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Animal Biodiversity and Conservation 46.2 (2023)
DOI: 10.32800/abc.2023.46.0127

Research paper

A spatial tool to identify potential conflict hot spots for the European ground squirrel in agricultural land

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Handling Editor:
Pelayo Acevedo

Received: 23/01/2023
Cond. acceptance: 10/03/2023
Final acceptance: 24/05/2023
Published: 22/07/2023

Cite:
Poledník L, Mateos-González F, Poledníková K, 2023. A spatial tool to identify potential conflict hot spots for the European ground squirrel in agricultural land. *Animal Biodiversity and Conservation* 46.2, 127-137. DOI: http://doi.org/10.32800/abc.2023.46.0127

ISSN: 1578-665 X
eISSN: 2014-928 X

Abstract

A spatial tool to identify potential conflict hot spots for the European ground squirrel in agricultural land. Some of the hardest challenges in conservation are those situations which occur when endangered species' and human interests collide. The European ground squirrel *Spermophilus citellus*, a mainly herbivorous rodent which feeds on agricultural crops when available, is an endangered species facing extinction in several countries. Sustainable conservation of the species can only be achieved in collaboration with all stakeholders, particularly farmers. However, in the past, this species was considered a pest, and farmers actively persecuted it, using invasive methods such as trapping and poisoning. In this situation, early monitoring and prevention are the best tools to minimise and mitigate potential conflicts. We developed a risk model to assess the potential for crop damages by ground squirrels, using data from three different locations with agricultural mosaic landscape in the Czech Republic. Our model is based on four parameters: occurrence and density of ground squirrels, migration potential, and type of habitat. The resulting model provides a graphical map of the local potential risk of crop damage. These maps can complement the regular monitoring of the European ground squirrel and its potential effects on agriculture, aiding the implementation of proactive management strategies to prevent conflicts and support the sustainable conservation of the species.

Key words: *Spermophilus citellus*, Crop damages, Sustainability, Preventive measures, Palliative measures, Spatial model

Resumen

Un instrumento espacial para detectar posibles puntos conflictivos de la ardilla terrestre europea en terrenos agrícolas. Algunas de las mayores dificultades en el ámbito de la conservación son las situaciones en las que existe un conflicto directo entre una especie en peligro de extinción y los intereses humanos. La ardilla terrestre europea *Spermophilus citellus* es un roedor principalmente herbívoro que, cuando tiene la oportunidad, se alimenta de cultivos agrícolas. Actualmente, esta especie se encuentra en peligro de extinción en varios países. Para lograr una conservación sostenible de la ardilla terrestre, es necesario contar con la colaboración de todos los interesados, especialmente de los agricultores. Sin embargo, en el pasado esta especie se consideraba una plaga y los agricultores la perseguían activamente utilizando métodos invasivos como trampas y venenos. En esta situación, el seguimiento temprano y la prevención son las mejores herramientas para minimizar y mitigar los posibles conflictos. Por ello, hemos desarrollado un modelo de riesgos para evaluar la probabilidad de que las ardillas terrestres ocasionen daños en los cultivos, utilizando datos de tres territorios agrícolas en mosaico de la República Checa. Este modelo se basa en cuatro parámetros: la presencia y la densidad de las ardillas terrestres, su potencial migratorio y el tipo de hábitat y da como resultado un mapa gráfico del riesgo potencial de que las ardillas ocasionen daños en los cultivos en las zonas de estudio. Estos mapas pueden complementar las actividades habituales de seguimiento de la ardilla terrestre europea y sus posibles efectos en la agricultura, lo que ayudaría a implementar estrategias de gestión proactivas para evitar conflictos y facilitar la conservación sostenible de la especie.

Palabras clave: *Spermophilus citellus*, Daños en los cultivos, Sostenibilidad, Medidas preventivas, Medidas paliativas, Modelo espacial

Introduction

Rodents, which include some of the major global pests, not only transmit diseases but also cause significant agricultural losses worldwide. They emerge as formidable competitors for food, leading us to allocate substantial resources to eradicate and control them (Stenseth et al 2003). These efforts contrast with those aimed at the conservation of endangered rodent species, which account for more than 51% of mammalian extinctions in the last 500 years (Ceballos and Brown 1995). Rodents continue to suffer from bias and neglect, partly due to their reputation and lack of public appreciation, despite their significant ecosystem functions (Ceballos and Brown 1995, Dickman 1999; Amori and Gippoliti 2000, 2003). This bias often favors more visually appealing mammal groups, undermining the recognition of rodents' ecological importance.

Certainly, achieving a balance between protecting endangered species and minimizing agricultural losses presents one of the most challenging aspects of conservation (Aplin and Singleton 2003). However, in recent decades, there has been an increasing demand for an ecologically-based approach that considers specific knowledge of the behavior, ecology, and biology of the species causing the conflict. This shift towards a more informed and targeted approach allows for the development of effective strategies that address the problem while minimizing negative impacts on both the species and agricultural practices. Singleton et al (1999) named this approach ecologically-based rodent management (EBRM), and it has become a widely accepted paradigm for rodent pest management, with remarkable results in Asia and Africa (Krebs 2006, Singleton et al 2021).

Most methods for pest control have been traditionally reactive, that is, decisions were typically made once there was evidence of damage to crops. Reactive decisions often led to poor management, or even illegal activities (e.g., uncontrolled poisoning), driven by social pressure and economic interest (Ferreira and Delibes-Mateos 2012, John 2014). In contrast, a key characteristic of EBRM is its proactivity, through the use of spatiotemporal factors: Predicting the movement and numbers of the rodents, based on their ecology and behaviour, allows for earlier, more targeted and effective intervention, reducing both pre- and post-harvest loses, and preventing uncontrolled damages to biodiversity (Singleton et al 2007, Krijger et al 2017).

Ecologically based management is particularly necessary in situations where the recovery of an endangered species can evolve into a potential conflict. In these cases, if the recovery of the species -and its potential effects on agriculture- are not monitored and preventively modelled, conflict can arise, increasing social and economic pressure for immediate responses. And a poorly planned, reactive decision can, directly or indirectly, undo years of recovery effort (Richards 2011, Loveridge et al 2019).

Spermophilus citellus (Linnaeus 1766), commonly known as the European ground squirrel, is a medium-sized sciurid that inhabits underground burrows and lives in colonies. Endemic to central and southeastern Europe, this species is currently listed as endangered on the IUCN Red List, and its populations are declining (Hegyeli 2019). Ground squirrels are predominantly herbivorous, feeding also on agricultural crops –seeds, grains, leaves, fruits– when available (Grulich 1960, Ružić 1978, Dănilă 1989, Ramos-Lara et al 2014). After decades of being considered an agricultural pest (Grulich 1960), in the Czech Republic, the westernmost edge of its distribution, the species has been critically endangered since the 90s due to habitat degradation and direct persecution. In 2008, an action plan was implemented to coordinate efforts to reverse the situation (Matějů et al 2010a) and, despite the collapse of several colonies, the total numbers of the species in the country have been steadily rising (Matějů et al 2019). Currently, 41 isolated populations are recorded within the territory of the Czech Republic (Matějů and Brzobohatá 2022), ranging in size from 5 to 1,000 individuals.

The growth of some of the colonies is certainly a conservation success, but it can also backfire if not closely monitored. As we continue our efforts to recover the species, it is important to take proactive measures to minimise potential damage to agriculture and ensure sustainable conservation. To address this challenge, we developed a spatial model that can identify and classify areas of potential conflict between ground squirrels and agriculture, providing a tool to facilitate prevention, environmental education, and mitigation measures to reduce the potential for conflict and support the conservation of the endangered European ground squirrels. We applied this model to create risk potential maps for three localities in the Czech Republic as examples.

Material and methods

Study area

We selected three ground squirrel populations situated in agricultural landscapes, each characterized by distinct density, growth trend, and habitat structure. These populations serve as representative examples of traditional agricultural mosaics with high diversity. The proportions of different habitat uses for the three localities are provided in table 1.

Miroslav

The study area is located southwest of Miroslav (48° 56' 52'' N, 16° 18' 45'' E), a town in the Znojmo District, in the South Moravian Region of the Czech Republic. The ground squirrel colony was established through translocation in 2008, in a grass airfield. Since then, the population has been steadily increasing, reaching up to 830 individuals in 2021. The ground squirrels have gradually occupied the entire airfield and, starting in 2014, have begun to spread to the nearby agricultural land. The surrounding area includes seasonal croplands of corn, rapeseed, pea, alfalfa, and a protected steppic area. As they move closer to the nearby town, the ground squirrels can be found in vineyards, orchards, and gardens.

Velké Pavlovice

This study area is situated in the agricultural land surrounding Velké Pavlovice (48° 54' 17'' N 16° 48' 58'' E), a town in the Břeclav District, in the South Moravian

Table 1. Proportions of the different habitats and land uses in the three study sites.

Tabla 1. *Proporción de los diferentes hábitats y usos de la tierra en las tres áreas de estudio.*

	Velké Pavlovice		Miroslav		Hrušovany u Brna	
Habitat	**ha**	**%**	**ha**	**%**	**ha**	**%**
Vineyard	190.2	47.2	66.3	40.0	10.3	27.4
Orchard	70.4	17.5	17.0	10.2	11.3	29.8
Crop field	63.9	15.9	41.3	24.9	10.2	27.0
Backyard gardens	10.0	2.5	2.2	1.3	2.0	5.4
Grassland	34.9	8.6	20.0	12.0	2.4	6.4
Shrubland	30.5	7.6	0.9	0.6	1.5	4.0
Forest	3.4	0.8	18.3	11.0	0.0	0.0
	402.9		166.0		37.8	

Region of the Czech Republic. The ground squirrel population has been monitored since 2005, when 20 individuals were recorded. Since then, the population has steadily increased to 600 individuals and remained stable until 2020, when it suddenly dropped back down to just 20 individuals (Matějů and Matoušová 2020). The ground squirrels in this area primarily inhabit vineyards and orchards.

Hrušovany u Brna

The ground squirrel population is situated on the southern side of Hrušovany u Brna (49° 2' 19'' N 16° 35' 39'' E), a village located in the Brno-Country District, within the South Moravian Region of the Czech Republic. Monitoring of this population began in 2008, initially recording approximately 100 individuals. Currently, the population size has increased to around 350 individuals (Matějů and Brzobohatá 2022). The ground squirrels in this area inhabit small orchards, vineyards, and backyard gardens.

Risk Model

The risk model is a qualitative assessment of the likelihood of damage to crops caused by ground squirrels. It is based on four parameters: the occurrence and density of ground squirrels, their potential for migration, and the type of habitat. These parameters were derived from field observations conducted between 2018 and 2021 in three study areas: Miroslav (2018-2021), Velké Pavlovice (2018), and Hrušovany u Brna (2021).

To measure the occurrence and density of ground squirrels, we mapped the distribution of active burrow openings (BO) in the study areas. Ground squirrels dig and inhabit burrow systems for refuge, reproduction and hibernation (Ružić 1978; Lagaria and Youlatos 2006). Previous research has shown a correlation between the number of burrows and the density of ground squirrels in an area (Biggins et al 1993, Hubbs et al 2000, McDonald et al 2011, Janák et al 2013). We then used the burrow data (BO) to obtain the area of occurrence (AO) by calculating a kernel density estimation (KDE) from the burrow opening. KDE is a well-established method used to identify spatial patterns. It calculates the density of events around each point, scaled by the distance from the point to each event (Silverman 1986). We calculated this using Arc GIS, ESRI© with an output cell size of 2 m to account for the accuracy of the geolocation, and a 36 m search radius, based on the average home range of ground squirrels (Ružić 1978, Matějů 2008, Turrini et al 2008). We grouped the resulting values of the kernel density estimation (KDE) into five categories of relative population density (RPD), corresponding to 1 to 4 quarters (RPD levels: 1,2,3,4) from the maximum observed density of burrow openings in the agricultural landscape of the Czech Republic, currently observed in Hrušovany u Brna.

To include a migration parameter in the risk model, we defined the area of potential occurrence (APO) in several steps. First, we calculated the minimum convex polygon (MCP) around the Area of Occurrence. Then, we added an additional buffer of 800 m, corresponding to the maximum recorded distance for a newly established satellite colony from the source colony within the study areas (Poledník et al 2019). Finally, we excluded areas behind migration barriers (e.g., roads, railroads, water courses) from the resulting polygon. These barriers were defined as any transportation route wider than 20 m or any water course with permanent water flow, habitats that small mammals are unable or unwilling to cross (Macpherson et al 2011, Andrews 2014). The values of this parameter were calculated as 0 for areas outside of the APO and 1 for areas within the APO.

The fourth parameter, type of habitat, was also derived from our field surveys of the study areas, and from information obtained from the cadastral map for each locality (Čúzk 2021). Each study area was divided into individual plots. One plot was defined as an area of land of the same habitat (table 1), so the risk of damage is considered the same for the whole plot. We assessed a total of 16,007 habitat plots, categorized

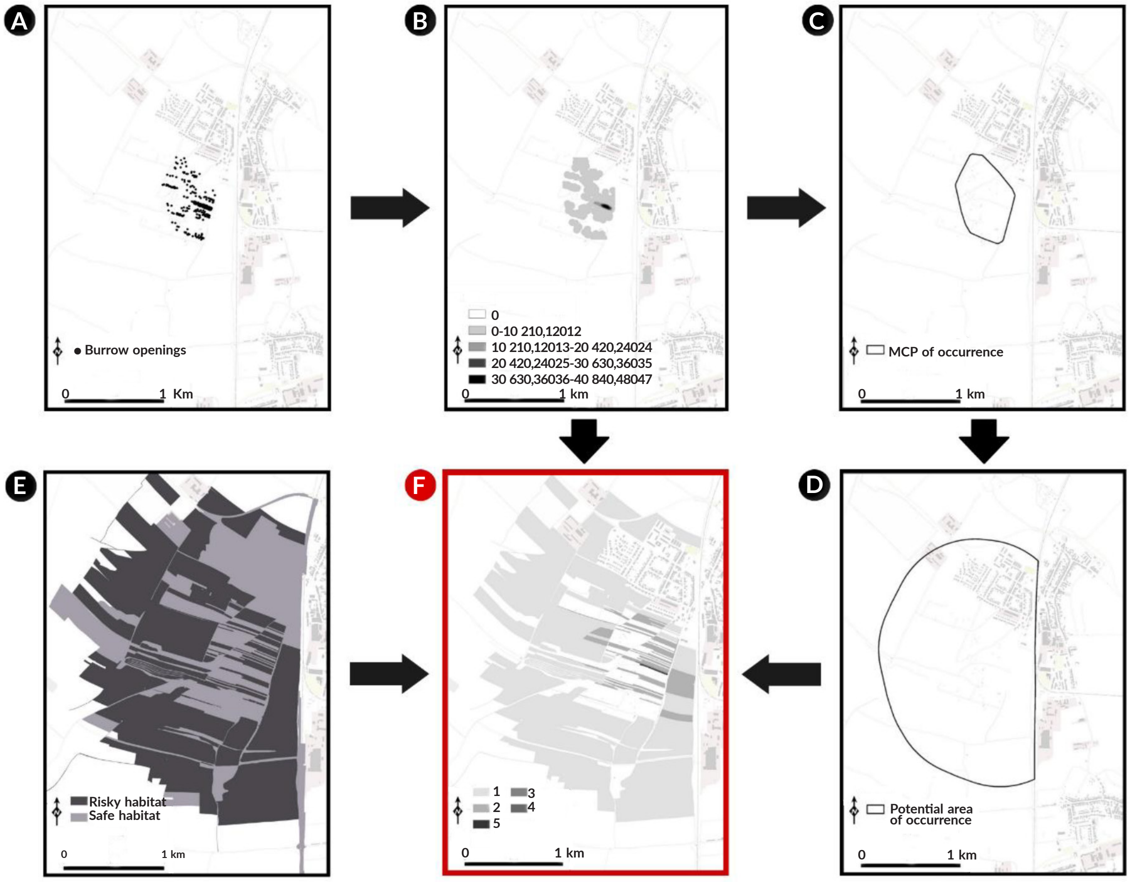

Fig. 1. Example of the process used to create the map of potential risk of crop damage caused by ground squirrels for the Hrušovany u Brna study area. The steps are described below: A, map of burrow openings: the first step in the process is to create a map of burrow openings in the study area; this map provides a visual representation of the occurrence and density of ground squirrels in the area. B, area of occurrence (AO), calculated by Kernel density estimation model: the area of occurrence is then calculated using a kernel density estimation model based on the burrow data; this model estimates the density of ground squirrels in the area based on the number of burrow openings and the average home range of these animals. C, MCP of area of occurrence: the minimum convex polygon (MCP) of the area of occurrence is then calculated, enclosing all burrow openings within the area. D, area of potential occurrence: the MCP is then expanded by adding a buffer of 800 m to account for the maximum recorded distance for a newly established satellite colony from the source colony; linear migration barriers, such as roads and water courses, are then excluded from the resulting polygon to define the area of potential occurrence (APO). E, type of habitat: the type of habitat within each plot is then identified as either 'risk' or 'safe' based on the definitions provided above. F, final risk of damage: the levels of potential damage are then calculated for each plot by adding the values for the migration parameter (0 or 1) and the relative population density (0-4) for plots with risk habitats within the APO; plots with risk habitats outside of the APO are assigned a value of 0; the resulting map shows the potential risk of crop damage caused by ground squirrels in each plot, with values ranging from 0 (no risk of damage) to 5 (very high risk of damage).

__Fig. 1.__ Ejemplo del proceso utilizado para crear elaborar el mapa de riesgo potencial de daños a en los cultivos causado ocasionados por las ardillas terrestres para el áreaen la zona de estudio Hrušovany u Brna. Los pasos de este proceso son los siguientes: A, mapa de las entradas de madrigueras de la zona de estudio; este mapa proporciona una representación visual de la presencia y la densidad de las ardillas terrestres en la zona. B, superficie de presencia (AO), calculada por el modelo de estimación de la densidad de Kernel: se calcula la superficie de presencia utilizando un modelo de estimación de la densidad de Kernel basado en los datos relativos a las entradas de madrigueras; este modelo permite estimar la densidad de ardillas terrestres en la zona a partir del número de entradas de madrigueras y el área de distribución de estos animales. C, polígono mínimo convexo (MCP) de la superficie de presencia: se calcula el polígono mínimo convexo de la superficie de presencia, englobando todas las entradas de madrigueras de la zona. D, superficie de presencia posible: se amplía el polígono mínimo convexo añadiéndole alrededor una zona de transición de 800 m para cubrir la distancia máxima recorrida por una colonia secundaria recién establecida desde la colonia original; posteriormente, a fin de determinar la superficie de presencia posible, se excluyen los obstáculos lineales para la migración, como carreteras y cursos de agua, del polígono que se haya obtenido. E, tipo de hábitat: el hábitat de cada parcela se califica como "en riesgo" o "seguro" atendiendo a las definiciones indicadas anteriormente (en inglés). F, riesgo de daños definitivo: se calcula el grado de daños potenciales en cada parcela añadiendo los valores del parámetro de la migración (0 o 1) y la densidad de población relativa (0-4) de las parcelas con hábitats en riesgo que están dentro del polígono mínimo convexo; a las parcelas con hábitats en riesgo que están fuera del polígono se les asigna el valor 0; el mapa resultante muestra el riesgo potencial de daños en los cultivos ocasionados por las ardillas terrestres en cada parcela, con valores que van de 0 (sin riesgos de daños) a 5 (riesgo de daños muy alto).

into two types: 'risk habitat' and 'safe habitat'. Risk habitat includes land where ground squirrels can cause damage, such as arable land, crop fields, and gardens. Safe habitat comprises areas where ground squirrels do not occur, do not cause damage, or their feeding behaviour does not impact human interests. Safe habitat types encompass orchards, vineyards, pastures, steppe grassland, short-cut lawns, tall lawns, forests,

Table 2. Levels of potential risk of crop damage caused by the ground squirrel. The relative density distribution (RPD) corresponds to 1 to 4 quarters from the maximum observed Kernel density estimates (KDE) in the agricultural landscape of the Czech Republic, currently observed in Hrušovany u Brna (40840). The RPD categories are expressed on an area unit scale, where each quarter represents a range of areas with increasing density of ground squirrel burrow openings per unit of area: KDE, Kernel density estimate; RPD, category of relative population density; RL, risk levels.

Tabla 2. *Niveles de riesgo potencial de daños en los cultivos ocasionados por las ardillas terrestres. La distribución relativa de la densidad (RPD) corresponde a los cuartos 1 a 4 de las estimaciones de densidad de Kernel (KDE) observadas en el territorio agrícola de la República Checa, actualmente observadas en Hrušovany u Brna (40840). Las categorías de RPD se expresan en una escala de unidades de superficie, donde cada cuarto representa un conjunto de áreas con una densidad creciente de entradas de madrigueras de ardilla terrestre por unidad de superficie: KDE, estimación de la densidad del kernel; RPD, categoría de densidad relativa de población; RL, niveles de riesgo.*

Habitat and migration	KDE	RPD	RL
Out of area of potential occurrence and/or in safe habitat	NA		0
Risk habitat within the area of potential occurrence, but outside of area of occurrence	NA		1
Risk habitat within the area of occurrence and first quarter of relative population density expressed in area unit scale	< 10,210	1	2
Risk habitat within the area of occurrence and second quarter of relative population density expressed in area unit scale	10,210-20,420	2	3
Risk habitat within the area of occurrence and third quarter of relative population density expressed in area unit scale	20,420-30,630	3	4
Risk habitat within the area of occurrence and fourth quarter of relative population density expressed in area unit scale	> 30,630	4	5

tree alleys, shrublands, ruderal areas, and built-up areas (Grulichn 1960, Poledník et al 2023).

Using the specified parameters, we were able to evaluate the level of potential crop damage for each plot on the cadastral map. Initially, we identified and selected only plots that had risk habitats within the area of potential occurrence (APO). These plots were assigned a score of 1, while those outside of the APO were assigned a score of 0. Next, we added the values of the relative population density (ranging from 0-4) calculated from burrow opening densities. By applying this approach to each plot, the resulting risk model displays levels of potential damage ranging from 0 (no risk of damage) to 5 (very high risk of damage). A detailed illustration of the individual steps involved in creating the risk model for the Hrušovany u Brna study area is provided in figure 1. The final step was to create a graphical map of the potential risk of crop damage caused by ground squirrels for each locality. This map was generated from the data obtained through the analysis of the four parameters described above. The resulting map provides a visual representation of the potential risk of crop damage caused by ground squirrels in each study area, allowing for the identification of areas with high levels of risk and the development of strategies for mitigating this risk.

Results

The potential occurrence and density of ground squirrels in our model were calculated by geolocating a total of 3,122 ground squirrel burrow openings in a surveyed area of 1,076 ha between 2018 and 2021. The calculated Kernel density estimates (KDE) ranged from 0 to 40,840 and the corresponding threshold values used for the categories of relative population density (RPD) are given in table 2.

The calculated sizes of areas for different parameters of the model are listed in table 3. The final maps are provided as figures (fig. 2-4).

Discussion

We developed a risk model to assess the potential for crop damage caused by European ground squirrels and applied it to three traditional agricultural mosaic-like landscapes in the Czech Republic hosting populations of this endangered species. The resulting maps showed differences in potential risk for the three landscapes, reflecting the variation in population density, habitat vulnerability to damage and the presence of migration barriers. The entire area of occurrence in Velké Pavlovice had a relative population density at risk level 1 (the lowest). The core of the populations in Hrušovany and Miroslav both had the highest relative population density at level 4, but while the core of the population with the highest ground squirrel density in Hrušovany was located in a single apricot orchard, in Miroslav it covered most of the airfield and the neighbouring alfalfa field. The area of potential occurrence (APO) in Hrušovany is smaller because the available habitat is limited both by type of habitat and by the presence of important barriers. In Pavlovice and Miroslav, ground squirrels are more widely distributed and form smaller groups that are further away from the main colony.

Table 3. Values of input parameters and outputs of the model for three localities: Velké Pavlovice, Hrušovany u Brna, and Miroslav. The inputs include the number of Burrow Openings (BOs), the size of the Area of Occurrence (AO), the Area of Potential Occurrence (APO), the area of risk habitat (RH), the area of safe habitat (SH), and the areas of the four categories of relative population density (RPD) - all measured in hectares. The outputs show the areas of Risk of damage level (RL) 0-5. The percentage values show the proportion of each input parameter in relation to the total area of the locality.

Tabla 3. *Valores de los parámetros de entrada y salida del modelo para tres localidades: Velké Pavlovice, Hrušovany u Brna y Miroslav. Los parámetros de entrada incluyen el número de entradas de madrigueras (BOs), el tamaño de la superficie de presencia (AO), la superficie de presencia potencial (APO), la superficie de hábitat de riesgo (RH), la superficie de hábitat seguro (SH) y la superficie de las cuatro categorías de densidad relativa de población (RPD); todas ellas medidas en hectáreas. Los parámetros de salida muestran la superficie de los niveles de riesgo de daño (RL), de 0 a 5. Los valores porcentuales indican la proporción de cada parámetro de entrada en relación con la superficie total de la localidad.*

	Velké Pavlovice		Miroslav		Hrušovany u Brna	
Locality	ha	%	ha	%	ha	%
BOs	477		2,231		414	
AO	58.57		42.08		23.82	
RPD 1	58.57		34.41		22.99	
RPD 2	0		4.27		0.47	
RPD 3	0		1.97		0.19	
RPD 4	0		1.44		0.16	
APO	1,208.83		875.26		329.37	
RH	339.18		575.27		245.08	
SH	976.85		429.12		141.63	
RL 0	976.85	74.2	429.12	42.7	141.63	36.6
RL 1	302.81	23.2	498.35	49.6	224.78	58.1
RL 2	36.37	2,8	39.09	3.9	19.85	5.1
RL 3	0	0	2.52	0.3	0.24	0.1
RL 4	0	0	0	0	0	0
RL 5	0	0	35.31	3.5	0.21	0.1

The main goal of our model was to create a simple and easy-to-build tool for local conservation authorities, and its four parameters (occurrence and density of ground squirrels, migration potential, and type of habitat) are straightforward to obtain, often from existing information. The regular monitoring programs established in most countries harbouring ground squirrel populations (Janák et al 2013) can provide updated estimations of occurrence and density. We determined the local occurrence of ground squirrels through mapping burrow openings, a method used regularly for monitoring in Hungary (Váczi et al 2019), Austria and Slovakia (Janák et al 2013). This information can also serve as a surrogate for species densities (Biggins et al 1993, Hubbs et al 2000, McDonald et al 2011, Janák et al 2013). Because European ground squirrel populations are quite dynamic in both abundance and spatial distribution (Hoffmann et al 2003, Matějů and Matoušová 2020, Kachamakova et al 2022), when applying our tool, it is advisable to use the most up-to-date information available, which national monitoring programs already provide annually.

While other direct sampling measures, such as trapping-requiring methods like Capture-Mark-Recapture, telemetry or GPS based tools can potentially provide a more accurate measure of density and more detail in movement patterns, they require more labour and cost intensive activities (Bean et al 2012, Byers et al 2019) and it is difficult to implement them at scale. Mapping burrow openings in large areas can also be labour intensive, but the use of non-invasive conservation drones and image processing techniques have already shown that this method could be at least semi-automated in areas not covered by vegetation (Gedeon et al 2022). The number of burrow openings can vary significantly depending on the season (Grulich 1960) and our experience indicates that habitat management can also affect the visibility of burrow openings. Therefore, the most suitable time for counting burrow openings during the active season may vary depending on the specific area and land use. Given that our model aims to provide a conservative estimate of the potential damage area, we recommend using data from the season with the highest number of burrow openings for the specific area.

The migration potential parameter is based on existing knowledge from the colonies included in the study, with the maximum recorded distance for a new colony being used to determine the extent of the potential risk. A similar maximum value has been observed in other studies (Turrini et al 2008, Kachamakova and Koshev 2021). This approach may be more conservative than using average recorded distances to calculate a more probable risk, but it ensures that authorities are aware of the full potential risk and can take appropriate precautions. The parameter can

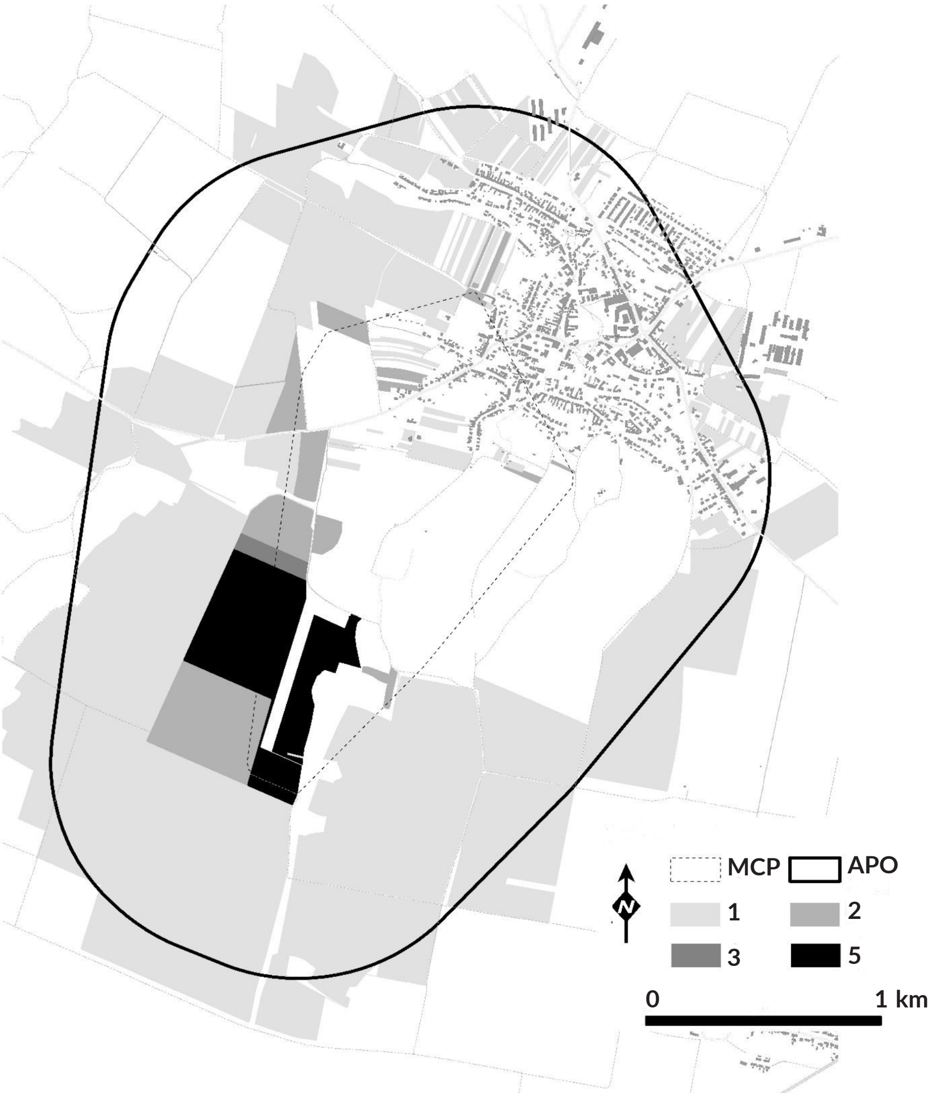

Fig. 2. Potential risk of damage by European ground squirrels in Miroslav (48° 56' 52'' N, 16° 18' 45'' E).

***Fig. 2.** Riesgo potencial de daños ocasionados por ardillas terrestres europeas en Miroslav (48° 56' 52'' N, 16° 18' 45'' E).*

be updated and adjusted as new data are obtained each season, and new colonies are established. Given the limited and variable availability of dispersal data on the species, we opted for a binomial approach to determine the area of potential occurrence (APO) parameter. The lack of systematic data makes reliable predictions challenging and adding such complexity to the model may not necessarily improve its accuracy. While this decision results in a less detailed and informative model in certain situations, adopting a more conservative approach benefits the species and provides clarity to authorities when using this tool. By prioritizing caution, we aim to ensure the protection of the species and promote responsible decision-making based on the available information. We conducted field surveys to assess the habitats in the study areas. However, it is worth noting that in many cases, ample spatial data is readily accessible. Various sources, including local government agencies, universities, and agricultural agencies, often provide valuable spatial information such as orthophotos or cadastral maps. Satellite imagery is also an option, available at national or even international scales. For instance, the Open Cadastral Map (EuroGeographics 2022) offers open-source, high-resolution cadastral data (from 1:100) for several European countries. Despite the availability of the habitat data, its evaluation might require careful consideration. When evaluating the sensitivity of a habitat to damage by ground squirrels, we took into account not only whether the species feeds on the crop, but also whether that feeding would have an impact on human interests. For example, even if ground squirrels occur in high densities in certain habitats such as orchards, the risk potential for human interests

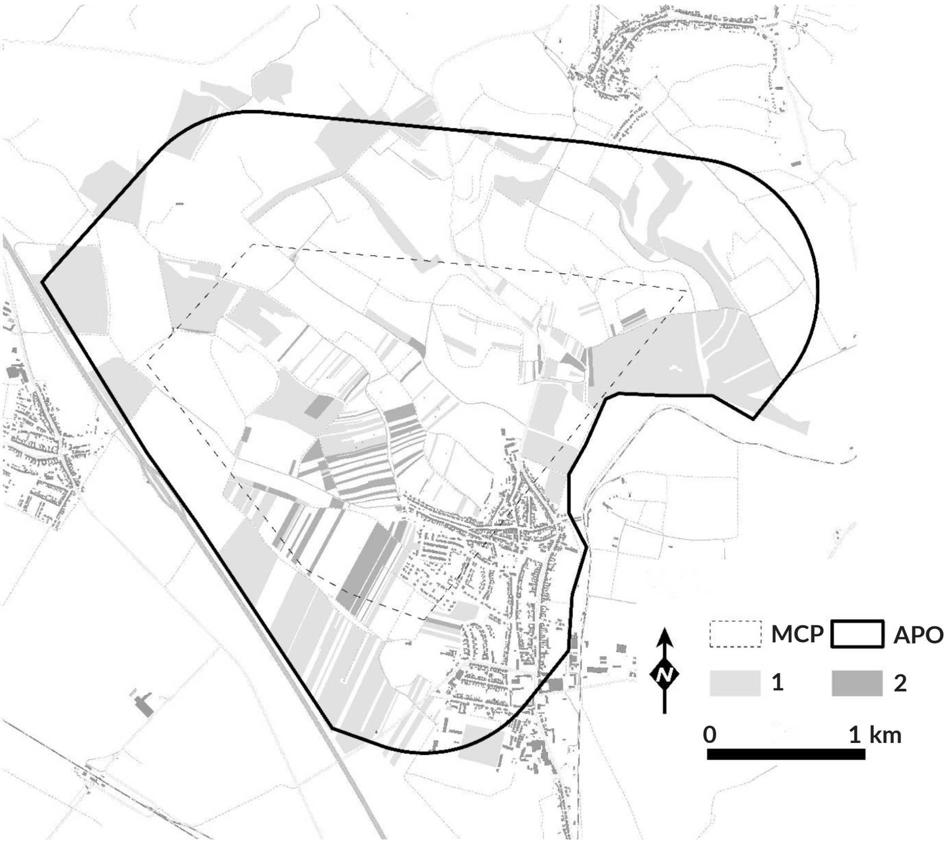

Fig. 3. Potential risk of damage by European ground squirrels in Velké Pavlovice (48° 54' 17'' N 16° 48' 58'' E).

Fig. 3. *Riesgo potencial de daños ocasionados por ardillas terrestres europeas en Velké Pavlovice (48° 54' 17'' N 16° 48' 58'' E).*

may be low if they only feed on fruit that has already fallen from trees and has no economic value. Some other habitats may be challenging to evaluate due to a lack of information or to differing perceptions among owners. For example, although we defined airfields as safe habitats, there are two different perceptions in two local airfields near Miroslav: while the owners of one airfield welcome ground squirrels on their land, the owners of a neighbouring airfield often complain that the squirrels digging increases the risk to landing planes. Similarly, we defined vineyards as safe habitats, although several winegrowers have mentioned some damage to newly planted vines. All ploughed land was classified as high-risk habitat even if the current crops were not sensitive to ground squirrel damage, because crops are likely to alternate from year to year.

Proactive measures to prevent potential conflicts have proven more effective than reactive measures regarding wildlife damage (Krebs 2006, Ferreira and Delibes-Mateos 2012, John 2014, Bautista et al 2021, Singleton et al 2021). Our risk potential maps provide a guide for identifying areas where proactive management strategies should be prioritised. In areas with a low or medium risk of crop damage, strategies such as public awareness campaigns and targeted fencing (Polednik, pers. comm.) can effectively prevent ground squirrel colonization of small plots in backyard gardens. For areas with a high risk of crop damage, measures like habitat restoration or cultivating crops that are less susceptible to ground squirrel damage can help mitigate conflicts. In economically or logistically important areas, these measures can be complemented with strategic compensation initiatives. Translocation projects, when carefully planned, can be considered as a last resort (Matějů et al 2012, Koshev et al 2019). On the other hand, plots with no risk could potentially be used to plant crops that are more sensitive to damage, such as alfalfa or vegetables. It is worth keeping in mind that while our model provides a useful tool for assessing the potential for crop damage by ground squirrels, it does not calculate the actual damage caused by ground squirrels but rather the risk of potential damage. As such, it could be useful when choosing where to promote –and potentially subsidize– prevention measures, but not as a reactive tool to calculate compensations for damage.

Our proposed tool has applications beyond assessing potential crop damage risks and planning preventive measures for existing natural colonies of the European ground squirrel. It can also play a crucial role in the planning and implementation of conservation translocations, which have been widely utilized in

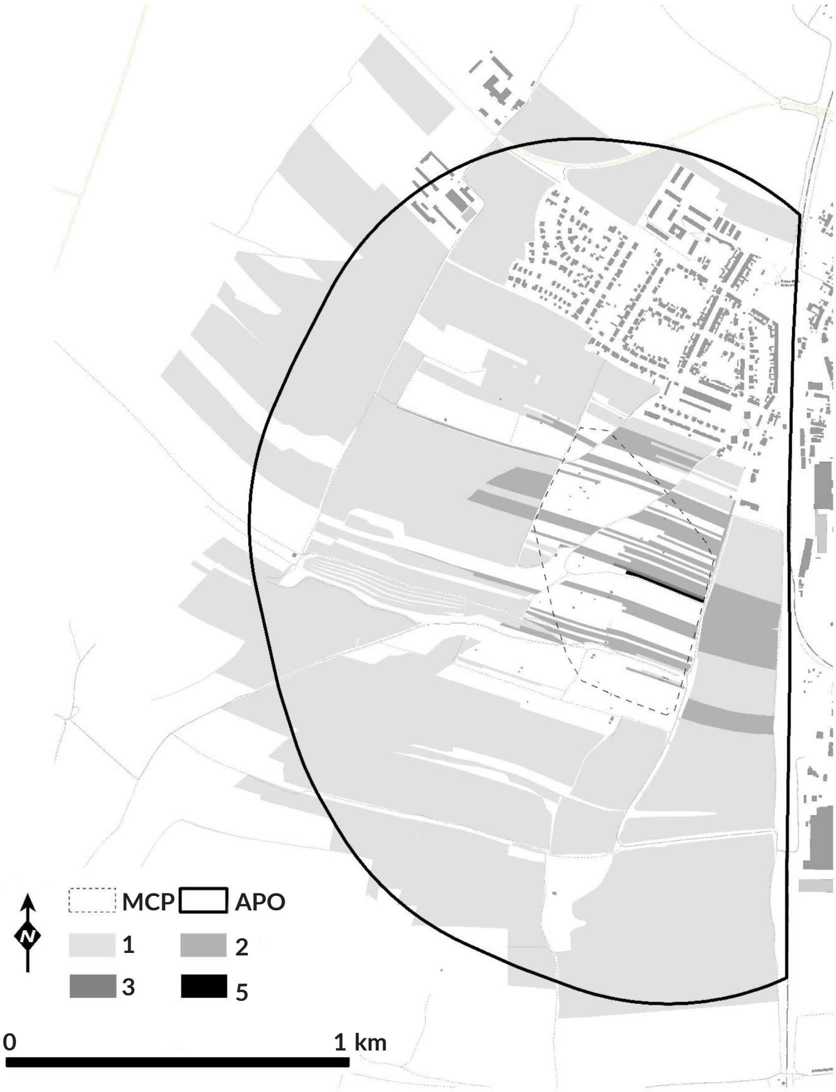

Fig. 4. Potential risk of damage by European ground squirrels in Hrušovany u Brna (49° 2' 19''N 16° 35' 39'' E).

Fig. 4. *Riesgo potencial de daños ocasionados por ardillas terrestres europeas en Hrušovany u Brna (49° 2' 19''N 16° 35' 39'' E).*

species management over the past few decades and are expected to remain essential (Matějů et al 2010b, Janák et al 2013, Kachamakova et al 2022). The model we developed can help identify risk-free areas suitable for repatriation efforts and areas that are appropriate for population reinforcement. Moreover, it can help identify populations residing in high-risk crop damage areas, where targeted translocations of individuals can help mitigate conflicts and reduce the potential for damage. By incorporating our model into translocation planning, decision-makers can strategically select suitable release sites, enhance conservation efforts, and promote the coexistence of the European ground squirrel with agricultural practices. This comprehensive approach enables a more proactive and informed management strategy for the species.

Our model and approach could also be applied to non-endangered but ecologically similar species, even if they are considered pests, such as California ground squirrels *Otospermophilus* spp., pocket gophers *Thomomys* spp., or voles *Microtus* spp. In such cases, particularly for native species, a proactive management strategy is also justified, not only because ecologically-based approaches have proven effective and beneficial (Krijger et al 2017), but also because native small mammals traditionally considered pests because of their high numbers are probably performing key ecological roles for the same reason, as described by Delibes-Mateos et al (2011) for other burrowing mammals, such as prairie dogs *Cynomys* spp., plateau pikas *Ochotona curzoniae*, and European rabbits *Oryctolagus cuniculus*. Finally, our model does not rely on data about specific damage but instead uses information about habitat or land use as a surrogate for risk. This makes it useful not only to assess the potential risk of damage; it could also be easily translated to other conflicts related to habitat or land use, not necessarily involving crop damage. For example, the model could be applied to the case of the edible dormouse *Glis glis*, occasionally considered a household pest (Amori et al 2016), or a threat to beech trees (Montecchio et al 2011). Obtaining up-to-date occurrence data from elusive, nocturnal species could be more challenging than for the European ground squirrel, but nocturnal acoustic surveys have proven efficient, particularly when combined with citizen science data (Adamík et al 2019). Maps of the potential risk of conflict would be particularly useful when planning forest uses in the northern range of the species where its populations are fragmented (Kryštufek 2010) and the species could be more sensitive to habitat alterations (Herdegen et al 2016).

While the model is robust, its limitation lies in our incomplete knowledge of processes such as population dynamics and migration, and the effect that habitat quality or patch size might have on these variables. Regular monitoring of specific ground squirrel populations is therefore essential for accurate results. The model's strengths include its simplicity, requiring no specialized knowledge, software, or tools. Additionally, most of the input parameters are easily obtainable, often from existing information sources. Compared to other models that focus on predicting damages and human-wildlife conflicts (Klees van Bommel et al 2020, Sharma et al 2020, Bautista et al 2021) or interviews with stakeholders that may be influenced by perceptions of damage (Broekhuis et al 2017, Thant et al 2021), our model stands out by assessing the vulnerability of ground squirrel habitats to damages. The model's use of habitat vulnerability is particularly relevant since the output is the risk of damage, rather than the amount of damage.

In conclusion, our model makes use of four easy-to-obtain parameters to create graphical maps of the potential risk of crop damage. These maps can be useful when implementing proactive management strategies to prevent conflicts and support both the sustainable conservation of endangered species and the ecologically-based control of non- endangered but still problematic species.

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Acknowledgments

We would like to express our gratitude to Ester Ekrtová, Libor Ekrt, Hannah Findlay, and Štěpán Zápotočný for their invaluable assistance during the fieldwork. We also extend our appreciation to Cristina Amador for her valuable contributions to the manuscript. We are grateful to the two anonymous reviewers for their constructive feedback, which greatly improved the previous version of this paper. Stuart Edmunds revised the English language.

Author contributions

LP, KP and FMG designed the study. LP, KP and FMG collected field data. LP analysed the data. FMG wrote the paper with significant input from all co-authors. All authors read and approved the final manuscript.

Conflicts of interest

No conflicts declared

Funding

This study received support from the Technology Agency of the Czech Republic under the program 'Environment for Life' (Project SS01010510).

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