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Distribution of the European green lizard, *Lacerta viridis* (Squamata: Lacertidae), in the Czech Republic: Real data and a predictive model

Jan Chmelař[1)], Petr Civiš[2)], David Fischer[3)], Daniel Frynta[1)], Lenka Jeřábková[4)] & Ivan Rehák[5,6)]

[1)] Department of Zoology, Faculty of Science, Charles University, Viničná 7, CZ–128 44 Prague 2, Czech Republic
[2)] Department of Ecology, Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Kamýcká 129, CZ–165 21 Praha 6, Czech Republic
[3)] Mining Museum Příbram, Hynka Kličky 293, CZ–261 01 Příbram, Czech Republic
[4)] Nature Conservation Agency of the Czech Republic, Kaplanova 1931/1, CZ–148 00 Praha 11 – Chodov, Czech Republic
[5)] Prague Zoo, U Trojského zámku 3/120, CZ–171 00 Praha 7, Czech Republic
[6)] corresponding author: rehak@zoopraha.cz

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Abstract. The European green lizard, *Lacerta viridis* (Laurenti, 1768), is listed in the Czech Republic as critically endangered. Its distribution in the Bohemia region is restricted to small isolated local populations which are located beyond the northern border of continuous range of this species and are closely related to very specific habitats. Populations in southern Moravia form the northwestern boundary of the continuous distribution of the species. Based on the statewide database of the Czech Nature Conservation Agency, we created a predictive model and determined key factors influencing the species distribution in the Czech Republic. The most relevant factors were: annual precipitation, terrain slope, average temperature of the warmest quarter and precipitation in the coldest quarter. The model is well compatible with published data on *Lacerta viridis* distribution in the Czech Republic and is applicable in both theory and practice of the species conservation – e.g. focusing faunistic research to certain areas, critical analysis of controversial presence reports and as an input for species management in the form of repatriation and introduction.

Key words. Distribution, predictive model, species management, conservation, monitoring, river phenomenon.

INTRODUCTION

In ecology, predictive models are becoming increasingly popular as a tool for complex distribution analysis and identification of key climatic and geographical factors (Elith et al. 2006, Civiš 2013). As the number of studies increases, the focus is not only on the distribution of plants, but is expanding to animals, including reptiles (Kaliontzopoulou et al. 2008, Sillero & Carretero 2013, Oraie et al. 2014, Hosseinian Yousefkhani et al. 2015, Wirga & Majtyka 2015), even in a relation to climate change (Dubey et al. 2013).

In the Czech Republic, the European green lizard *Lacerta viridis* (Laurenti, 1768) is generally rare and declining, as a result of habitat degradation (Baruš et al. 1989, Rehák 1996, 2015, 2017, Mikátová & Nečas 1997, Moravec 2015). According to legislative regulations in the Czech Republic, the European green lizard remains listed among the critically endangered species even though the current Red list for the Czech Republic decreased the category to endangered (Jeřábková et al. 2017). The reason for this change is a generally better state of populations in southern Moravia (in contrast to populations in Bohemia).

Although the oldest (Lower Miocene) central European fossil remnants of a lizard closely related to *Lacerta viridis* have been described from Dolnice in the Cheb District (Čerňanský 2010), the recent distribution of European green lizard in the Czech Republic is the result of post-glacial expansion of the species from south-glacial refuges (Baruš et al. 1992, Godinho et al. 2005, Böhme et al. 2006, Rehák 2015). All Czech populations belong to the nominotypical subspecies. In Bohemia, the European green lizard distribution is isolated from the continuous range of the species (Nettmann & Rykena 1984, Gasc et al. 1997, Crnobrnja-Isailović 2009, Moravec 2015, Rehák 2015).

Molecular data confirmed genetic affinities of the Bohemian populations to those in neighboring parts of *Lacerta viridis* distribution in NE Germany (Elbe River) and Moravia (Böhme et al. 2006, Böhme & Moravec 2011). Moreover, individual relic Bohemian populations are also more or less isolated from each other and genetically slightly distinct (Böhme et al. 2006, 2007, Böhme & Moravec 2011). These populations are ecologically notable as inhabitants of biotopes retaining ancient characteristics and they can differ significantly in autecology parameters (Fischer & Rehák 2010, Blažek 2013, Chmelař 2014, Rehák 2015, Fischer et al. 2016).

Since 2007, Czech Nature Conservation Agency has been monitoring presence of the European green lizard in order to get the most up-to-date and comprehensive picture of the species distribution. While certain places of occurrence have traditionally been well known in the long term since 1851 (Štěpánek 1949, Moravec 2015), no published data are available in other areas of the Czech Republic, where natural conditions do not exclude the presence of *Lacerta viridis*.

The focus of recent paper is to review yet unpublished Nature Conservation Agency faunistic reports, to analyze available distribution records, to identify the key factors affecting the distribution of European green lizards and to create a predictive model of the European green lizard distribution in the Czech Republic. We intend to help to prioritize the monitoring effort (to focus on places where the predicted probability of presence is high, but no real presence has been recorded). At the same time – by comparing the predictive model with the known distribution of the European green lizard in the Czech Republic (based on critically evaluated published and our own data) – to evaluate the usefulness of creating predictive distribution models for the theory and practice of conservation and species management in particular.

MATERIAL AND METHODS

As a source of the European green lizard presence sites was used a statewide database maintained by the Nature Conservation Agency of the Czech Republic. The database contained 1,333 records from the whole territory of the Czech Republic collected within the period from 1932 to 2014, with only 103 records being older than 1980.

The Predictive Distribution Model was created using MaxEnt software, version 3.3.3k, the output being a GIS document in .asc format. This software was specifically chosen to work well with presence-only data (Elith et al. 2006, Hernandez et al. 2006). As the European green lizard presence prediction value, the "Logistic threshold" was defined, i.e. the optimization between the sensitivity of the model and the location of all real places of presence in the predicted areas.

For modeling purposes, a total of 74 layers were created for the Czech Republic: the lowest, highest and average temperatures for individual months (36 layers in total), precipitation in individual months (12), bioclimatic variables according to worldclim.org methodology – see Appendix (19), altitude, surface exposure, human footprint, slope, road network, water bodies, watercourses (Civiš 2013).

For modeling via the Maxent interface, WorldClim Worldwide database is standardly used as the source of climate variables. This database, however, uses only data from two meteorological stations for the Czech Republic (Hijmans et al. 2005), which is why it was inappropriate for our research, and we have created layers for the bioclimatic variables manually.

All layers were created in ArcGis 9.3 (ESRI 2008) in the 2D coordinate system S-JTSK Krovak East-North. The layers of climate variables were created based on the Climate Atlas of Czechia (Tolasz et al. 2007), which includes data from 1961 to 2000.

RESULTS AND DISCUSSION

The predictive strength of the model is very high (AUC=0.958). Only 4.2% of the actual real presence points were located below the predicted occurrence threshold, including several remote presence points from areas where the European green lizard occurrence is unlikely – for example area near Krnov and Mladá Boleslav. These are points that the national database has taken over from sources labeled as controversial. The number of these points is negligible and we consider it a tax for a large data sample from a wide spectrum of informants. Since the database is only open for authorized zoologists, included records are reliable and the size of the input data set contributes to prediction strength (Hernandez et al. 2006, Merow et al. 2013). The "logistic threshold" prediction, when the sensitivity of the model is equal to its specificity, was 0.208. Therefore, any higher value means that the model predicts the European green lizard presence, see Fig. 1. The most important contributors to the resulting model were: BIO 12 – annual precipitation (explaining 29.9% variability), slope – terrain slope (12.9%), BIO 10 – Average temperature of the warmest quarter (10.5%) and BIO 19 – precipitation in the coldest quarter (9.2%). Graphs of these variables are shown in Figs. 2–5.

According to the model, the probability of presence of the European green lizards is highest in the range of annual precipitation between 500–550 mm (Fig. 2). The probability also grows with increasing inclination of the terrain up to 20–25° (Fig. 3). It is almost constant at the average temperatures of the warmest quarter 10–18 °C, the highest for temperatures of 19–20 °C and above 20 °C sharply drops below the threshold of prediction (Fig. 4). According to the precipitation in the coldest quarter, the probability is highest if it exceeds 150 mm (Fig. 5).

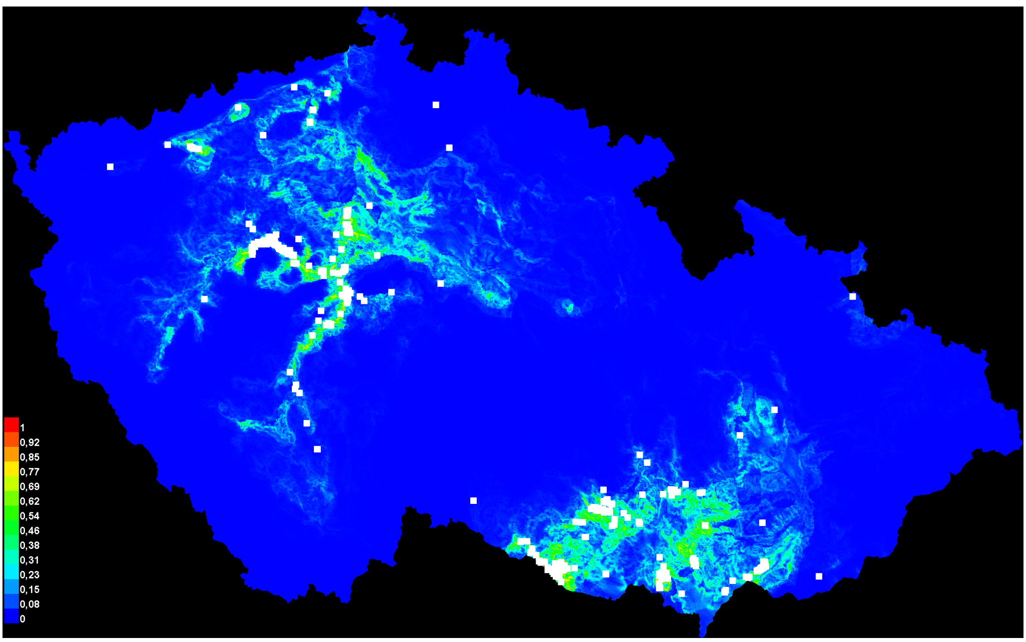

Fig. 1. Predicted distribution of the European green lizard, *Lacerta viridis* (Laurenti, 1768) in the Czech Republic – white points represent recorded presences from the national database.

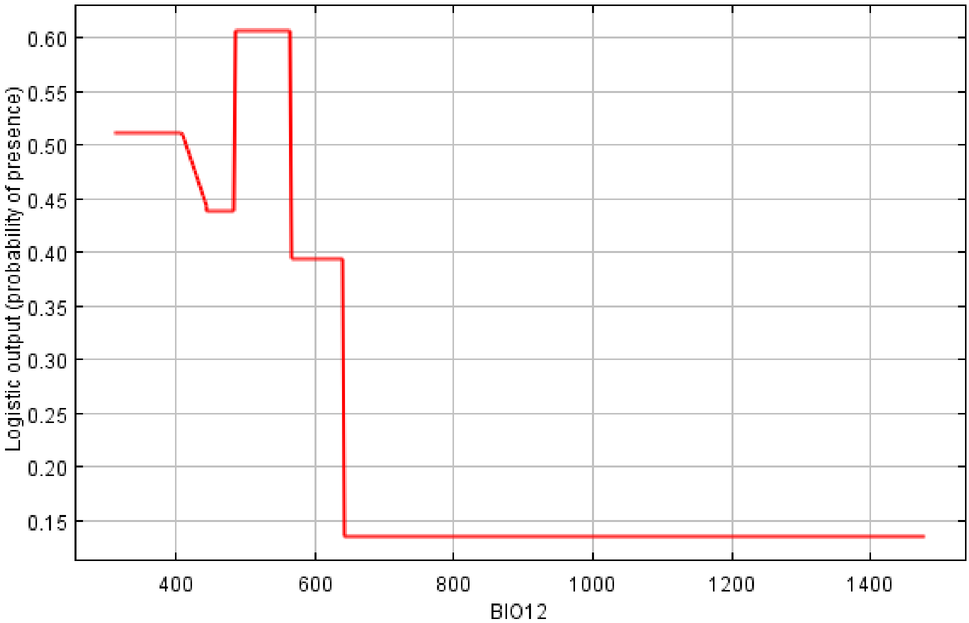

Fig. 2. Response curve of the annual precipitation variable (mm).

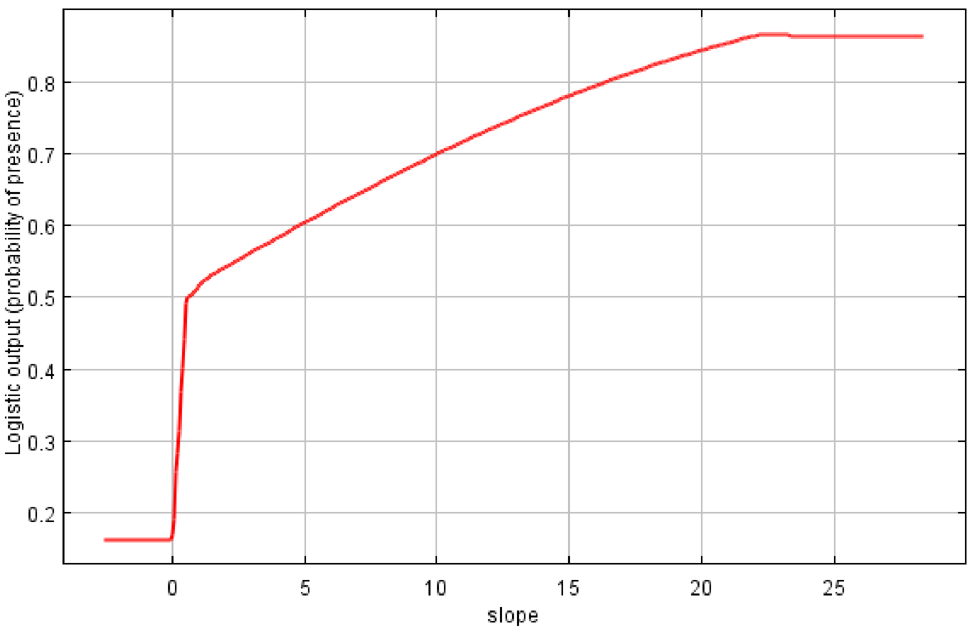

Fig. 3. Response curve of the slope inclination variable (°).

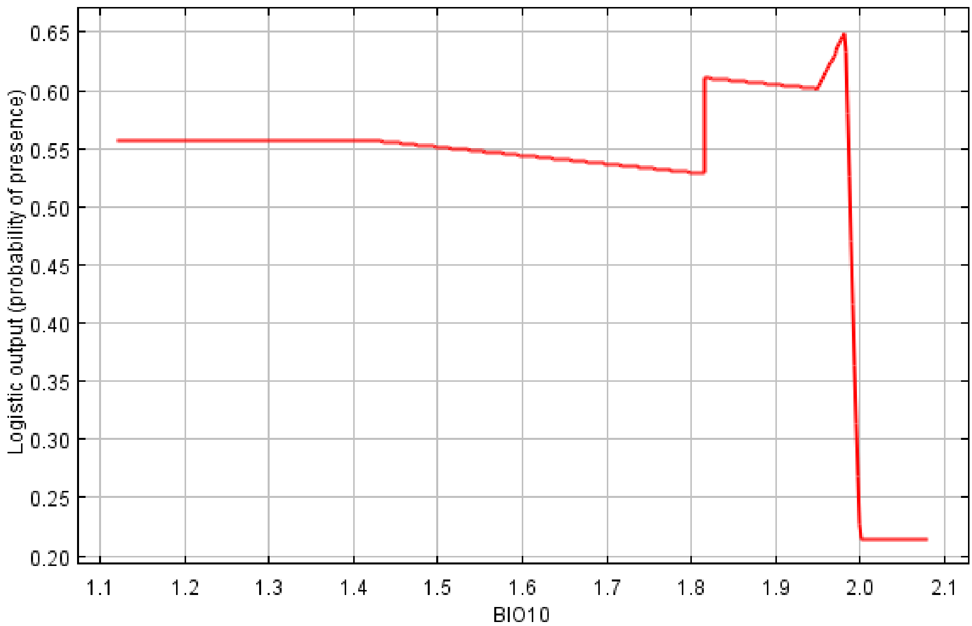

Fig. 4. Response curve of the mean temperature of warmest quarter variable (°C / 10).

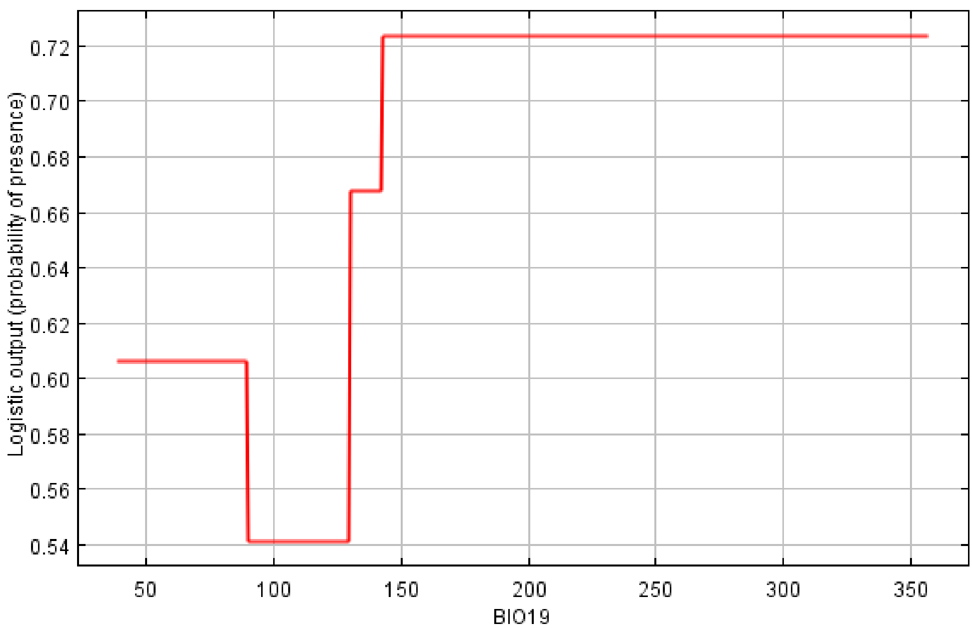

Fig. 5. Response curve of precipitation in coldest quarter variable (mm).

The annual precipitation variable is an expected result, given that the green lizards are located mostly in warm and dry habitats in Central Europe. The precipitation range 500–550 mm per year corresponds to the avoidance of excessively humid locations (Mikátová 2001, 2002, Fischer & Rehák 2010, Moravec 2015).

The increasing probability of presence with increasing slope inclination corresponds to the theory of *Lacerta viridis* distribution being linked to so-called river phenomenon (Jeník & Slavíková 1964, Vannote et al. 1980, Ložek 1988, Strödicke 1995, Ward 1998, Mikátová 2001). This theory indicates that thermophilous organisms can be found behind the northern boundary of their continuous area in the deeply cut river valleys on the slopes with southern exposition. For the European green lizard distribution in Bohemia, the link to the river phenomenon was well documented (Ložek 1988, Mikátová et al. 2001, Mikátová 2002, Fischer & Rehák 2010, Moravec 2015, Rehák 2015, Fischer et al. 2016). The resulting map of the species presence in Bohemia is in full compliance with the occurrence of a river phenomenon in the Czech Republic. In this model, the slope explains a large portion of variability, but only when combined with other significant variables. Examples of European green lizards from localities in Bohemia (isolated from the continuous area of species distribution) and from localities in South Moravia (northwestern border of the continuous species range) are shown in Figs. 6–12.

The dependence of prediction on average temperatures in the warmest quarter is self-evident, but it is interesting to see a sharp drop when exceeding the 20 °C threshold. During sunny weather,

Fig. 6. *Lacerta viridis* (Laurenti, 1768) – adult male, Praha-Troja, Central Bohemia, 27 April 2018. Photo by I. Rehák.

Fig. 7. *Lacerta viridis* (Laurenti, 1768) – adult female, Albertovy skály, Central Bohemia, 28 May 2016. Photo by D. Fischer.

the surface temperatures of the exposed parts of habitats can easily exceed 80 °C, it is likely that the long-term excess of these temperatures will have a negative effect on the green lizard presence. There is also a strong assumption of intercorrelation of average annual precipitation with average annual temperatures (Schulz & Halpert 1993).

Dependence on precipitation in the coldest quarter is somewhat surprising. Based on this, the probability of presence is growing. A possible interpretation is that the European green lizards require a snow cover for a successful wintering. The snow isolates the wintering site from extreme frosting, but also from sun heating, which can interrupt wintering, and an individual will often not survive this interruption in hibernation (Vongrej et al. 2007).

The most recently published map of distribution (Moravec 2015) is in good consistency with our predictive model, but since it is a square network map without precise locations and coordinates, a more detailed comparison is problematic – especially with regard to the extraordinarily variable geomorphological relief of the Czech Republic and to the distribution of the European green lizard in the Czech Republic, where there is a strong correlation with the geomorphological relief variability – in this case the network mapping easily includes the areas where the species is not present.

We consider the result of finding large areas with high probability of modeled prediction where real occurrence is not reported to be extraordinarily important. Here we see the need to direct species monitoring to these places and search for historical data. Also, these sites should be considered as a matter of priority for possible repatriation efforts and for conservation management by species introduction if the nature conservation authority decides for them.

The comparison of our predictive model and real distribution shows that the predicted and real distribution is almost fully accordant. Thus we consider a creation of predictive distribution models as a helpful instrument to facilitate monitoring and conservation efforts.

Fig. 8. *Lacerta viridis* (Laurenti, 1768) – adult male, Havraníky, Southern Moravia, 5 June 2017. Photo by D. Fischer.

Fig. 9. *Lacerta viridis* (Laurenti, 1768) – adult female, Nový Hrádek, Southern Moravia, 26 May 2012. Photo by D. Fischer.

Fig. 10. *Lacerta viridis* (Laurenti, 1768) – adult male, Praha-Troja, Central Bohemia, 31 August 2020. Photo by I. Rehák.

Fig. 11. *Lacerta viridis* (Laurenti, 1768) – adult male, Šobes, Southern Moravia, 25 May 2015. Photo by D. Fischer.

Fig. 12. *Lacerta viridis* (Laurenti, 1768) – a couple (female on top), Albertovy skály, Central Bohemia, 17 May 2006. Photo by D. Fischer.

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APPENDIX

Bioclimatic variables according to worldclim.org methodology

BIO1 = Annual Mean Temperature
BIO2 = Mean Diurnal Range (Mean of monthly (max temp – min temp))
BIO3 = Isothermality (BIO2/BIO7) (×100)
BIO4 = Temperature Seasonality (standard deviation ×100)
BIO5 = Max Temperature of Warmest Month
BIO6 = Min Temperature of Coldest Month
BIO7 = Temperature Annual Range (BIO5-BIO6)
BIO8 = Mean Temperature of Wettest Quarter
BIO9 = Mean Temperature of Driest Quarter
BIO10 = Mean Temperature of Warmest Quarter
BIO11 = Mean Temperature of Coldest Quarter
BIO12 = Annual Precipitation
BIO13 = Precipitation of Wettest Month
BIO14 = Precipitation of Driest Month
BIO15 = Precipitation Seasonality (Coefficient of Variation)
BIO16 = Precipitation of Wettest Quarter
BIO17 = Precipitation of Driest Quarter
BIO18 = Precipitation of Warmest Quarter
BIO19 = Precipitation of Coldest Quarter

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