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Distribution of Hermann's tortoise across Serbia with implications for conservation

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Abstract: Hermann's tortoise (*Testudo hermanni*) is among the conservation priorities in the European Union. Consequently, it is included in Annexes II and IV of the EU Habitats Directive, Annex II of the Bern Convention, and Annex II of the CITES Convention. Hermann's tortoise conservation programs compile insights on the threats affecting population viability, along with factors shaping the species' distribution. Serbian populations of the eastern subspecies (*Testudo hermanni boettgeri*) seem numerous and therefore prosperous, but recent population viability analyses revealed that they are susceptible to rapid demographic changes and/or habitat destruction. This implies the need for effective population monitoring and protection, as well as mapping and preservation of suitable habitats. In this paper we summarized current knowledge about the geographic distribution of Hermann's tortoise in Serbia and modeled its ecological niche. Our results corroborate and uphold the known species' distribution in Serbia. Most suitable habitats are situated in the lowland areas of eastern, central and southern Serbia, under semi-open habitats, such as pastures and shrubs, broadleaf forests, and all successional stages in between. The results provided in this paper should be considered in the selection and shaping of NATURA 2000 sites in Serbia.

Keywords: *Testudo hermanni boettgeri*; ecological niche model; species distribution model; conservation; Serbia

INTRODUCTION

Among the major vertebrate groups, Chelonians are considered to be the second most threatened by extinction (after Primates), with 56.2% of all species already categorized as Vulnerable, Endangered or Critically Endangered according to the IUCN criteria [1]. Life-history characteristics, such as slow sexual maturation and low dispersal capacity, make tortoises especially fragile to habitat destruction and demographic catastrophes [2,3]. It was suggested that even a single intensive disturbance could critically reduce their population sizes, or even drive local populations to extinction [4,5].

Hermann's tortoise (*Testudo hermanni*) is a species with high public profile, recognized as a flagship taxon [6]. It is listed as Near Threatened according to the IUCN Red List [7], with habitat loss and illegal collecting of individuals from the wild identified as the main negative factors. The urgency to protect Hermann's tortoise populations and their habitats have led to its inclusion within the EU Habitats Directive (Annexes II and IV) and in the Bern Convention (Annex II). Populations of the western subspecies (*T. h. hermanni*) are scattered, mutually isolated and declining, while the population status of the eastern subspecies (*T. h. boettgeri*) appears to be better, with

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more numerous populations [8,9]. However, recent studies have shown that even numerous populations on the Balkan Peninsula might become vulnerable due to rapid changes in demography and/or habitat destruction [3,10].

Serbian populations of Hermann's tortoise, as well as Balkan populations in general, were heavily exploited during the last century [11], with devastating effects on the harvested populations. The species is now protected in Serbia (Official Gazette of the Republic of Serbia Nos. 5/2010 and 47/2011) and is assessed as Near Threatened on a national level [12]. Wild-caught tortoise trade and harvest are formally regulated nationally, by the Ordinance on the control of use and trade in wild flora and fauna (Official Gazette of the Republic of Serbia Nos. 31/2005 45/2005 22/2007 38/2008 and 09/2010), and internationally, by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES: Annex II). Nonetheless, illegal tortoise collection continues, although on a smaller scale [3].

Effective conservation programs for the protection of Hermann's tortoises should take into account threats affecting population viability and factors shaping the species' distribution [13]. In addition to the results on the effects of disturbances on *T. h. boettgeri* population viability published by Nikolić et al [3], here we will provide data on its ecological niche and therefore the natural factors that determine its geographical distribution. We summarized current knowledge on the distribution of Hermann's tortoises in Serbia and developed an ecological niche model for the species. The model serves to suggest the factors affecting the species' ecological niche and to create a prediction map of its distribution in Serbia. This is of special importance, not only to guide further field surveys but also to help designate national ecological networks and the upcoming NATURA 2000.

MATERIALS AND METHODS

Ethics Statement

Data collection did not involve the handling of animals, and is in accordance with ethical laws in the Republic of Serbia.

Species distribution map

A distribution map is produced to summarize the known Hermann's tortoise records in the Republic of Serbia. In order to be consistent with previous publications, the map is compiled of 10×10 km squares labeled using MGRS (Military Grid Reference System) notation, which is based on UTM (Universal Transverse Mercator) map projection. The known localities were recently summarized in the Red Book of Fauna of Serbia II – Reptiles [12] with some additions from Tomović et al. [14]. In this paper we included 416 new and reconfirmed observations, compiling the authors' data (332) and other free licensed data (84) saved in the Biologer online database [15]. The final map was compiled in QGIS v. 3.6.0 (http://qgis.osgeo.org).

Ecological niche model

Maxent v. 3.4.1 was used to model the ecological niche of Hermann's tortoise [16,17]. The model was fitted using the default options of the dismo package in R v. 3.5.3 (https://www.R-project.org). Environmental parameters were extracted from a set of freely available GIS layers: Bioclim 2 [18], Digital Elevation [19], Land Cover [20] and Vegetation Continuous Fields [21]. All layers were reprojected and scaled to a resolution of 25 m. Variables for Slope, Northness and Eastness were derived from digital elevation data using the raster package in R. To remove multicollinearity between climatic variables and altitude, we used the variance inflation factor (VIF) scores from the regclass package in R. A single variable was removed from the analysis in each cycle until the VIF score reached values below 10. The final list of 14 variables is given in Table 1. To present the most important variables affecting the species' ecological niche, we showed each variable's contribution (%) and the results of the jackknife analysis. The jackknife or "leave one out" procedure rebuilds the model multiple times, using different combinations of variables, and compares fitted models. Maxent's procedure shows model gain if a certain variable is excluded from the model and if a model is created using a single variable only. The univariate response curves of the most important variables were explored to see how each variable influences the species' ecological niche.

All but the closed licensed observations of Hermann's tortoise were gathered from the online Biol-

Table 1. The list of variables used to model the ecological niche of Hermann's tortoise. A short description of each variable is given with its derivation where required.

Variable name	Variable description
Altitude	Digital Elevation Model that accounts for altitude above sea level with spatial precision of 25 m over Europe.
Slope	This variable is derived from the altitude and gives the steepness of the terrain in degrees.
Northness	Aspect variable in radians is first derived from altitude, then Aspect was cosine transformed to Northness, ranging from -1 (due south) to 1 (due north).
Eastness	Aspect variable in radians is first derived from altitude. Then Aspect was sine-transformed to Eastness, ranging from -1 (due west) to 1 (due east).
Annual Mean Temperature	Bioclim variable showing yearly averaged temperature with resolution of about 1 km.
Mean Temperature of Wettest Quarter	Bioclim variable showing averaged temperature in the wettest quarter of the year with resolution of about 1 km.
Mean Temperature of Driest Quarter	Bioclim variable showing averaged temperature in the driest quarter of the year with resolution of about 1 km.
Isothermality	Bioclim variable that quantifies how large the day-to-night temperature oscillations are relative to the summer-to-winter (annual) oscillations with a resolution of about 1 km.
Temperature Seasonality	The amount of temperature variation over the years based on the standard deviation of monthly temperature averages with a resolution of about 1 km.
Annual Precipitation	Bioclim variable showing the yearly sum of precipitation with a resolution of about 1 km.
Precipitation of Warmest Quarter	Bioclim variable showing total precipitation in the warmest quarter of the year with a resolution of about 1 km.
Precipitation Seasonality	Bioclim variable representing variation in monthly precipitation totals over the course of the year (index of variation). It is expressed as the percentage with a resolution of about 1 km.
Vegetation Continuous Fields	The tree-cover percentage taken from the year 2015 in the spatial resolution of 30 m.
Land Cover	Categorical variable showing CORINE Land Cover classes over Europe in resolution of 100 m.

oger database – 416 observation records. However, to completely cover the species' ecological niche, we also used the authors' unpublished personal observations from Mediterranean countries, the Republic of North Macedonia (39 observations by D. A.) and Montenegro (33 observations by S. G. and V. I.).

The occurrence records were preprocessed before any further analyses. In the first step, we removed coordinates with precision lower than 25 m, coordinates without precision data and duplicate observations. Since Hermann's tortoise is commonly introduced as a pet animal, we also removed occurrences outside its natural range (i.e. from the Province of Vojvodina) and several observations from urban areas (such as home gardens or city centers). Furthermore, both live and dead tortoises are regularly recorded along the roads. To remove the road effect, we inspected all the data and removed the observations along roads if there were additional nearby records within the natural habitat. If no neighboring (several kilometers) records were found in the area, we moved the coordinate to the closest natural habitat within a 50-m radius of the original observation. Since the "Land Cover" variable had a coarse resolution, several records appeared in inland waters and had to be removed from the analysis. Finally, to account for spatial autocorrelation between the observation records, we used the spThin package in R and selected only a single random occurrence record within a distance of 5 km. This resulted in 124 occurrence records to be used for model fitting.

The Maxent model was fitted using the localities where tortoises were recorded (occurrence points) and a set of 10000 random points sampled in a 50-km radius from the known occurrences (background points). Despite some of the criticism, we used the AUC score to test the model performance [22]. AUC (area under the receiver operating characteristic curve) is a measure of model performance that ranks true and false positives. A value of 0.5 suggests that the model does not describe reality better than the random model, while a value of 1 suggests that the model is a perfect representation of reality. Besides train data (occurrence points used to fit the model), we tried to compile independent test data from species occurrences that were not used in model fitting. This test dataset was preprocessed in the same way as train data, resulting in 60 test occurrences.

RESULTS

Distribution of Hermann's tortoise in Serbia

Hermann's tortoises were previously recorded in 172 10 × 10 km UTM squares in Serbia [12,14]. The data used in this paper confirmed the presence of tortoises at 69 of these UTM fields and presented 32 UTM squares where Hermann's tortoises were not previously noted (Fig. 1). Only one of these novel data, near Vrbas in Vojvodina, is beyond the previously known distribution range and is probably the record of an abandoned pet. Therefore, we confirmed that the rivers Danube and Sava delineate the northern boundary of the natural distribution of this species in Serbia.

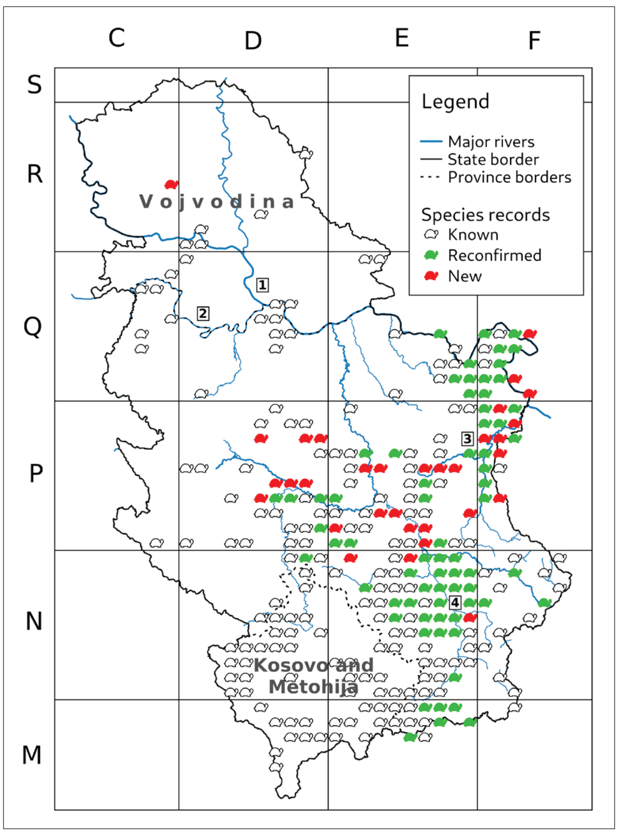


Fig. 1. Map of the observed distribution. Records of Hermann's tortoises in Serbia shown on an MGRS UTM map, Zone 34N. Letters represent large UTM squares (100×100 km). River systems are given by numbers: 1 – Danube, 2 – Sava, 3 – Timok, 4 – Južna Morava and Toplica. 172 UTM fields (10×10 km) with published (known) data are shown along 101 squares with our recent observations (32 new and 69 reconfirmed UTM fields).

Ecological niche model

The AUC value for the ecological niche model was 0.89 for train data and 0.86 for test data, which suggest good model performance and allowed us to use this model and make species ecological niche inferences. The variable "Altitude" was the most important when explaining the ecological niche (Figs. 2, 3): negative correlation was exhibited between species presence and altitude (Fig. 4). Among other variables, "Land Cover", "Precipitation Seasonality", "Mean Annual Temperature", "Vegetation Continuous Fields" and "Northness" could be considered as important factors affecting the ecological niche of the species (Figs. 2 and 3). Among natural habitats, transitional areas from scrubland to broadleaved forest areas were preferred (Fig. 4). "Land Cover" showed that tortoises regularly occupy habitats in urban and agricultural areas (such as construction sites and parks, vineyards, orchards, pastures and other less intensive agricultural

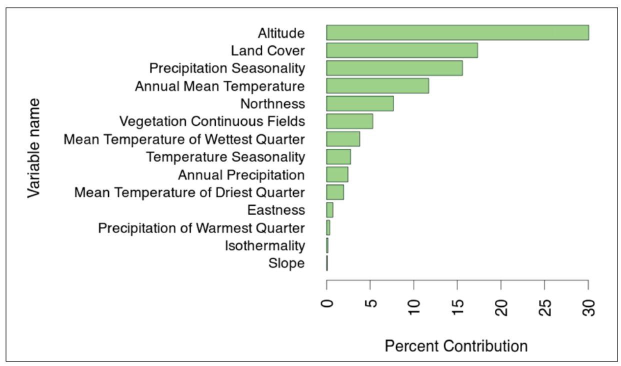


Fig. 2. The contribution of each variable in model fitting given as percentage.

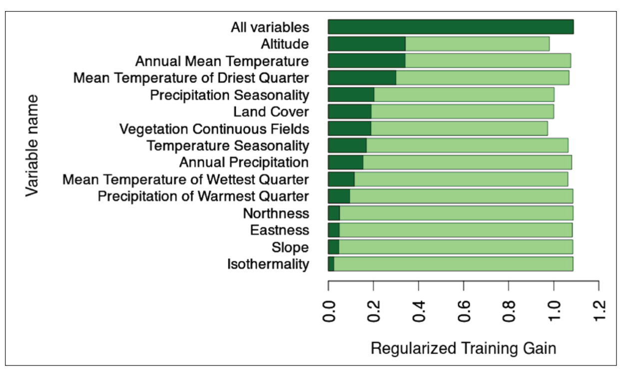
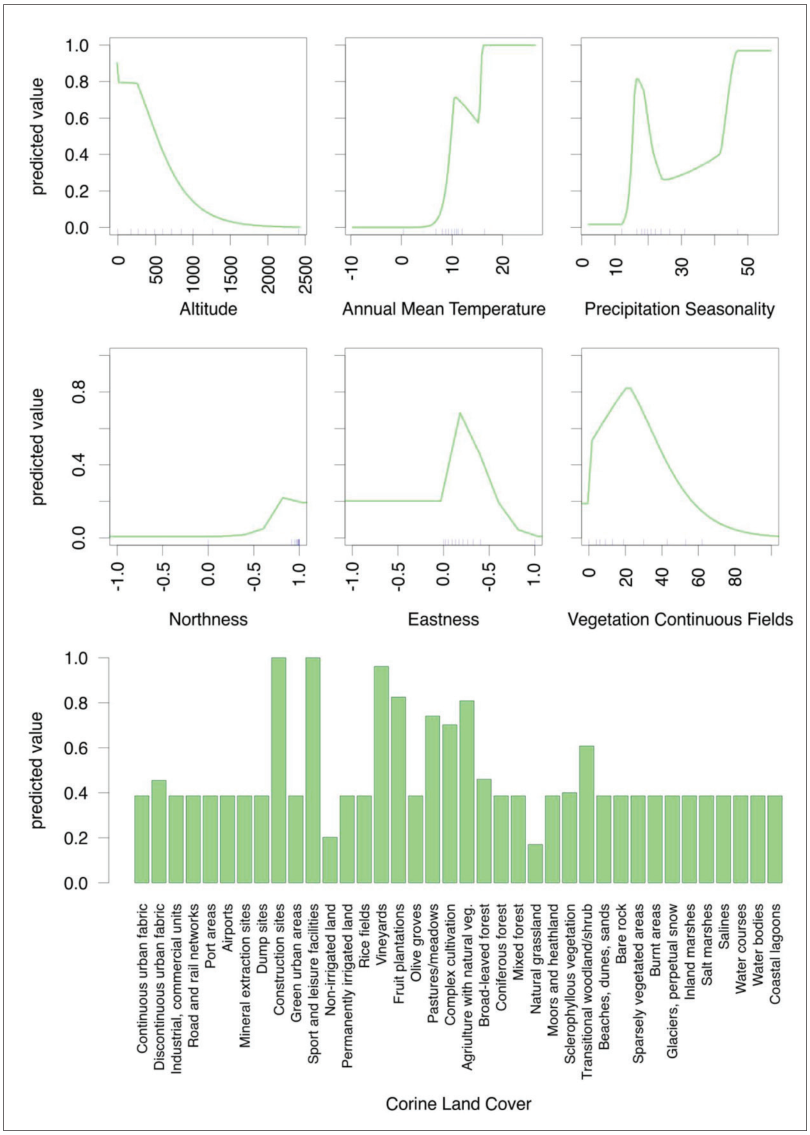


Fig. 3. Jackknife test of variable importance in modeling the ecological niche of Hermann's tortoise. A variable contains more useful information if it achieves higher gain when used alone and if it lowers the gain when excluded.



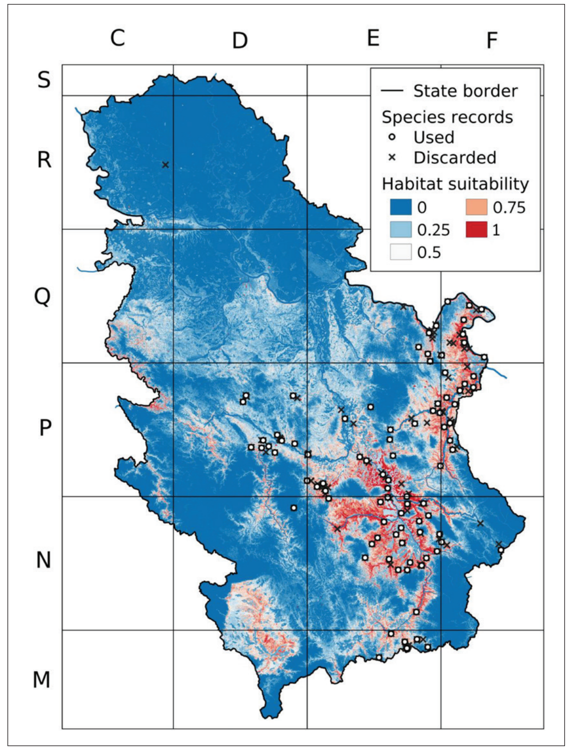


Fig. 4. Response curves of the seven most important variables affecting the ecological niche model of Hermann's tortoise.

Fig. 5. Predicted distribution map. Maxent model of the realized ecological niche of Hermann's tortoise in Serbia shown as a prediction map in geographical space. Letters represent large UTM squares (100×100 km). The tortoise records from Serbia are displayed differently if they are used to fit the model or are discarded from the analysis.

areas). The "Vegetation Continuous Fields" variable also suggested that tortoises mainly occupy more open areas and avoid very dense forest cover and bare land (Fig. 4). Tortoises also demonstrate a clear preference for higher annual temperature values and a prominent positive effect of precipitation seasonality, although the response curves were abrupt (Fig. 4). The species is more likely to be present on the northern and eastern slopes (Fig. 4), although this effect was always weak (Fig. 3).

The predicted distribution (Fig. 5) matched well the observed distribution of Hermann's tortoise (Fig. 1). This was also true for the southeastern parts of the country that lack data from recent field surveys. The most suitable habitats are found in the lowland areas of eastern, central and southern Serbia. Northern parts of Serbia, as well as some areas in the western part of the country are less hospitable for Hermann's tortoise (Fig. 5), and a handful of records are considered as individual introduction events. A GeoTIFF file with predicted habitat suitability is provided as Supplementary material.

DISCUSSION

Our results corroborate and uphold previous findings on the distribution of Hermann's tortoise in Serbia

[12,23]. The distribution predicted by the ecological niche model is in accordance with the observed distribution, without any larger discrepancies. Although the distribution of Hermann's tortoise in Serbia seems to be well described, the model suggests that additional field work might uncover some new localities occupied by the species. The gaps in the observed distribution could be filled with the aid of a model to specifically target additional field investigations. This is especially true for the central part of the Kosovo and Metohija province, and for the Šumadija and central Serbian regions where the modeled distribution map predicts suitable habitats, while field records are less numerous. We would also like to highlight the importance of citizen science, which is repeatedly confirmed as a significant source of information about species distribution [24,25]. In Serbia, citizen science is still neglected and unexploited, and this work could be considered as one of the pioneering studies to promote such an approach using data from the newly developed Biologer platform.

In Serbia, *T. h. boettgeri* is at its northern distribution edge on the banks of the Danube River [12,23]. Only a few isolated and reduced populations are found north of this river, at the Iron Gate National Park in Romania [8,26]. It should be noted that populations of wild species found on the edges of their distribution ranges usually exhibit some differences compared to core populations and could be of special conservation interest [27]. Besides the fact that the River Danube represents a physical obstacle to the further expansion of tortoises, our model shows that Vojvodina (a Serbian province north of the Danube and Sava rivers) does not provide suitable habitats for the species (Fig. 5). Vojvodina underwent considerable habitat changes during the last 300 years as a result of chemical and mechanical treatments, drainage and irrigation, which made it suitable for intensive agriculture. As a result, two million hectares (i.e. 92% of its territory) is now used for agriculture [28] and wildlife is cornered into isolated, small patches of semi-natural habitats [29]. Despite the lack of suitable habitats, some isolated observations of Hermann's tortoises were collected from Vojvodina. In addition, occasional sightings of Hermann's tortoises in western and northern parts of the country are referred to as introduced individuals, outside of the species' natural range [12]. On the other hand, the most suitable habitats for Hermann's tortoises are found in the lowland areas of eastern, central and southern Serbia. In eastern Serbia, the most suitable habitats lie in a wide region along the Timok river and its tributaries and further north up to the Danube throughout the Ključ region. In central and southern parts of Serbia, the most suitable habitats are also found in lowlands around the rivers Južna Morava and Toplica, as well as in parts of the Kosovo province.

The realized ecological niche model corresponds well with the observed distribution of the Hermann's tortoise. The model suggests that the natural habitats of Hermann's tortoises are characterized by lower altitude slopes under semi-open areas, such as shrubs, broadleaf forests and pastures. These findings are in accordance with previous descriptions of the species' habitat preferences [8,25,30,31]. It was suggested that populations of Hermann's tortoises mainly inhabit bright thermophilic oak forests (e.g. *Quercus frainetto* and *Ostryo-Carpinion orientalis*) and their degradation stages [23]. In contrast to a previous modeling study that showed the negative effect of urbanization, arable land and vineyards [31], our model suggests that tortoises avoid only areas under intensive agricultural practice, while they preferentially occupy extensive agricultural areas, such as pastures, vineyards and orchards. They probably benefit from the loose soil and controlled grass height in orchards, which are suitable for basking and nesting, while they use fallen fruits as an additional food source [8]. Our model also suggests that even urban areas, such as parks, leisure fields and construction sites are suitable habitats for tortoises. In eastern Europe, it is easy to imagine that tortoises sporadically shift from deteriorating natural habitats to anthropogenic areas with less intensive agricultural areas and that some urban spaces still provide acceptable habitats for their survival. But this effect is shown to be opposite in areas of intensive agriculture and urbanization, showing a negative trend as in western Europe [31]. Contrary to our expectations that Mediterranean species prefer southeastern hill slopes at these latitudes, Hermann's tortoise showed preferences for northern aspects. However, the overall effect of the aspect was not very prominent. It should be mentioned that frequent wildfires pose a strong negative impact on the presence and abundance of Hermann's tortoise across the Mediterranean [8,9,31]. This effect should be less intense in areas with a continental climate, such as Serbia, although some small areas inhabited with tortoises have been under occasional fire in the last decades (authors' personal observations).

Populations of Hermann's tortoises in Serbia are apparently numerous and in a good state. Population viability analyses have shown that these populations could remain stable until they are faced with large-scale threats and disturbances, but when disturbances are added (e.g. harvesting of individuals), simulations indicate that populations might drastically decline within a decade [3]. One of the crucial steps towards an effective conservation of Hermann's tortoise populations lies in the preservation of their remaining habitats and of mosaic structures in landscapes [13,26]. Here we point out the areas that could represent sanctuaries for tortoise populations and preferred habitats that should be conserved in order to preserve this species. In addition to natural habitats used by the tortoises, considerable attention should be paid to the semi-natural, successional, agricultural and urban areas that are favored by this species. The realized ecological niche model of Hermann's tortoise is included as Supplementary Fig. S1. These data are easily accessible in widely used software packages and should be considered during the selection of NATURA 2000 sites in Serbia.

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Supplementary Data

Supplementary Material. GeoTIFF raster file of the realized ecological niche of the Hermann's tortoise in Serbia, modeled using the Maxent algorithm. In order to create a small file size the values were multiplied by 100 and saved using JPEG compression.

Available at: http://serbiosoc.org.rs/NewUploads/Uploads/4163-18343-1-SP.zip