades (Németh et al., 2009; Csorba et al., 2015). The conservation status of the Hungarian blind mole rat (*Nannospalax hungaricus* Nehring, 1898), the Vojvodina blind mole rat (*N. montanosyrmiensis* Savić and Soldatović, 1974) and the Srem blind mole rat (*N. syrmiensis* Méhely, 1909) is a cause for concern, and the two former species are among the most endangered mammals in Hungary (Csorba et al., 2023; Németh et al., 2013a).

Blind mole rats have been protected in Hungary since 1974 and strictly protected (which gives the species priority conservation status under Hungarian legislation) since 1979 (Temesi, 2020); however, less than half of their known habitats are situated within protected areas where their conservation is a priority (Csorba et al., 2023). There are several threats to the survival of the populations outside the protected areas, and to ensure the long-term persistence of the species, all existing populations need to be maintained (Németh et al., 2013a). Recent developments such as the declaration of protected areas dedicated to blind mole rat conservation (e.g. the Körös-ér Landscape Protection area in 2012, and the Blind Mole Rat Reserve of Baja in 2017), certainly contribute to the improvement of the conservation status of the critically endangered Vojvodina blind mole rat (Csorba et al., 2023). However, in several other sites, the nature conservation authorities could only impose restrictions on land use, but no formal designation of protection was possible. This could effectively prevent the imminent extinction of the populations, but it is doubtful whether it can ensure their long-term persistence.

The establishment of new populations through the translocation of individuals from existing populations can be a promising tool to increase the chances of long-term persistence of threatened species (Griffith et al., 1989; Gaywood et al., 2022; Pullin and Bajomi, 2008; Seddon et al., 2007). Introductions (individuals translocated to new, suitable areas) or reintroductions (individuals translocated to sites where the species was known to exist historically) have long been applied to reduce the chances of extinction in species that have only a few remaining populations (Griffith et al., 1989; Gaywood et al., 2022; Reading and Kellert, 1993). Such conservation measures can be especially challenging in highly specialised species that show extreme adaptations to their environment (Hunter-Ayad et al., 2021; Berger-Tal et al., 2020; Gaywood et al., 2022; Reading and Kellert, 1993), such as blind mole rats. This may explain why, to the best of our knowledge, no translocation projects involving any species of Eurasian blind mole rat or other small mammal with a similarly extreme subterranean lifestyle have been attempted outside Hungary to date (Németh et al., 2013b).

The aim of this study was to assess the efficiency of introductions of blind mole rats to suitable new habitats. We collected data from seven such projects implemented in Hungary. We provide a brief description and evaluation of each project, discussing their successes or lessons learned, and exploring how translocation can enhance or threaten the conservation status of threatened subterranean mammals worldwide.

2. Methods

2.1. The study system - Pannonic dry grasslands

The Carpathian or Pannonian Basin is a geo-morphologically and biogeographically well-defined, predominantly lowland unit of the European landscape (Varga, 1995; Moores and Fairbridge, 1997; Sundseth, 2009). The Pannonian Biogeographic Region (PBR), which is among the smallest of the 11 biogeographical regions of Europe (Sundseth, 2009), lies almost entirely in the Pannonian Basin and encompasses the entire area of Hungary and substantial parts of adjacent countries (Sundseth, 2009; Szanyi, 2012). Vast territories of the PBR were originally covered by dry steppe grasslands, which take on a variety of forms depending on local climatic and soil conditions. The PBR hosts some of the world's most diverse grasslands in terms of vascular plant taxon diversity (Dengler et al., 2014; Habel et al., 2013; Wilson et al., 2012). Several grassland habitat types high in biodiversity and globally unique to the PBR include Pannonic sand steppes and Pannonic loess steppic grasslands (Willner et al., 2017; Sundseth, 2009). Steppe habitats in the PBR have suffered considerable loss, degradation and fragmentation due to human activities since prehistoric times (Németh et al., 2017). In the last 250 years, more than 90 % of the former area of sand grasslands and loess steppes have been lost, mostly to cropland cultivation (Biró et al., 2018). Most of the 11 mammal species that have become extinct from the Pannonian Basin in historic times were typical grassland species (rodents, large herbivores and carnivores); eight steppe-dwelling species went extinct between 5000 and 4000 years BP, whereas three species of large herbivores survived in forest refugees until the Middle Ages (Németh et al., 2016). The remaining dry grasslands are still threatened by urban/industrial development, shrub encroachment, invasive species and lack of proper management (Biró et al. 2018; Mihók et al., 2017).

2.2. Projects to establish new populations

Although the idea of establishing new blind mole rat populations is not new (Németh et al., 2010), the lack of general knowledge on the translocation of specialised subterranean mammals first required the careful development of a methodological protocol. The protocol (Németh et al., 2013b) addressed numerous aspects, ranging from the selection of the source and target areas to the monitoring of the newly established population and detailed the issues and problems that may arise during the translocation. The first translocation project was conducted in 2013–2014, and until recently was followed by six other translocations (Fig. 1, Table 1). Three of the projects targeted the Vojvodina blind mole rat (*N. montanosyrmiensis*) and four the Hungarian blind mole rat (*N. hungaricus*) (Fig. 1).

In the translocation of blind mole rats, an artificial tunnel system is developed to release the individuals into a new habitat (Fig. 2) (Németh et al., 2013b). This system consists of cardboard tubes and chambers made from roof tiles, dug into the soil at 0.5 m depth, and joined to the soil surface by a tilted (45°) entrance tube. Animals are released into the entrance tube, which is sealed with a soil plug after the release. The underground system contains elements important for the short-term survival of individuals: (i) a food store filled with vegetables, (ii) a sleeping chamber filled with soft bedding material, and (iii) an empty chamber for excretion. The entire system is surrounded by a 0.5-m tall fence dug 0.5 m deep in the soil to prevent the surface movements of individuals and to ensure that they can leave the release site only underground (Németh et al., 2013b).

Each translocated individual was marked with a subcutaneous microchip for unique identification. In addition, genetic sampling was performed on the individuals involved in the translocation for subsequent genetic monitoring of the new populations established (Németh et al., 2013b).

2.3. Monitoring of new populations

We collected data to evaluate the success of translocations. We recorded the number and the spatial and temporal distribution of the mounds that blind mole rats built. As blind mole rats are solitary animals that protect their territories from conspecifics (Vásárhelyi, 1926), we considered mounds aggregated within 4–5 m as a sign of a single individual. After the individuals were released, we recorded the coordinates of the appearing mounds daily or once every two days using a handheld GPS device (Garmin Oregon 600) or mobile phone for four weeks. After this initial period, the sites were monitored at least once a month for at least 1 year. This means that the total number of monitoring days for all projects combined is 397, not including the monitoring activity of the four-week period following the translocations. By evaluating the position and spatial aggregation of the mounds, it is possible to track the activity, movement, and migration of individuals in the habitat (Moldován, 2014, Schneider et al., 2019). To avoid double-counting, we flattened part of the mounds already counted and recorded. Monitoring efforts varied across the projects due to limitations in survey capacity (Table 1). In most translocation sites, it was not possible to individually identify the translocated blind mole rats after about one year. Therefore, after this timeframe, we monitored blind mole rats in the entire area using linear transects along a grid overlaid on site maps to estimate the number of individuals.

We inferred the successful reproduction of the blind mole rats in the new sites by the activity pattern of the individuals. During the year-round monitoring, periods of mating and parental care can be clearly identified based on the increased activity of the individuals and separated by periods of reduced tunnelling and mound-building activity. Certain morphological features of the mounds may also indicate successful reproduction in a year, particularly when juveniles disperse in the early summer (Moldován, 2014). The presence of multiple piles (double or triple mounds) in a particular area is an indication that the individual is engaged in extensive digging. Typically, these are made by individuals soon after being released, when they create new tunnel systems in the new sites. A similar pattern of mounds observed during the next summer suggests the presence of dispersing juveniles (Moldován, 2014), whom, being separated from their mother, dig their own tunnel system sprouting out from the maternal tunnel system (Rado et al., 1992).

Geospatial data collected during the monitoring were stored and processed by using the Quantum GIS program (Rosas-Chavoya

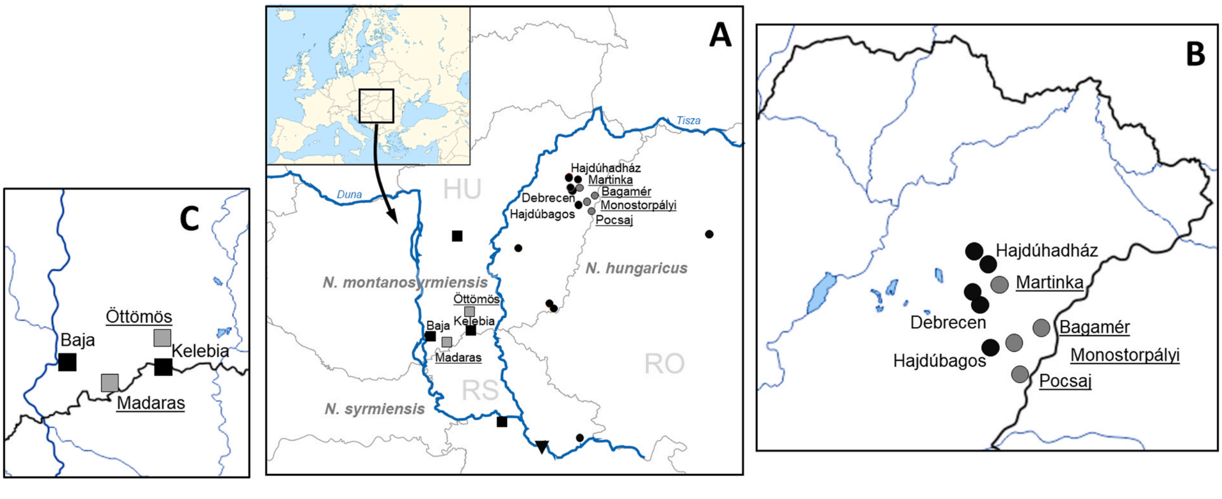

Fig. 1. A) *Nannospalax* populations in the Pannonian Basin; B) source and established populations of *N. hungaricus*; C) source and established populations of *N. montanosyrmiensis*. Full circle: *N. hungaricus*, square: *N. montanosyrmiensis*, upside-down triangle: *N. syrmiensis*. Black symbols indicate natural populations, whereas grey symbols and underlined names mark populations established by translocating individuals.

Table 1
Main characteristics of the translocation projects.

ID	Years	Target species	Source population	Target population	N of individuals released (males, females)	Monitoring frequency	Total N of mounds	Reference
1	2013–2014	*N. hungaricus*	Hajdúhadház	Bagamér	22 (10, 12)	Weekly for 1 yr	2321	Moldován, (2014)
2	2014–2018	*N. hungaricus*	Debrecen	Pocsaj	24 (10, 14)	Biweekly for 6 months	622	This study
3	2016–2018	*N. montanosyrmiensis*	Kelebia-Ásotthalom	Öttömös	17 (6, 11)	Monthly for 1 yr	516	Németh et al. 2018
4	2017	*N. montanosyrmiensis*	Baja (solar park)	Baja BMR Reserve	10 (1, 9)	Biweekly for 1 yr	634	Schneider et al. (2019)
5	2020–2022	*N. montanosyrmiensis*	Baja BMR Reserve	Madaras	27 (13, 14)	Weekly for 3 yr	4165	Schneider et al. (2022)
6	2023–2024	*N. hungaricus*	Hajdúbagos	Monostorpályi	21 (9, 12)	Biweekly (ongoing)	1424	This study
7	2023–2024	*N. hungaricus*	Hajdúhadház	Martinka	20 (7, 13)	Biweekly (ongoing)	1148	This study

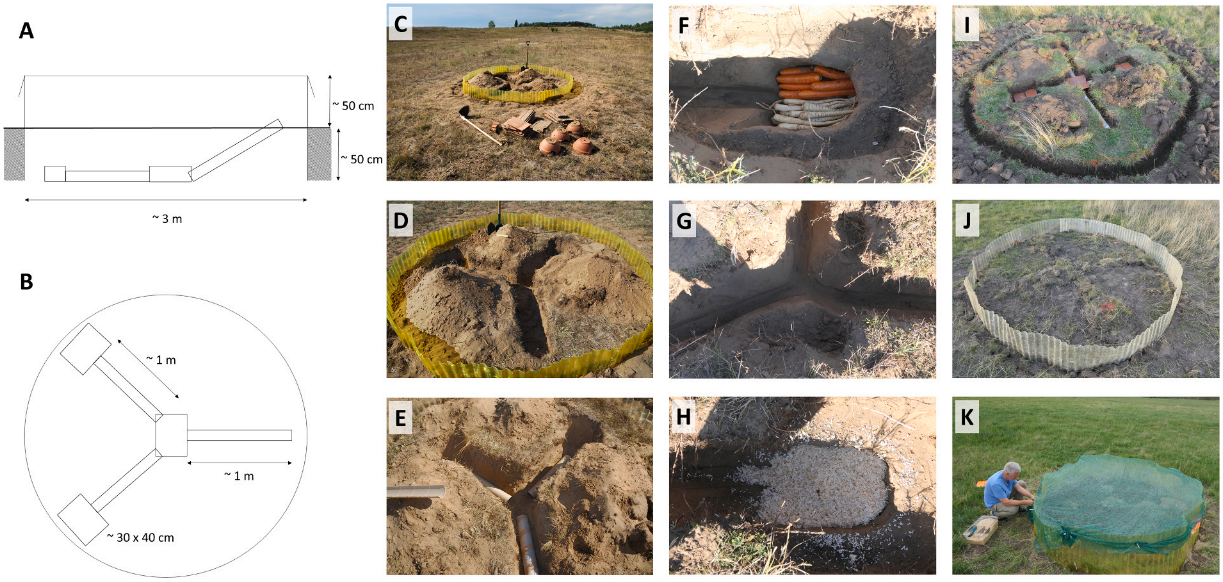

Fig. 2. Artificial tunnel systems designed to release blind mole rats during translocations. Schematic drawing and dimensions of a Y-shaped system (side view A, top view B). In sites with compact soil or areas with low food availability, X-shaped tunnel systems were constructed containing one extra food store. The photos (C-K) show the process of building an artificial tunnel system: preparation tools (C); excavation of the tunnel system (D); insertion of the tubes forming the tunnels (E); food storage (F); empty chamber at the junction of the tunnels (G); sleeping chamber filled with soft bedding material (H); completed, loaded chambers covered with roof tiles (I); the system covered with soil and enclosed with a fence (J); installation of the protective net after the individual was released (K).

et al., 2022).

2.4. *Conservation assessment of the translocation projects*

Assessments of translocation can vary by the methods used to measure success (Wolf et al., 1996). We used three demographic parameters recommended in the literature: (i) the survival of the released individuals, (ii) the reproduction of the released generation and their offspring (proposed by Seddon, 1999; Seddon et al., 2007) and (iii) the proportion of individuals surviving the first year after translocation (proposed by Lee and Hughes, (2008), and modified for blind mole rats by Olajos, (2012); Ruzsa et al., 2020). We estimated the survival and reproduction of the released generation and the proportion of surviving individuals based on the detailed data collected in the first year after translocation (see above). The ultimate measure of success is the long-term survival of the established population (Seddon et al., 2007) or the existence of a self-sustaining population of more than 500 individuals (Beck et al., 1994). To estimate this criterion, we compared the population size at the end of the monitoring period (current population size) to the number of translocated individuals. With regard to the latter, there is only one existing natural population of over 500 individuals among those considered to be stable and self-sustaining in Hungary (Csorba et al., 2023). In other words, there is no recently established population that meets this criterion; therefore, this criterion could not be used in this study.

To develop recommendations for future translocation projects, we also assessed the causes of successes and failures based on relevant parameters. These parameters primarily included data on the number of translocated individuals (in total and in a given year), the sex ratio of the translocated individuals, and the distance the translocated individuals were released. Other parameters that were evaluated included data on habitat characteristics, soil types and microtopography, landscape history and vegetation, recorded in both the source and the target areas.

Habitat characteristics included parameters such as the habitat type and size of the site, type and intensity of management, which were recorded before the translocation projects. Habitat type was inferred based on the Á-N É R system of Hungary (Bölöni et al., 2008; Fekete, Horváth, 1997), and site area was measured by digitisation of source and target areas in Google Earth (Google Earth Pro, version 7.3.2.5776). The type and intensity of management (mowing, grazing, species and number of livestock present in the vegetation period) were recorded at each site involved in translocation.

Soil types and microtopography are important because, as subterranean species, blind mole rats technically spend their entire lives underground and low-lying areas can be flooded in spring, forcing blind mole rats to higher ground. For soil characteristics, we used Kreybig's "Revised Soil Characterization Maps" (Kreybig, 1934) at a scale 1:25,000, which shows the main physical and chemical properties of the soil, the "Sygmond-type" soil classes, representative soil profiles at given sites, and soil profiles that characterise soil heterogeneity (Nagy et al., 2001). For microtopography, we used maps from the Institute of Geodetic and Remote Sensing (FÖMI, Budapest, Hungary) at a scale of 1:10,000.

To examine landscape history and assess past changes in land use, we compared historical maps from the First (1783), Second (1858) and Third (1881) Military Surveys and military maps from World War 2 (1941). Changes in habitats between 1959 and 2007 were quantified from aerial photographs from Lechner Non-profit Ltd. (http1–5). Finally, recent land use changes were followed by comparing Google Earth maps prepared in the last 20 years (Google Earth Pro, version 7.3.2.5776).

Being exclusive herbivores, vegetation composition and structure are crucial for the persistence of blind mole rats. Data from vegetation surveys were obtained from the management and maintenance plans of Natura 2000 sites provided by the national park directorates (Kerpely, 2014; Magura 2014a, 2014b; Szilágyi, 2007) or from vegetation surveys in the Grassland LIFE-Nature conservation project (LIFE17IPE/HU/000018, Somogyi, 2020).

Finally, we also examined whether and how each translocation project matched the recommendations set out in generally accepted guidelines for translocations (Lee and Hughes, 2008; Olajos, 2012), and in particular, the widely used IUCN translocation guide (IUCN/SSC, 1998, 2013). We slightly modified both the scoring system of Lee and Hughes (2008) by removing points that are not relevant for blind mole rat translocations and the IUCN evaluation system by adapting the criteria to the blind mole rats (Ruzsa et al., 2020). Finally, we also evaluated the compliance of each project with the detailed blind mole rat translocation protocol (Németh et al., 2013b). We used these scores to test the correlation between compliance scores (two variables: IUCN and protocol guidelines) on one side and the score of translocation success by using Spearman's rank correlations. Finally, we also used Spearman's rank correlations to study which IUCN or protocol criteria show correlations with translocation success scores.

3. Results

3.1. Results of the translocation projects

In the seven projects, a total of 141 blind mole rat individuals were translocated, of which 56 were males and 85 were females (Table 2). In all but one project, more than 80 % of the individuals survived the translocation intervention and started to build their own tunnel systems in the new site; the only exception was the Öttömös project, where between 50 % and 80 % of the individuals survived (Table 2). First-year survival was high in four projects and lower but over 50 % in two projects and less than 50 % in one project (Table 2). Evidence of reproduction in the new population was found in four projects, and although there was no direct evidence of the presence of locally born juveniles in two projects, population trends strongly suggest their presence is likely; no evidence of reproduction was found in one project (Table 2). The new population increased in four projects, was stable in one project, first decreased then increased in one project, and decreased to local extinction in one project (Table 2), with a rapid increase in four cases and a slow increase in two projects. Of the seven projects, four resulted in self-sustaining populations, and a further two are promising, but not enough time has elapsed to determine their status.

The total of success scores ranged between 2 and 13 or 15–100 % (Table 2). The Bagamér and the Madaras project reached maximum scores (100 %), the Pocsaj and Öttömös projects reached intermediate scores (69 % and 62 %, respectively), and the scores were low for the Baja project (Table 2). The scores of the two latest projects are not complete because the existence of self-sustaining populations cannot yet be assessed; nevertheless, success scores for these projects are higher than for the Pocsaj and Öttömös projects (Table 2).

3.2. Evaluation of success across translocation projects

3.2.1. Bagamér

Translocated individuals were captured from the largest population of Hungarian blind mole rats in Hungary, near Hajdúhadház (Csorba et al., 2023) and were released in a protected area near Bagamér in the fall of 2013–2014. All translocated individuals survived the capture and transportation. In both years, fresh mounds were produced as early as the first days after translocation. Mating

Table 2

Values and scores (in parentheses) of criteria related to the success of translocation projects. The scoring system is given in Table S1.

New population	N individuals released	Percent surviving translocation	Per cent surviving first year	Evidence of reproduction	Population trend	Self-sustaining population?	Rate of increase	Total score	Per cent of maximum score
Bagamér	22 (2)	$>$ 80 % (2)	$>$ 80 % (2)	Definite (2)	Increase (2)	Yes (1)	Rapid (2)	13	100 %
Pocsaj	24 (2)	$>$ 80 % (2)	50–80 % (1)	Most probable (1)	Stable (1)	Yes (1)	Slow (1)	9	69.2 %
Öttömös	17 (1)	50–80 % (1)	50–80 % (1)	Definite (2)	Decrease then increase (1)	Yes (1)	Slow (1)	8	61.5 %
Baja	10 (0)	$>$ 80 % (2)	$<$ 50 % (0)	No (0)	Decrease to extinction (0)	No (0)	None (0)	2	15.4 %
Madaras	27 (2)	$>$ 80 % (2)	$>$ 80 % (2)	Definite (2)	Increase (2)	Yes (1)	Rapid (2)	13	100 %
Monostorpályi	21 (2)	$>$ 80 % (2)	$>$ 80 % (2)	Definite (2)	Increase (2)	–	Rapid (2)	12	92.3 %
Martinka	20 (2)	$>$ 80 % (2)	$>$ 80 % (2)	Most probable (1)	Increase (2)	–	Rapid (2)	11	84.6 %

occurred in the new site in 2014, and the new population expanded in space through the dispersal of juveniles (Moldován, 2014). The minimum number of individuals was estimated at 44 in 2016, 72 in 2019 and more than 100 in 2022. The increase was also confirmed by the capture of individuals born locally and the large increase in the area occupied by blind mole rats, with practically all suitable area now inhabited by the species.

3.2.2. Pocsaj

The source of this project was a population of Hungarian blind mole rats found in an alfalfa field in 2014 in the outskirts of Debrecen, where the population was threatened by a number of factors (Németh et al., 2020). While all individuals survived the translocation, the discovery of blind mole rat bones found in the soil of the mounds suggested that at least three individuals died at the new site. However, we also recorded signs of reproduction and spatial expansion of the population to new areas. While the monitoring effort here was lower than at other sites (Table 1), we counted roughly the same number of individuals over the years, indicating a

Table 3

Scores measuring compliance with the IUCN Guidelines for the translocation projects studied. The scoring system assesses the pre-translocation activities, the implementation of the translocation and the post-translocation activities. Each question can be rated from zero to four points. A full match is worth four points, a partial match is worth three, two or one point, and a total deviation from the instructions is worth zero points. All mandatory criteria in the IUCN Guidelines are given equal weight. Following two of the two recommendations in the guide may earn an additional one point. The detailed scoring system is given in Table S2.

Criteria of the IUCN Guidelines	Bagamér	Pocsaj	Öttömös	Baja	Madaras	Monostorpályi	Martinka
Examination of system status	4	4	4	4	4	4	4
Examining the causes of the decline in population numbers	2	2	4	4	4	4	4
Examining the needs of the species	4	4	4	4	4	4	4
Population and habitat viability analysis	4	3	2	2	4	4	4
Examining reports of reintroductions of similar species	2	2	2	2	4	4	4
Is the translocation site within the former distribution?	4	4	4	4	4	4	4
In the middle or on the periphery?	4	4	4	4	4	4	4
Is the translocation site protected?	4	4	4	4	4	4	4
Is the relocation site appropriate in terms of habitat suitability?	4	2	2	1	4	4	4
Is the ecological carrying capacity of the translocation site appropriate?	4	2	2	0	4	4	4
Have the causes of previous population decline been eliminated?	4	4	4	2	4	4	4
Was there a habitat restoration programme?	4	3	2	0	4	3	4
Are the animals involved in the translocation originated from the wild or from captivity?	1	1	1	1	1	1	1
Was it pre-defined which populations/individuals will participate in the resettlement programme?	4	4	2	4	4	4	4
Has the impact of capture on the source population been investigated?	4	2	1	4	4	4	4
Was there a health examination before the release?	4	4	4	4	4	4	4
Was special care taken to maximise survival in the new habitat?	4	4	4	4	4	4	4
Was long-term financial support for the project assured?	3	3	4	3	4	4	4
Was long-term political support for the action assured?	4	4	4	4	3	4	4
Has there been a socio-economic survey?	0	0	4	0	0	0	0
Have the views of local residents been taken into account?	0	0	1	0	4	0	0
Was the attitude of the local community supportive?	1	1	3	1	4	1	1
Were all the necessary permits for the operation available?	4	4	4	4	4	4	4
Was there an expert group supervising the activity?	4	4	4	4	4	4	4
Have indicators of short-term success been defined?	4	4	4	4	4	4	4
Have indicators of long-term success been defined?	4	4	4	4	4	4	4
Was the length of the programme fixed?	4	4	4	4	4	4	4
Have there been genetic examinations?	4	4	4	4	4	4	4
Diseases have been tested?	1	1	1	1	1	1	1
Was veterinary assistance available?	4	4	4	4	4	4	4
Was there a release strategy?	4	4	2	4	4	4	4
Was there a social programme?	0	0	2	0	2	0	0
Were the locals involved in the programme?	0	0	4	1	4	2	2
Have the translocated individuals been monitored?	4	2	2	4	4	4	4
Has the cause of any deaths been investigated?	4	4	4	4	4	4	4
Was human intervention possible during the programme if necessary?	4	4	4	0	4	4	4
Have habitat conservation measures been taken following translocation?	4	4	4	0	4	4	4
Was there any PR activity after the relocation?	4	1	4	0	0	4	4
Has the success rate been evaluated?	4	4	4	4	4	0	0
Has the project been published for the general public?	4	1	4	0	0	4	4
Has the project been published for the profession?	4	4	4	4	4	2	2
Total score	134	118	133	106	143	134	135
Per cent of maximum score	81.7 %	72.0 %	81.1 %	64.6 %	87.2 %	81.7 %	82.3 %

stable population with only probable reproduction (Table 2).

3.2.3. Öttömös

The source of this project was a population of Vojvodina blind mole rats threatened by the construction of the border fence and the maintenance road on the border between Serbia and Hungary as part of the Hungarian government's response to the refugee crisis. Two of the nine individuals translocated first were lost immediately after the release in 2016, and only one individual was translocated late in the season in adverse weather in 2017. In 2018, the final year of the project, seven additional individuals were translocated. The concept and priorities of the translocation changed during the years, and a detailed plan for translocations was adopted only in the last year (2018) (Ruzsa et al., 2020). The initial monitoring frequency was low, and data showed a decrease in the number of individuals. It is likely that none of the individuals translocated in the second and third years survived. Subsequent surveys indicated the presence of a higher number of individuals from 2020. In 2022, we confirmed the presence of juvenile individuals born locally, and the recapture of

Table 4
Scores measuring compliance with the blind mole rat translocation protocol for the projects studied. The scoring system assesses activities related to selecting translocation sites and source populations, implementing capture, keeping individuals in captivity, releasing them and monitoring new populations. Each question can be awarded between zero and four points. A full match is worth four points, a partial match is worth three, two or one point, and a total deviation from the instructions is worth zero points. All criteria are given equal weight. The detailed scoring system is given in Table S3.

Criteria of the blind mole rat translocation protocol	Bagamér	Pocsaj	Öttömös	Baja	Madaras	Monostorpályi	Martinka
Selection of the translocation (release) sites							
Landscape historical survey	4	4	0	0	4	4	4
Is it historically appropriate?	4	4	1	1	4	4	3
Examination of size and mosaicism	4	4	4	2	4	4	4
Is the topography sufficiently varied?	4	4	3	0	4	4	4
Is it large enough?	4	2	4	1	4	4	4
Are the source and target areas similar in topography?	4	0	0	2	2	4	4
Pedological surveys	2	4	0	0	4	2	2
Are the source and target areas pedological similar?	4	4	2	3	2	4	4
Vegetation survey	4	4	0	0	4	4	4
Are the source and target areas vegetation similar?	4	1	3	1	2	4	4
Examination of the presence of predators	0	0	0	0	2	2	2
Habitat legal protection assessment	4	4	4	4	4	4	4
Is habitat protection guaranteed?	4	4	4	4	4	4	4
Is the population monitoring in the target area is feasible?	4	4	4	4	4	4	4
Selection of the source populations							
Genetic/taxonomic analysis	4	4	4	4	4	4	4
Is it genetically/taxonomically appropriate?	4	4	2	4	4	4	4
Source population in the same region?	4	3	4	4	4	4	4
Is the source population large, strong, stable?	4	1	0	4	4	4	4
Rescue of threatened individuals, translocation of entire population?	4	0	0	0	2	4	4
Implementation of the captures							
Have a sufficient number of individuals been translocated?	4	4	2	0	4	4	4
Does the capture of a sufficient number of individuals threaten the long-term survival of the source population?	4	2	0	4	4	4	4
Are the individuals translocated in the required sex ratio?	4	3	1	0	4	4	4
Did the captures take place during the ideal autumn period?	3	4	2	4	3	4	4
Was the method of capture scientifically appropriate?	4	4	4	4	4	4	4
Have the captures and translocations been carried out according to the planned schedule?	4	4	0	4	4	4	4
Temporal captivity of the individuals							
Were the conditions under which the animals were held in temporary captivity appropriate?	4	4	2	4	4	4	4
Release of the individuals							
Are the artificial tunnel systems properly constructed?	4	4	4	4	4	4	4
Did the release take place at a suitable season?	4	4	3	4	4	4	4
Is the distance and spatial position of neighbouring individuals appropriate?	4	3	1	2	4	4	4
Control and monitoring							
Were the translocated animals being safeguarded during the initial period?	4	3	1	1	4	4	4
Was there intensive monitoring until the first mounds appeared?	4	4	2	3	4	4	4
Was there regular monitoring afterwards?	4	2	1	4	4	4	4
Were the released individuals individually tagged?	4	4	4	4	4	4	4
Has the story of the dead/lost individuals been traced and clarified?	4	4	1	3	4	4	4
Were genetic samples taken?	4	4	4	4	4	4	4
Is the success of the project evaluated?	4	4	3	4	4	0	0
Total scores	137	116	74	91	133	136	135
Per cent of the maximum score	95 %	81 %	51 %	63 %	92 %	94 %	94 %

one translocated individual confirmed that at least some of the original individuals translocated in the first year survived. The current population size is estimated at 35–40 individuals, all of which may be descended from individuals translocated in the first year and presumably from a single male.

3.2.4. Baja

The source of this translocation was a small population of Vojvodina blind mole rats close to the Blind Mole Rat Reserve at Baja, which was threatened by the construction of a solar park. In 2017, all known blind mole rats in the construction site ($n = 10$) were caught and translocated to a part of the reserve not inhabited by blind mole rats. Each of the translocated individuals started to dig tunnels after their release. However, later monitoring showed a steady decrease in number; by the summer of 2018, only two specimens were found, while in 2019, none were found in the area. Observations hinted that the translocated individuals could not collect and store enough food to survive their first winter in the new habitat, most probably because of the unsuitable habitat conditions.

3.2.5. Madaras

The source population was the largest known population of the Vojvodina blind mole rat in and near the reserve at Baja (Csorba et al., 2023). All but one of the translocated individuals survived the translocation, and fresh mounds appeared in the first days after release. One individual came to the surface on the second night in the autumn of 2020 and became prey of most probably a long-eared owl (*Asio otus*). The presence of juveniles born locally was confirmed. By the spring of 2024, the population counted at least 40 individuals, and was steadily increasing in number and spreading in the area.

3.2.6. Monostorpályi and Martinka translocations

The latest translocation projects, were conducted in the Nyírség region, started in 2023 (Table 1). In the first, individuals were translocated from the population at the Hajdúbagos blind mole rat reserve to a protected area at Monostorpályi, and in the second, individuals from the Hajdúhadház population were translocated to a protected area near Martinka. All translocated individuals survived the transport, started digging tunnels, and the presence of juveniles born locally was observed as early as the first year, and both populations are expanding in size and area occupied.

3.3. Examination of the correspondence with the translocation guides

The total score measuring compliance with the IUCN Guidelines ranged between 106 and 135 (65 % and 87 % of the maximum score possible, respectively) (Table 3). Score values were high (> 80 %) for the Bagamér and Öttömös projects and the three most recent projects and were intermediate for Pocsaj and low for the Baja project (Table 3). It should be noted that some scores could not be assessed for the two most recent projects; thus, their overall score may even be higher once they are completed. There was a significant positive correlation between the score of compliance with the IUCN Guidelines (Table 3) and the total score of success of translocation (Table 2; Spearman's rho = 0.883, $n = 7$, $p = 0.008$). Of the 24 IUCN criteria that were not invariant (Table 3), four criteria showed significant positive correlations (Spearman's rho > 0.8, $p < 0.05$) with success scores: (i) population and habitat viability analysis, (ii) appropriateness of the relocation site in terms of habitat suitability, (iii) appropriateness of the relocation site in terms of ecological carrying capacity, and (iv) existence of a habitat restoration programme.

The total score measuring the compliance with the more specific blind mole rat translocation guidelines ranged between 74 and 137 (51 % and 95 % of the maximum score possible, respectively) (Table 4). Score values were high (>90 %) for the Bagamér, Madaras, Monostorpályi and Martinka projects, intermediate for the Pocsaj project and low for the Öttömös and Baja projects (Table 4). The two ongoing projects scored particularly high relative to their recent start (Table 4). Again, there was a significant positive correlation between the score of compliance to the translocation guidelines (Table 4) and the total score of success of translocation (Table 2; Spearman's rho = 0.811, $n = 7$, $p = 0.038$). Of the 28 criteria of the translocation protocol criteria that were not invariant (Table 4), three showed significant positive correlations (Spearman's rho > 0.8, $p < 0.05$) with success scores: (i) appropriateness of the sex ratio of the translocated individuals, (ii) the appropriateness of the distance and spatial position of the neighbouring individuals, and (iii) whether animals were safeguarded during the initial period.

3.4. Comparison of habitat characteristics of capture and translocation sites

The comparison of the characteristics of the habitats of the source and the target population showed in some cases high similarities, while large differences in others (Table S4). Examples of high similarity between the two habitats are the Bagamér project, where the habitats were almost identical in landscape composition and structure, topography, soil properties and vegetation (food availability) (Table S4). Translocated individuals thus could experience habitat conditions similar to those in the source area.

In the three translocation projects that followed the Bagamér project in time, habitat characteristics differed between the source and target habitats. In the Pocsaj project, the source habitat was an alfalfa field poor in plant species but rich in nutrients, whereas the translocation site was a loess steppe with outstanding plant species diversity but with low nutrient availability, even though the soil type was similar (Table S4). Translocated individuals thus could find themselves in a different environment from what they were used to before.

In the Öttömös project, the characteristics of the two habitats appeared similar at first sight and alternative sites were not considered. However, post-translocation edaphic surveys revealed important differences (Table S4). The source habitat was a partly quicksand hilly ridge, with light-coloured, loose-textured coarse sand soil. In contrast, the translocation site was originally a flat and wet, marshy landscape on dark-coloured clayey fine sand soil (Kreybig, 1934) that had been drained and where *Molinia* meadows and alkali marshes gave way to dry sandy vegetation a long time ago (Gaskó 2006). The target area thus superficially appeared similar to the source area in vegetation but proved much less suitable for blind mole rats.

In the Baja project, the target area differed substantially from the source area in landscape history, topography, hydrology and vegetation (Table S4), and was not able to support a viable population of blind mole rats due to low food availability (Schneider et al., 2019).

In the Madaras project, the target area had heavier and more fertile soil and more diverse vegetation than the source area. Their topography was rather similar as both sand hills and lower-lying, wetter areas were present in both sites (Table S4).

In the two latest projects, we explicitly strived for the similarity of the source and target areas and the selection of sites was based on a series of surveys over many years. As a result, habitat characteristics were almost identical in both sites in both projects (Table S4).

4. Discussion

4.1. Causes of success or failure

The variation in success can be explained by two fundamental reasons: (i) the deviations from the protocols and/or (ii) the suboptimal selection of the translocation sites. There was no sign that success or failure depended on which of the two species of BMRs was involved.

Strict adherence to the recommendations of the guidelines often increases the chances of success in reintroduction projects (Lee and Hughes, 2008; Olajos, 2012; Bajomi et al., 2023), and our results also corroborated this (Tables 3, 4). However, there was some difference as to which guideline was considered: projects varied less in their compliance to the general IUCN Guidelines (65–87 %, Table 3) than in their compliance to the blind mole rat translocation protocol (51–95 %, Table 4). This difference emphasizes the importance of developing taxon-specific guidelines. Nevertheless, our results support the view that the degree of compliance with the recommendations of the protocols enhances the success of translocations. Thus, following the protocol as closely as possible can facilitate the successful establishment of new populations.

The results of the scoring based on the IUCN Guidelines did not fully match the results of the scoring based on success values. This was mainly due to low scores given to criteria related to the involvement of local inhabitants and the existence of socio-economic surveys. While these considerations are fundamental in the majority of conservation projects, we found that they might not be directly relevant for blind mole rat translocations. These rodents, extremely adapted to a subterranean lifestyle and released in a protected area, have very little interaction with local inhabitants. However, certain stakeholders can be important partners. Livestock farmers play a role in managing the grassland habitat through hay harvesting or grazing. This maintains the open grassland habitats that are essential for blind mole rats (Németh et al., 2013a; Csorba et al., 2015). This can influence the success of establishing and subsequently spreading the new population.

While the translocation projects to establish new populations (for which the protocol was originally developed) were generally successful, they proved less so in rescuing entire populations from looming threats, i.e. solar park constructions. Capturing all individuals, even from a small population, is rather challenging and time-consuming. In addition, it is difficult to capture a sufficient number of individuals from smaller populations, and to ensure an acceptable sex ratio – both are critical for the establishment of the new population. An additional factor of failure is the time constraints when decisions have to be made under different pressures and without thorough surveys. It is thus not surprising that the three "rescue-type" projects initiated after the Bagamér project proved the least successful ones.

The suboptimal selection of target areas is likely the second main reason for the varying success. Loess grasslands in good condition and to a proper extent are critical habitat for blind mole rats, but these have largely disappeared from Hungary (Biró et al. 2018). In all but one of the projects, the target area was deemed generally suitable for the given species, but differences between success rates were probably due to habitat characteristics differences between the source and the target areas. In the Pocsaj project, for example, individuals captured in a flat alfalfa field on loess soil found themselves in a loess steppe on a steep slope; however, during the last three projects, special attention was paid to selecting a suitable site for the new population. Although the habitat features of the Madaras site partly differed from the source population of Baja in both soil and vegetation, after a long period of consideration and based on several surveys, expert consensus was reached that the habitat could be suitable for individuals from Baja, allowing that the capture and the release sites were fine-tuned, using only those parts of the areas that are most similar to each other. If the available sites differ somewhat in habitat characteristics, this solution could be recommended.

Expert consensus is also critical in ensuring the success of translocations. A forced compromise due to a lack of consensus after a deep and divisive debate between experts on alternative target areas probably contributed to the failure of translocation in the Baja project (Schneider et al., 2019). Although Madaras was already one of the options at that time, the site was not yet legally protected. The other possibility was a site already inhabited by blind mole rats, but there were strong arguments against potential genetic introgression that could have arisen by mixing the translocated individuals in the resident population. Debates among experts also surrounded the Öttömös project. The original plan was to establish a new population by translocating only one or two individuals from every small subpopulation of the Kelebia-Ásotthalom population to avoid threatening the persistence of any of these small remnants. The new population would have guaranteed the genetic survival of the original population in the event of any disaster. However, the construction of the border fence between Serbia and Hungary during the refugee crisis in 2015 represented an imminent threat to some subpopulations, and the new focus became the rescue of all the threatened individuals. Later, the decision whether to return to the original concept or to follow the rescue-type operation led to serious debates among professionals in several forums. The resulting compromise made it difficult to implement the action in line with the recommendations of the translocation guide. All these problems have left their mark on the project and certainly contributed to its modest success.

4.2. Methodological recommendations

The relatively small number of translocation actions examined in this study (n = 7) does not allow complex statistical analyses. It should therefore be noted that the recommendations set out below are based on qualitative, broadly correlational data rather than comparative statistical analyses based on quantitative data. Nevertheless, the recommendations that can be made on the basis of the translocation actions carried out so far could make a major contribution to the success of the efforts to protect many endangered species.

The selection of target sites seems to be very important, but also a very difficult task. The main selection criteria should be the suitability of the new habitat for blind mole rats. The legal status of the new site is less important as it is probably easier to change than its suitability. Suitability has several aspects: (i) landscape history, i.e., whether the area was previously suitable or acquired its present condition after the transformation of some unsuitable habitat; (ii) size, topography, and mosaic character of the area, i.e., whether it is sufficiently large and varied to support a new population even under extreme climatic and weather conditions; (iii) soil characteristics; (iv) vegetation; (v) presence and abundance of predators and if predation pressure can be decreased by extra protection measures; and (vi) the legal protection of the site to ensure the long-term survival of the new population.

Habitat suitability is crucial for the survival of translocated individuals during unfavourable periods such as the first winter. Although the food offered for translocated individuals (Fig. 2F) helps their overwintering, survival in the first year requires a habitat with high suitability, which is best ensured if the source and target sites are as similar as possible. However, this is probably only relevant if the source site is a natural habitat (but not relevant in case of, for example, an alfalfa field).

Another important criterion seems to be the number of individuals translocated in the first year because the probability of population establishment likely increases with the number of introduced individuals (Brichieri-Colombi, Moehrenschlager, 2016; Germano and Bishop, 2009; Morris et al., 2021). In the most successful projects, this number was 10 (Martinka) or more (13 in Bagamér and Monostorpályi, 16 in Madaras). These animals represent the core of the new population, which can be reinforced by further translocations in subsequent years. Additionally, the sex ratio of the individuals translocated in the first year is also important. Blind mole rats are monogamous, and the population sex ratio is 1:1 (Topachevskii, 1969; Horváth et al., 2007), although our field experience shows that there are far more females than males in the natural populations (Németh et al., 2013b). Monitoring data show that the majority of individuals who perished during the first year were males, likely due to male-biased dispersal or risk-taking behaviour. Nevertheless, we aimed for a 1:1 sex ratio among the translocated individuals to ensure that there is a sufficient number of males to initiate or support population growth.

Because blind mole rats spend their entire lives underground (Topachevskii, 1969; Horváth et al., 2007), they cannot be released on the soil surface where they could be threatened by predators (Németh et al., 2016). Consequently, we propose using the artificial tunnel system described in the methodology section (Chapter 2.2). In sites with high predation pressure, we also attach a net across the top of the fence to protect the individuals from predators.

The timing of the translocation changed between the projects. Initially, translocation was recommended for early summer (Németh et al., 2013b), when juveniles disperse, often far away from their original habitat and presumably suffer significant mortality (Németh et al., 2016, 2021). However, the Bagamér project revealed that by early summer, young individuals are highly stressed due to the forced dispersal, which is exacerbated by the capture and translocation disturbance to a degree that poses a serious threat to their survival. Therefore, the start of the autumn activity period was proposed for translocation (Moldován, 2014) and all the later projects were timed for this period.

With regard to the distance between the artificial tunnel systems, the translocation guide suggested at least as large a distance as the average size of the territories in the source population (Németh et al., 2013b), because blind mole rats are extremely aggressive towards their conspecifics (Nevo, 1999; Nevo et al., 1992). In the Pannonian region, the size of the territory of individuals is largely influenced by the nature of their habitat. According to the available data, in the least productive habitats (sandy grasslands), individuals are located within a radius of approximately 15 m from each other (Mikes et al., 1982; Moldován et al., 2025). In more productive habitats, this distance is smaller (Moldován et al., 2021). This distance could not be followed in the Bagamér project due to restrictions in the topography of the site, but in subsequent projects (Pocsaj, Öttömös, Baja), we adhered to the original recommendations. It was later found that, surprisingly, the establishment of new populations works well when individuals are closer together, likely because individuals need to detect the presence of conspecifics nearby; otherwise, they will try to leave the release site. In later projects (Madaras, Monostorpályi, Martinka), a smaller distance (cc. 10–12 m apart) was used.

The artificial tunnel systems should be arranged spatially to allow individuals to dig away from each other to minimise their chances of crossing paths. On the side of a long hill, for example, the release sites can be lined up at intermediate elevation, which allows individuals to move freely towards higher or lower terrains. Around a hill or a wet depression, release sites can be placed in a circular shape, so that the individuals can move towards higher or lower ground without conflicting with one another. During the initial critical period following the release of the individuals (two to three days, but at least 48 h), it is essential to guard the translocated animals and to check for any individuals wandering on the surface.

To ensure effective monitoring of translocated individuals, each animal should be individually marked, such as by implanting a microchip under the skin. This allows for their identification if they are found later. If the establishment of the new population is successful, individuals captured years later can be identified as either translocated or born locally. Additionally, to monitor genetic changes within the population, it is crucial to collect genetic samples from all translocated individuals, following the method of Sós et al. (2009). Based on our experience to date, including the recapture of individuals and the monitoring results of the established populations in new sites, the genetic sampling does not compromise the subsequent survival of the individuals.

4.3. *Conservation tool to recover grassland ecosystems*

Subterranean ecosystem engineer species, such as blind mole rats, play an important role in maintaining species-rich dry grasslands of high conservation value (Szabó and Zimmermann, 2012; Valkó et al. 2022b; Zimmermann et al., 2014). Their most important impacts are the modification of the soil structure, the disturbance caused by their mound-building to the plant community, the selective consumption of certain plant species, and the indirect dispersal of vegetative plant parts (Bodnár, 1928; Szabó and Zimmermann, 2012; Valkó et al. 2022b; Zimmermann et al., 2014). Of these effects, disturbance to plant communities can be particularly significant for conservation, as it provides bare soil surfaces free of competitors for germination, enhances the survival of certain plant species, and increases species richness. This effect is particularly significant in highly productive, closed grasslands, where bare soil surfaces are not otherwise present (Valkó et al. 2022b; Zimmermann et al., 2014). Rare or endemic plant species of high conservation value that rely on such bare soil surfaces include Hungarian pasque flower (*Pulsatilla flavescens* or *P. hungarica*), *Adonis volgensis*, milkvetch species (*Astragalus* spp., such as *Astragalus peterfii*), nodding sage (*Salvia nutans*), tatarican colewort (*Crambe tataria*), aster species (such as *Aster oleifolius*), thistle species (i.e. *Cirsium furiens*), spring meadow saffron (*Colchicum bulbocodium*) and Turkish starflower (*Sternbergia colchiciflora*) (Farkas, 1999, Molnár, 2003).

Newly established populations caused substantial changes in the landscape (Fig. 3). In Bagamér, for example, mounds built by blind mole rats became the dominant feature of the landscape (Fig. 3C vs. D). The matrix of previously closed grasslands was broken up by the mounds that appeared after successful translocations (Fig. 3E vs. F). The patches affected by the blind mole rats differed from the undisturbed grassland matrix both in species composition and vegetation structure (Valkó et al. 2022b). More detailed vegetation studies showed that the mounds provided important microsites for germination and growth for many dry grassland plant species including rare species of conservation value (Fig. 4A-D) (Valkó et al. 2022b). Such microsites are key to the conservation of dry grassland plant species (Klaus et al., 2018). The mounds of blind mole rats are significantly larger than those of other subterranean species, e.g. European mole *Talpa europaea* (Horváth et al., 2007; Moldován et al., 2021); thus, this effect on biodiversity is more pronounced in blind mole rats than in other subterranean mammals (Valkó et al. 2022b). The activity of blind mole rats leads to increased spatial heterogeneity compared to grasslands without these rodents, thereby increasing the compositional and structural diversity of habitats (Lengyel et al., 2016). The spatio-temporal dynamics of mound development and vegetation patterns may thus be an important driver in the long-term persistence of many plant species and the maintenance of plant community diversity and stability. The introduction of blind mole rats as ecosystem engineers may be directly applied in the restoration of dry grassland ecosystems to enhance habitat diversity (Lengyel et al., 2020), and mounds may be ideal as establishment gaps for the passive colonisation or for the active introduction of rare plant species in restoration projects (Kiss et al., 2021; Limb et al., 2010).

Observations during monitoring also suggested that the mounds are regularly used by many animal species (Fig. 4E-K). Invertebrates, such as several species of carabid beetles, used the mounds for heating up, feeding or resting; antlions (Myrmeleontidae)

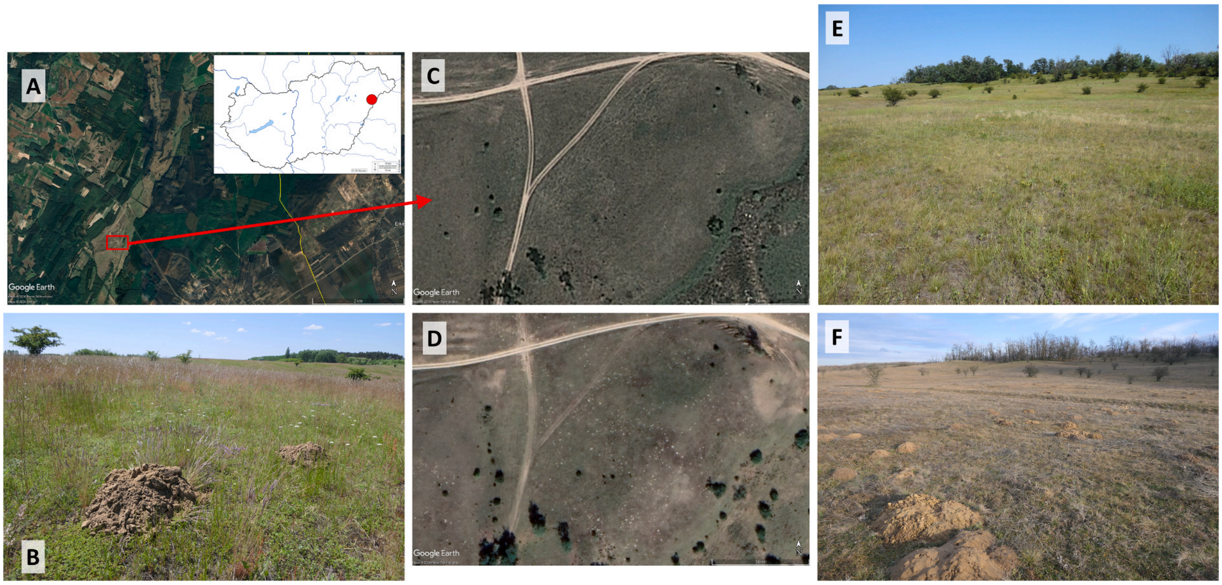

Fig. 3. Examples of the impact of introduced blind mole rats on a dry sandy grassland near Bagamér (red dot) (A). Blind mole rats' mounds (B) fundamentally changed the grassland, c.f. no mounds in the area before the translocation (June 2011, C) and many mounds after the translocation (September 2020, D). Mounds have become a dominant feature of the landscape, c.f. no mounds before (June 2012, E) and mounds after (December 2024, F) the translocation.

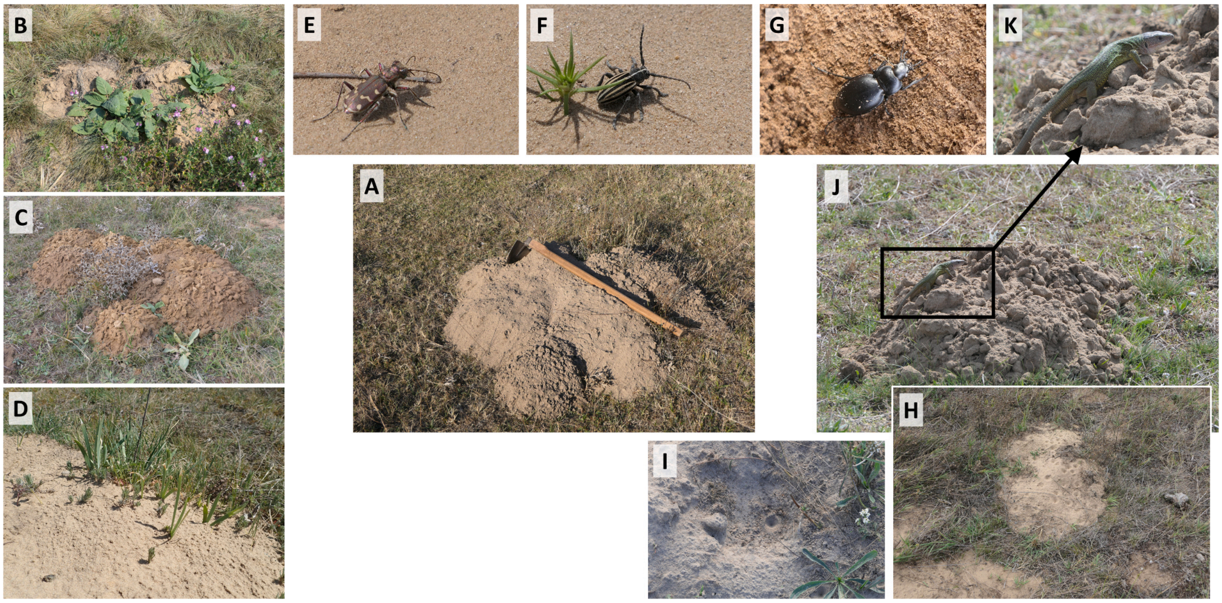

Fig. 4. Blind mole rats as ecosystem engineers in dry grassland ecosystems. Large mounds (A) can promote the establishment or spread of certain plant species (B, C), modify competition between plant species (i.e. excavated sand covers grasses and facilitates the vegetative spread of rare species such as *Iris humilis*) (D). The bare soil surface of the mounds is also used by numerous animal species ranging from beetles (E, F), including the strictly protected *Carabus hungaricus* (G) and other habitat specialists such as antlions that often make their pit-traps on mounds (H, I) to vertebrates such as reptiles (J, K).

often dug their ant-catching pit traps on the mounds (Fig. 4H, I), indirectly suggesting that the mounds are also frequently used by ants (Formicidae). Mounds are also used by vertebrates such as lizards for sunbathing (Fig. 4K) and by birds for singing, resting or territory surveillance.

5. Conclusion

In the Pannonian Basin, the distribution range, number of populations and individuals of blind mole rats have continuously declined over the last 200 years. Nevertheless, recent conservation efforts to establish new populations by translocation of individuals from existing populations were mostly successful and reversed the 200-year trend of decline. The number of the populations of these species is increasing for the first time in a long period. The method is thus promising for saving blind mole rats from extinction and for ensuring their long-term survival. The protocol followed to reach this goal is specifically tailored for rodent species that have a solitary lifestyle, feed on plants, and inhabit temperate dry grasslands. The evident success of BMR translocations can also be encouraging for the conservation of other endangered subterranean mammal groups with different traits (social or insectivorous species, populating different habitats). Modifications following the main principles outlined here, using local knowledge, are of utmost importance. However, if recommendations are followed thoroughly, new populations of ecosystem engineer species can facilitate the improvement of the conservation status of other grassland plant and animal species and can be a promising tool in the restoration and recovery of grassland ecosystems.

Ethics Statement

If this manuscript involves research on animals or humans, it is imperative to disclose all approval details.

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Declaration of Competing Interest

The authors declare no competing interest.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2025.e03756.

Data availability

Data will be made available on request.

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Glossary

Subterranean mammals: Fossorial mammals that not only seek shelter and den in tunnels and chambers dug in the soil but also forage underground and spend all or much of their lives under the surface.

Pannonic sand steppe: Formations dominated by medium or tall perennial grasses, with lacunar ground cover, together with their associated therophyte communities developed on mobile or fixed sands within the range of the Pannon Biogeographic Region.

Pannonic loess steppe: Primary species-rich, relatively closed, multi-strata steppe grasslands, on deep chernozems, the main Pannonian representative of the Eurasian steppe vegetation. Originally widely distributed throughout the Pannonian basin, but now reduced only to small fragments because of intensive agricultural activity. This habitat is of major conservation importance and harbours numerous rare and threatened taxa.

Molinia meadow: A distinctive wet grassland community developed on nutrient-poor soils (nitrogen, phosphorus) and characterised by a relatively species-rich sward dominated by *Molinia* spp., which is generally between 20 and 60 cm tall.

Nomenclature

http 1.: First Military Survey 1782–85. Map of the Military History Institute and Museum of the Ministry of Defence, Arcanum Data Base Ltd., Budapest. http://mapire.eu/hu/map/firstsurvey/

http 2.: Second Military Survey 1806–1869. Map of the Military History Institute and Museum of the Ministry of Defence, Arcanum Data Base Ltd., Budapest. http://mapire.eu/hu/map/secondsurvey/

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http 4.: Second World War Military Survey 1941. Map of the Military History Institute and Museum of the Ministry of Defence, Arcanum Data Base Ltd., Budapest. http://mapire.eu/hu/map/hungary1941/

http 5.: Aerial photographs from 1959 to 2007. Digital Aerial Photograph Archive, Lechner Nonprofit Ltd. Aerial Film Library (FÖMI, Budapest) https://www.fentrol.hu/hu/