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LONG TERM (1985–2018) CHANGES OF THE HABITAT SUITABILITY OF EUROPEAN SOUSLIK ASSESSED BY MAXENT MODELLING BASED ON LANDSAT SATELLITE IMAGERY – A CASE STUDY FROM A MOUNTAIN LANDSCAPE OF CENTRAL BULGARIA

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The spatial and temporal aspects of the habitat suitability of the European souslik (*Spermophilus citellus* L.) in an area of Sredna Gora Mountain (Bulgaria) were studied. We used Landsat satellite imagery data to model changes in the habitat suitability of the species from 1985 to 2018. The obtained results demonstrate that the habitat suitability of the European souslik increased during the studied period, presumably due to raised temperatures and the accompanying drought during summertime, as well as the human-caused modifications in pasture livestock breeding. Based on statistical modelling, the employed procedure applies to long-term monitoring and assessment of the role of land cover change because of climate change and human activity on the habitat suitability of the European souslik. This approach can be useful for conservation planning.

Keywords: *Spermophilus citellus*, statistical modelling, climate change.

INTRODUCTION

The Earth's average surface temperature has been rising at a high rate over the last 35 years (https://www.giss.nasa.gov/research/news/20170118/). In addition to global climate change, ecosystems in Bulgaria have been modifying especially dynamically as a result of the socio-economic changes after 1989. Cycles of decline and intensification of agriculture alternated, and this especially affected the open habitats.

The European souslik (*Spermophilus citellus* L.), a rodent with a declining population in the country for the last decades (Stefanov 2006, 2015, Koshev 2009, 2012, Stefanov & Markova 2009), is one of the key mammalian species in grasslands and is one of those affected by the above-mentioned causes. The species is listed as "Endangered" in the 2020 IUCN Red List. Human activities contributing to the loss or deterioration of optimal habitat, as well as climate change (droughts, storms, and flooding in particular), are identified as some of the major threats to its diminishing populations (Hegyeli 2020).

The European souslik occupies grasslands in various soils, usually with good water retention and medium aeration (Janderková *et al.* 2011). The condition of the habitat mostly depends on the structure of the vegetation. According to Kis *et al.* (1998), the height of the grass cover is more important than the existence of specific plant species. The height of the grass should not exceed 15–20 cm in providing both shelters from predators and the possibility of a wide view (Straschil 1972, Stefanov 2009). The absence of management of grasslands and especially pastures has an adverse effect. Coarse grasses take the grass communities over, and the low-growing plants become sparse. Various shrubs spread and may cover extensive areas where the treatment of the grassland is of lower intensity. These changes reduce the habitat suitability of the European souslik.

For this reason, one of the primary conservation objectives is to keep optimal for the species structure of grassland vegetation by active management, which encompasses grazing, mowing, or a combination of both. Some studies suggest grazing as the most appropriate way to manage grass habitats and biodiversity (During & Willems 1984, Butaye *et al.* 2005). However, these measures are occasionally conflicting with the conservation targets for other species that prefer better-developed grass and shrubbery. These inconsistencies can be resolved by more spatially and temporally adapted means, such as mosaic mowing, the adoption of electric shepherds, and rotation grazing (Janák *et al.* 2013).

In this context, monitoring the changes in habitat features is essential for the conservation of the European souslik. To be effective, it must cover extensive territories and allow for quantitative analysis of tendencies in the key factors related to global climate and socio-economic change and the synergy between them. Until recently, gathering reliable, systematic, and quantitative data in these aspects over large areas was difficult. Current views on directions in habitat transformation are based on indirect evidence of trends in various forms of agricultural activity (Stefanov 2015).

In the late decades, remote sensing became an important environmental survey tool. Nowadays, there is a wide variety and extent of data from various sensors. All of them, in diverse forms, give valuable material for mapping habitats and their condition. Medium spatial resolution sensors of Landsat 5 (TM), Landsat 7 (ETM+), and Landsat 8 (OLI/TIRS) are specifically useful for land-cover monitoring at the country and provincial levels. Direct mapping of the fine details of land-cover based on remotely sensed evidence is often challenging at a landscape scale. At this scale, adding ancillary data such as inferred from different geographical features have been demonstrated to improve the classification of homogenous land-cover types such as grasslands when merged with spectral data and indirect techniques, such as species distribution modelling (Schmidtlein & Sassin 2004, Rocchini *et al.* 2010).

The present study aimed to assess the applicability of satellite images and species distribution modelling to track modifications in the habitat of the European souslik at the landscape level for several decades, as well as to associate the identified changes with the effect of climatic and socio-economic factors. In light of the lack of reliable large-scale quantitative data in this regard, the present study is exploratory in nature, looking for clues and trends that will help lay the basis for future conservation, management and monitoring efforts.

MATERIAL AND METHODS

Study area – The survey area (Fig. 1) is a semi-mountainous and mountainous landscape in Central Bulgaria (Pazardzhik district) with an altitude ranging from 500 to 1400 m a.s.l. To the south, it extends to the town of Panagyurishte, and to the north – to the

Fig. 1. Satellite view of the study area. White circles represent the location of the colonies from which the coordinates of individual holes were taken for inclusion in maxent habitat modelling

ridges of Sredna Gora Mountain. Most of the territory is covered by deciduous, mainly beech forests. There are vast areas across broad ridges covered by pastures, semi-natural grassland, and small parcels of arable land. In the southern and lower parts of the area, there are settlements that, together with their neighbourhoods, represent territories with practically destroyed plant cover. Conversely, the higher parts of the region belong to the Natura 2000 site Sredna Gora (BG0001389). Here, the open habitats are relatively protected and used mainly for grazing. On the ridge parts of the region, "Species-rich *Nardus* grasslands on silicious substrates in mountain areas" (habitat code 6230) are spread, while in the lower parts "Lowland hay meadows" (habitat code 6510) predominate (NATURA 2000 – Standard Data Form – BG0001389 SPA Sredna Gora). Livestock breeding is well developed in the research area. The region falls in the southern central Bulgarian planning region, which, according to statistics for the period 2001–2018, has the largest number of grazing livestock in the country (Gerginova *et al.* 2015, Anonimous 2016–2020). The review of the statistical data shows a decline until 2008, after which the livestock number remains almost stable (Fig. 2). Livestock husbandry in the study area is based on free grazing during the growing season. There are many summer cattle barns and ponds for watering the herds. In

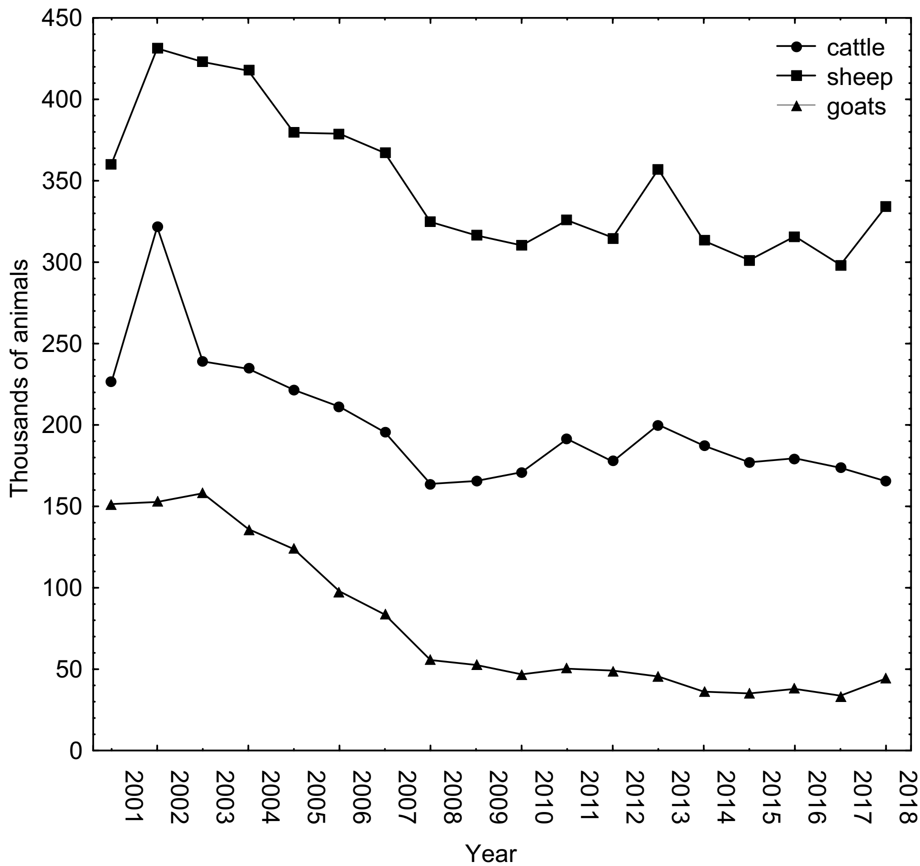

Fig. 2. Changes in the number of grazing livestock in the southern central Bulgarian planning region for the period 2001–2018

late years, regulations have been introduced, altering the usage of pastures. Among them, Ordinance 44 of the Ministry of agriculture, which prescribes the fencing of leased state and municipal pastures, is particularly important as it restricts the free and uncontrolled movement of herds. Also, due to the diminished number of animals, many of the fenced pastures are not grazed intensively, promoting the preservation of a tall grass cover.

Climate data – The long-term climatic features of the region were characterized based on data (584 m a.s.l.), covering the period 1985–2018 from the meteorological station Sofia (https://www.stringmeteo.com/synop/bg_climate.php). This station was selected based on geographical proximity to the study area, similar landscape features, and the availability of a sufficiently long series of meteorological data to assess long-term climate dynamics. Temporal climate peculiarities and trends were analyzed by using the TTAinterfaceTrendAnalysis package v. 1.5.1, (https://www.rdocumentation.org/packages/TTAinterfaceTrendAnalysis). The analysis of the average annual temperature for 1985 - 2018 shows a statistically proven upward trend (p-value: 0.0123) with a slope of 0.0405 degrees Celsius per year. This tendency is also well manifested in the study of temperature anomalies (Fig. 3). Each anomaly is the difference between the value aggregated at the time step and the median of this time step for the entire regularized time series. The analysis of precipitations, both annual and those in the interval April–July, do not show statistically proven trends during the study period.

Souslik occurrence data – Thirty-five georeferenced occurrences of *S. citellus* (data from the summers of 2018 and 2020) were used to identify relationships between the species distribution and the environmental variables presented below. Georeferenced locations were coordinates of haphazardly picked entrances of inhabitable burrows situated at a distance of more than 100 m from each other. Some of them were part of clearly defined colonies (Fig. 1), while others were single burrows from colonies on the verge of extinction. As most of the point occurrences were part of souslik's colonies, they were inevitably clustered, but the clusters were widely scattered across the study area. Thus, the georeferenced records adequately represent the variability of conditions within the optimal souslik's habitat.

Environmental variables – The environmental variables employed in habitat modelling were of two types. The first type was represented by the spectral bands of satellite images. The second type comprised variables based on landscape features.

Satellite images of Landsat 5 TM and Landsat 8 OLI/TIRS downloaded from the U.S. Geological Survey's Global Visualization Viewer/EarthExplorer (http://earthexplorer.usgs.gov/) were used. They have medium resolution with a sampling ground distance of 30 m, making them useful for regional-scale studies. The downloaded images were cut to the extent of the polygon enclosing the study area (the coordinates of the rectangular polygon angles were as follows N42.62° E24.28°; N42.51° E24.28°; N42.51° E24.15°; N42.62° E24.16°). The resulting rasters were thoroughly inspected, and scenes exhibiting minimal deterioration due to in-scene contamination by clouds were collected. As a result, 12 scenes from July were utilized: Landsat 5 TM – 9 scenes from 1985/07/27, 1993/07/03, 1996/07/27, 1998/07/01, 2000/07/06, 2004/07/01, 2005/07/20, 2007/07/10, and 2007/07/26; Landsat 8 OLI/TIRS – 3 scenes from 2015/07/09, 2015/07/25, and 2018/07/01. The nomenclature of Landsat 8 bands was equated to that of Landsat 5 based on wave length range (in parentheses, micrometres): B1 (0.45–0.52), B2 (0.52–0.60), B3 (0.63–0.69), B4 (0.76–0.90), B5 (1.55–1.75), B7 (2.08–2.35).

Two other variables, Euclidean distances to a watering spot (mainly micro-dams and fountains) and to a cattle barn, represent the pressures caused by livestock on the pasture. Near these features, the ground is heavily compacted, the grass cover has degraded, and the soil surface erosion is extensively spread. The watering sites and cattle barns were initially digitized on a topographic map 1: 50 000. Then, the obtained points (shape files) were converted to kmz format, imported into Google Earth, and proved on a satellite image of 2020.

For those points for which the existence of these features was confirmed, exact coordinates were taken, which afterwards were used to compile these two variables in ArcGIS 10.1.

Modelling – The maximum entropy modelling technique, implemented as the free program 'Maxent' was applied to predict habitat suitability based on environmental variables and georeferenced species records. Through the ENMeval package (Muscarella *et al.* 2014), the optimal parameters for Feature classes and Regularization multipliers were selected based on the method "block" that is most relevant for transfer models. As the souslik is rigorously confined to open habitats, a mask for selecting background points has been set up when fitting the model. It was a raster file in which all Corine land-cover classes at the third level representing open habitats were given a value of 1, and the rest were marked as no data. In this manner, background points characterized the available environment suitable for the species, while the presence points characterized the environment inhabited by the species. To evaluate the goodness of fit and stability of the model, 30 bootstrap replicates were run. Variable importance was assessed based on two methods - Percent contribution and Permutation importance. The Area Under the ROC Curve (AUC) was used for model verification, offering a threshold independent metric. In general, it shows how closely the model can predict presence and absence. However, since Maxent uses presence-only data, the AUC evaluates how well the model can discern presence from the background. The AUC value ranges from 0 to 1, the closer the AUC value to 1, the better the model.

Based on the climate changes presented above, the study period was divided into two parts – the first from 1985 to 2005 and the second from 2006 to 2018. The second part is identified by a predominantly warmer climate and expanding areas of some types of land cover due to anthropogenic impact on the landscape (reduction in the number of grazing animals and changes in pasture use practices), offering suitable habitats for the souslik. The raster

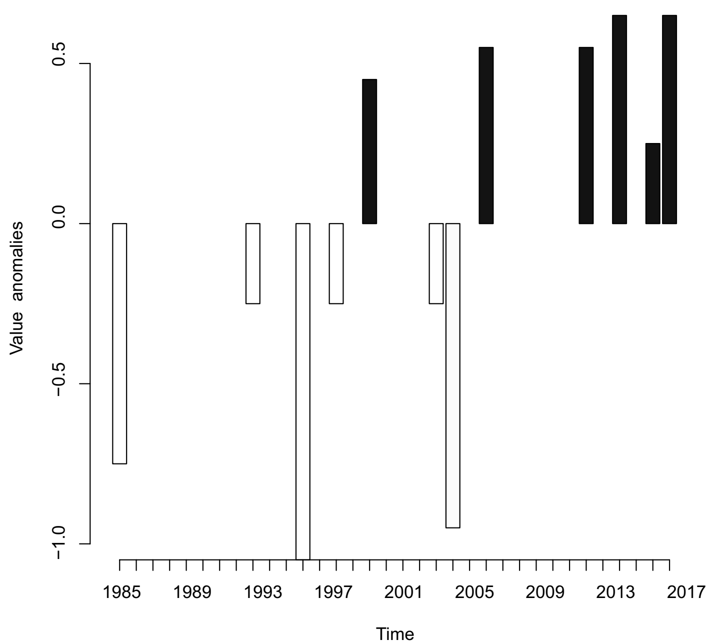

Fig. 3. Negative and positive anomalies (white and black bars) of the Mean Annual Temperature time series for the period of 1985–2018 (data from the meteorological station Sofia)

Table 1. Summary of importance of environmental variables. ED – Euclidean distance

Variable	Percent contribution	Permutation importance (%)
ED from water sources	39.3	23.2
Band 5	18.3	53.1
ED from cattle barns	16.3	1.9
Band 3	13	9.9
Band 4	8.8	6.4
Band 1	4.3	5.4
Band 7	0.1	0
Band 2	0	0

Table 2. Number and area of the polygons with the highest habitat suitability (over 0.5) for the European souslik.

Polygons with HS over 0.5	period 1985–2005	period 2006–2018
Number	52	219
Mean area [ha]	0.173	0.55
Total area [ha]	9.00	121.53

bands of the satellite images were averaged within each of these periods. The model was calibrated on the averaged rasters for the second period, corresponding to the time of collection of the occurrence data. The resulting model was back-projected onto averaged images comprising the first period from 1985 to 2005. The distances from water sources and barns were the same for both periods – as they existed during both stages, as far as they were available on a topographic map from 1985.

To assess the current status of the European souslik in the study area and to relate it to the modelling results, we collected data on the relative abundance of the species in four colonies with the following geographical coordinates: Luda Yana – N42.52315° E24.20355°; Panagyurski kolonii – N42.59091° E24.22968°; Belotrup – N42.610683° E24.257267°; Beli Manastiri – N42.56379° E24.27392°. It was estimated by counting the number of active burrows at transects 100 m long and 5 m wide in summer (data from 2017 to 2021). The total number of transects was 91.

RESULTS

Temporal changes in habitat suitability

Only one Maxent model with Feature classes L, LQ, and Regularization multipliers 0.5 convinced the model choice criteria. It has a high degree of reliability – the average training AUC for the replicate runs was 0.986, and the standard deviation was 0.004. This result is particularly indicative, considering that the modelling was done solely within the open habitats, where no well-defined spatial contrast in the ground cover, resp. habitat suitability was expected. Both Band 5 and the distance to the water source have shown the strongest influence on habitat suitability (Table 1).

The relationships between habitat suitability and the values of the environmental variables are displayed in Figure 4. Response curves for bands 1–4 and 7 are of optimal type, while for band 5 the habitat suitability increases

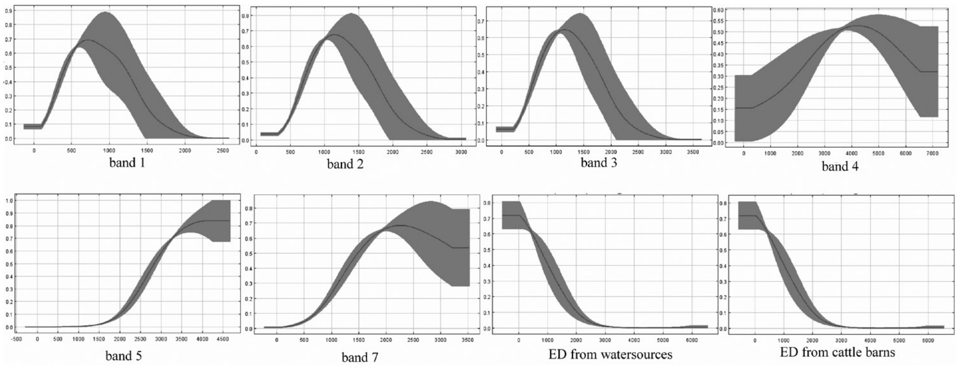

Fig. 4. Response curves, representing the dependence of predicted suitability both on the selected variable and on dependencies induced by correlations between the selected variable and other variables. ED – Euclidean distance [m]

with increasing surface reflectance. The comparison between the two periods indicates that during the first period, the habitat suitability is lower and more spatially restricted (Fig. 5).

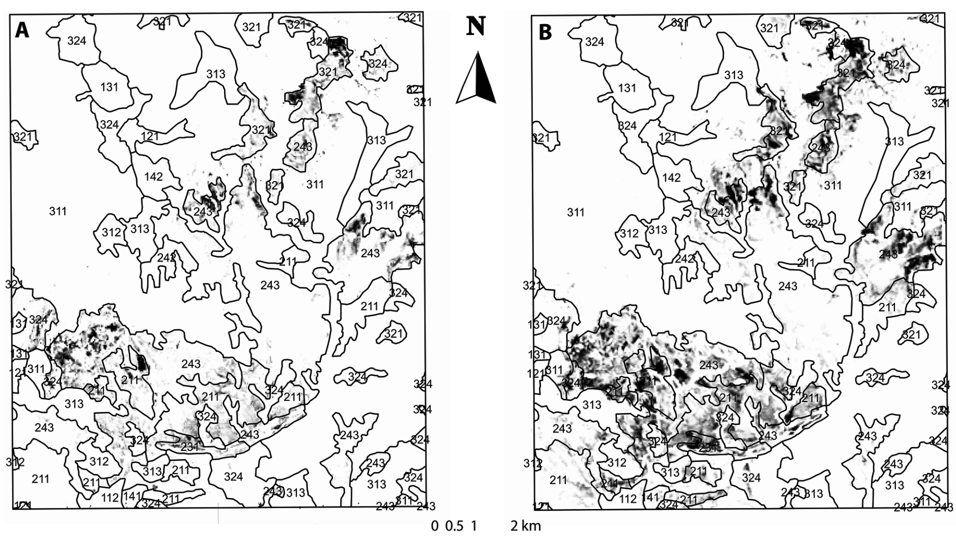

Fig. 5. Changes in the habitat suitability in the study area (white – not suitable, black – high suitability) of European souslik assessed by maxent modelling based on data from 2006–2018 (B) and extrapolated for the period 1985–2005 (A). The results are presented in the context of the types of land cover at the third level of Corine 2018: 112 = discontinuous urban fabric; 121 = industrial or commercial units; 131 = mineral extraction sites; 141 = green urban areas; 142 = sport and leisure facilities; 211 = non-irrigated arable land; 231 = pastures; 242 = complex cultivation patterns; 243 = agriculture with significant areas of natural vegetation; 311 = broad-leaved forest; 312 = coniferous forest; 313 = mixed forest; 321 = natural grasslands; 324 = transitional woodland-shrub

A more thorough analysis based on the polygons with the greatest habitat suitability above 0.5 shows that their number is much greater during the second period and with a larger average area (Table 2).

In most instances, the polygons showing high values (above 0.5) of habitat suitability during the first stage coincided with those from the second period or were in proximity to them. The differences between the two periods in these cases were expressed in the expansion of the area of the polygons with habitat suitability above 0.5. The inspection of the polygons on historical photographs of Google Earth indicated that more than 98% of the polygons with high habitat suitability were areas having a degraded grass cover.

The estimation of the relative abundance of the European souslik in the studied area shows that three of the colonies ("Luda Yana", "Panagyurski kolonii" and "Belotrup") are characterized by comparatively great abundance (Fig. 6). Moreover, the gathered data for colonies "Panagyurski kolonii" and "Belotrup" reveal a positive trend during a 3–4 years period. The habitat of the colony near the town of Panagyurishte (Luda Yana) was destroyed during the study because of the construction of the Luda Yana water supply reservoir. Before that (in July 2018) the sousliks were translocated to the periphery of the "Belotrup" colony (Zidarova *et al.* 2018). The resulting extinction of the colony near Panagyurishte is not the subject of the study, but our data show that the abundance in that colony has been quite high before the start of the construction works.

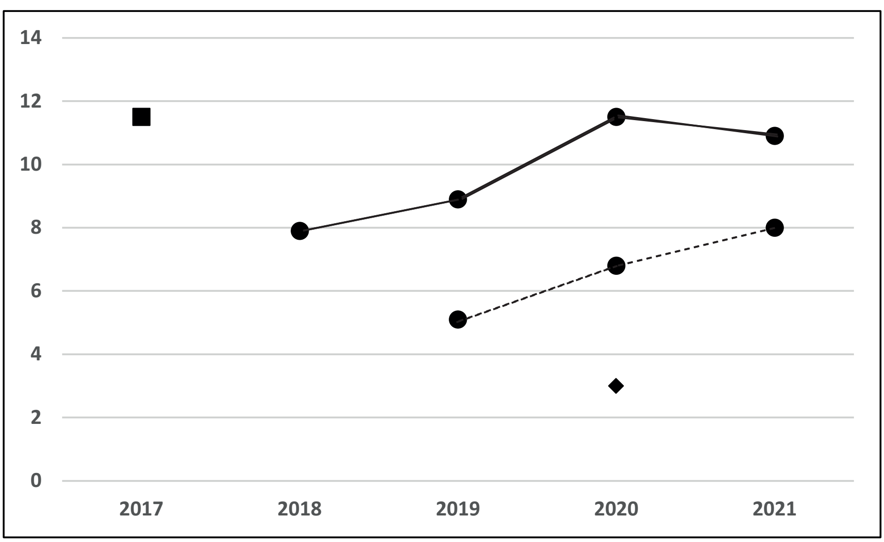

Fig. 6. Abundance (mean number of burrows/100 × 5 m transect) of *S. citellus* in 4 colonies in the study area in summer (for the period 2017–2021)
■ = Luda Yana; — ● — = Belotrup; ---- ● ---- = Panagyurski kolonii; ◆ = Beli Manastiri

DISCUSSION

Towards to interpret the modelling results, it is necessary to determine the extent to which the spectral information provided by the Landsat images reflects real changes in ground cover and the extent to which their adoption is valid from a statistical point of view. Downloaded scenes are a high-level product, meaning they are pre-treated in a way assuring that the brightness value of each pixel serves as the actual reflectances as if measured on the ground. This was carried out as the digital numbers were initially converted to the corresponding radiance values and next transformed into dimensionless surface reflectance values through the process of atmospheric correction (Young *et al.* 2017). Since the spectral data was collected in the same month, earth-sun distance and solar illumination angles were coherent between dates, and then radiometric differences between dates because of these variables were also diminished. Thus, it can be expected that the spectral information provided by the Landsat images mainly reflects tendencies in the land cover change during the research period (1985–2018). To test this assumption, within the individual channels, a comparison was performed between the satellites (Landsat 5 and Landsat 8) in terms of the average values for each band for the whole polygon. No statistically significant difference was found. Therefore, it can be said that the differences between satellite images are not related to the influence of technical factors but reflect changes over time in the characteristics of the Earth's surface, especially the state of vegetation.

The present modelling is based mainly on spectral reflectances as explanatory variables. These variables are strongly correlated, which is an issue with traditional statistical models. However, Elith *et al.* (2011) have indicated that high collinearity is hardly an obstacle for machine-learning methods such as Maxent. This is because of the ability of Maxent to penalize over parameterization, and, as a result, many of the predictors contributed to the algorithm may have reduced or no impact on the model (Warren *et al.* 2020). When predictive accuracy is the research objective, as in the present study, including all rational predictors in the model and letting the algorithm choose which ones are significant via regularization is a valid approach (Merow *et al.* 2013).

In the present study, spectral bands of one month were used. The question arises as to what extent this restricted period can comprehensively present the habitat status of the species. Satellite images from July have been considered representative in this respect since they conform to the peak activity of the target species (both adults and dispersing juveniles are active above ground) and reflect the state of the land cover in its maximal development. The latter circumstance is crucial because vegetation provides both a nutritional base for the species and is an essential component of its habitat.

The shapes of the habitat suitability curves for bands 1–4 are the optimal type, which shows that the habitat suitability increases to some extent with increasing brightness and then decreases (Fig. 4). Vegetation with high moisture content and active photosynthesis usually absorbs light in these ranges and correspondingly has a low reflection. Conversely, dry vegetation and bare soil surface have great reflectance. Thus, it can be stated that the model reveals the preference of the European souslik for microhabitats with moderately degraded grass vegetation. Moreover, the response curves related to the distance from the reservoir and the distance from cattle barns indicate that the suitability is higher in the vicinity of these objects, i.e. where the pasture is the most degraded due to the concentration of herds. These results agree with Ragyov *et al.* (2015), reporting a higher density of the souslik closer to the barns. In addition, our interpretation is confirmed by a more detailed analysis of the rasters of Band 5 between the two periods. This band was most important for modelling of the habitat suitability of European souslik in the studied landscape (Table 2). The comparison of the reflectance values of Band 5 between the two periods within polygons of the highest habitat suitability (above 0.5) demonstrates consistently greater values for the second period. As far as the intensity of the reflection in this band is inversely related to the degree of development of the grass vegetation, it can be suggested that the greater habitat suitability during the second period is due to the deterioration of the grass cover.

These changes are most likely related to the climatic differences between the two periods. Higher temperatures in the second stage are probably associated with more pronounced summer droughts, which affect the condition of the grass cover, recorded by higher reflectance values in the Band 5 range. This interpretation is in accordance with data presented by Koshev and Kocheva (2007) and Zaharia *et al.* (2016), which show that the warming and the accompanying drought during summer have a positive effect, as they cause degradation of the grass cover, thus bringing it closer to the optimal for the species.

The presented results demonstrate that the habitat suitability of the souslik in the study area has been increasing in recent times, probably due to the overall effect of climate change and the local effect of livestock breeding. The relative abundance and its tendency in "Panagyurski kolonii" and "Belotrup" colonies in recent years support this interpretation (Fig. 6). However, the pace of recovery of local populations in terms of their spatial expansion is far slower.

To some extent, the obtained results and their interpretation contradict the general tendency for deterioration of the conservation status of the species during the last decades. In particular, for the study area, some data indicate a reduction in the number and distribution of the European souslik (Koshev 2013). This trend corresponds to the decrease in the number of grazing animals resp. the reduced intensity of grazing. Thus, although open habitats exist, they become less suitable for the species due to the higher grassy vegetation (Kis *et al.* 1998). This effect is further enhanced by the introduction of regulations on the mandatory use of fences (electric shepherds) in leased state and municipal pastures, reducing livestock movement. As a result, significant areas remain inaccessible to grazing animals, leading to the aforementioned unfavourable vegetation changes for the souslik – the grass cover remains dense and high, thus compensating for its climate-induced degradation. On the other hand, this leads to the concentration of grazing animals in the unfenced areas, among which the pastures near drinking troughs and pens occupy a central place. This enhances the local effect of grazing animals, which is actually reflected in the modelling results.

The observed changes affect a specific part of the souslik's environmental niche, related to the conditions in the mountain and semi-mountain landscapes. In the climatic conditions of Bulgaria, in the absence of anthropogenic impact, these landscapes are not suitable for the souslik, as the climate is cooler and wetter, forests predominate, and the natural meadows are usually vegetated by tall grasses and herbs (Bondev 1991, Meshinev 2007). Historically, anthropogenic changes in these landscapes included deforestation and the conversion of cleared areas into pastures. The mountain pastures are traditionally grazed during the summer, when the lowland pastures are not productive enough due to summer droughts (Pedashenko *et al.* 2015). These landscape changes have created conditions for the spread of the souslik in the mountains.

Rising temperatures in recent decades have led to a further increase in the suitability of grassland habitats for the souslik, as the results of the present study show. However, global warming and associated environmental changes are predicted to become more pronounced in the near decades. The temperate mountains of the northern hemisphere are expected to experience two to three times the rate of warming recorded in the 20th century (Nogues-Bravo e*t al.* 2007). In addition, projected hot spells and decreasing rainfall will intensify the summer droughts (Beniston *et al*. 1997, 2007, Parry 2000). It can be expected that the conditions in the mountains will become increasingly unfavourable for the souslik. They will approach the current ones in the lower parts of the country and in the southernmost parts of the souslik's range, where population decline is already an ongoing process, largely related to global warming (Rammou *et al.* 2022). This can also be predicted based on the bell-shaped response curves (Fig. 4) on some of the parameters related to the quality of the grassy vegetation, indicating that shifting the condition of the vegetation away from the currently registered optimums will decrease the suitability of the souslik's habitats.

Currently, souslik's distribution is restricted in the study area due to the habitat deterioration caused mainly by the reduction of grazing in previous periods. Nevertheless, there are still two colonies that are characterized by high abundance and show a positive trend ("Belotrup" and "Panagyurski kolonii"). With a growing population of the souslik in the area and increasing the suitability of its former habitats, the recolonization of these habitats would be possible, but the process will be slow and arduous due to the comparatively low dispersal ability of the species and its low breeding potential (one litter a year). In addition to proper pasture management, reintroduction steps could be taken to support this process.

In general, our investigation revealed that satellite images and species distribution modelling are applicable for tracking the trends in the habitat of European souslik at the landscape level. The population dynamics in the habitat suitability of the species is the result of the influence of more or less global factors (climate change, socio-economic transformations, etc.), as well as local ones (construction works, local developments in agricultural practices, number of livestock, land use, etc.). This approach could be applicable to future conservation planning. It would be helpful in assessing the suitability of particular habitats, thus supporting the right choice of optimal sites for relocations and translocations of the European souslik.

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