Vestnik zoologii, **49**(6): 551–558, 2015
DOI 10.1515/vzoo-2015-0065

DE GRUYTER
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UDC 598.1 : 591.9 (477.43/.44)

USING ECOLOGICAL NICHE MODELING FOR BIODIVERSITY CONSERVATION GUIDANCE IN THE WESTERN PODILLYA (UKRAINE): REPTILES

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Using Ecological Niche Modeling for Biodiversity Conservation Guidance in the Western Podillya (Ukraine): Reptiles. Tytar, V., Sobolenko, L., Nekrasova, O. Mezhzherin, S. — Maximum entropy niche modeling was employed as a tool to assess potential habitat suitability for 10 reptile species and to map their potential distribution in the Western Podillya (Ukraine). We used climate, topography and human impact (assessed by the Human Footprint) as predictor variables. "Isothermality", "temperature seasonality" and the "mean temperature of coldest month" were three most important factors in predicting habitat suitability and distribution. A profound contribution to the modeling has been displayed by the Human Footprint, meaning that human infrastructure may benefit reptile species. Areas have been distinguished that in the first place should be of interest to biodiversity conservationists targeting reptiles and maps summarizing predicted habitat suitability and species richness were produced for guiding conservation efforts.

Key words: *Maxent*, ecological niche modeling, species distribution modeling, reptiles, Ukraine.

Моделирование экологической ниши как инструмент для планирования мероприятий, направленных на сохранение биоразнообразия Западного Подолья (Украина): рептилии. Титар В., Соболенко Л., Некрасова О., Межжерин С. — Моделирование экологической ниши методом максимальной энтропии было использовано для оценки условий пребывания 10 видов рептилий и их распространения на территории Западного Подолья (Украина). Среди предикторов были использованы показатели климата, рельефа и антропогенного воздействия (оценивается по интегрированному индексу «человеческий след»). Среди важнейших факторов, которые определяют пригодность и распределение мест обитания рептилий, были «изотермичность», «сезонность температурного режима» и «средняя температура самого холодного месяца». Также существенный вклад вносит индекс «человеческого следа». Это может означать, что инфраструктура, созданная человеком, может формировать благоприятные условия для рептилий. Отмечены территории, которые в первую очередь должны представлять интерес для охраны рептилий, и созданы карты, которые обобщают прогнозируемую пригодность среды обитания и видовое богатство исследованного региона, что может быть использовано для целенаправленных природоохранных мероприятий.

Ключевые слова: *Maxent*, моделирование экологической ниши, моделирование распространения видов, рептилии, Украина.

Introduction

Even though population declines have been documented, the reptile fauna is not often taken into account as a conservation objective. Fragmentation and habitat loss threatens reptiles with extinction, and habitat specialists, such as endemic or rare species, are more vulnerable to changes in habitat gradients. Estimates indicate that 15–36 % of the world's species of reptiles are threatened (Böhm et al., 2013). This is higher than for bird species (12 %) and around the same level with the percentage for all mammals (25 %) (Brandon et al., 2005).

Protected areas have the potential to aid in the conservation of reptiles by protecting their remaining habitat and eliminating the threats that are causing their decline. The need to recognize the distribution of a species in a specific area should be considered baseline information for developing studies and management plans for its conservation. Unfortunately, insufficient basic ecological information and the actual distribution of their populations has become a problem for planning conservation strategies.

For most of species, the possibility of occurrence in a certain area can be predicted by species distribution models (SDMs). SDMs are becoming an important method and have been widely used (Hanspach et al., 2010; Johnson, Gillingham, 2008). SDMs are techniques that using the relationship between species occurrence and environmental conditions to model the geographical ranges of suitable-habitat for the certain species (Varela et al., 2011).

However, with the increase of human activities and the development of human society, many anthropogenic impacts have been generated, which means the occurrence of species might not only relate to environmental conditions but also might rely on anthropogenic factors. Similarly as SDMs can connect species occurrence with environmental conditions, SDMs could also become a tool to investigate empirical relationships between species occurrence and anthropogenic factors when anthropogenic factors are involved in building the models.

A variety of distribution modeling methods are available for predicting the potential geographical range of a species, however the performances of most species distribution modeling methods are poor when sample size is small (for instance, < 10). Under these circumstances *Maxent* (Phillips et al., 2006) stands out because it has been found to perform best among many different modeling methods (Elith et al., 2006) and may remain effective despite small sample sizes. *Maxent* is a maximum entropy based machine learning program that estimates the probability distribution for a species' occurrence based on environmental constraints (Phillips et al., 2006). It requires only species presence data (not absence) and environmental variable (continuous or categorical) layers for the study area.

Significantly, this study is a local proposal that addresses the distribution of reptile species in the Western Podillya in Ukraine, so that more effective strategies can be accomplished. In particular, our objectives were to (1) identify the factors associated with (species) habitat distribution; (2) predict potential distributions of the species using known presence observations; and ultimately (3) produce a regional map of reptile species richness for conservation guidance.

Methods[1]

Occurrence Data Collection and Processing

For generating the occurrence data set used in the modeling we digitized published presence survey data from L. Sobolenko (2010), I. Dotsenko (2003); T. Hrynchyshyn (2008); T. Kotenko, O. Kukushkin, O. Zinenko (2008); I. Skil's'kyi, N. Smirnov, L. Khlus, L. Meleshchuk (2008); N. Smirnov, I. Skil's'kyi (2008); Vikyrchak, N. Smirnov (2014) and unpublished reports from O. Vikyrchak, M. Drebet, and O. Nekrasova. Georeferencing (in *OziExplorer* v. 3.95.4 m) was accomplished for 297 point data obtained for 10 species: *Anguis fragilis* Linnaeus, 1758 (22), *Coronella austriaca* Laurenti, 1768 (29), *Emys orbicularis* (Linnaeus, 1758) (15), *Lacerta agilis* Linnaeus, 1758 (45), *Lacerta viridis* (Laurenti, 1768) (70), *Zootoca vivipara* (Jacquin, 1787) (16), *Natrix natrix* (Linnaeus, 1758) (39), *Natrix tessellata* (Laurenti, 1768) (26), *Vipera berus* (Linnaeus, 1758) (6) and *Zamenis longissimus* (Laurenti, 1768) (29). These species make extensive use of both wetland and upland habitat and have been negatively impacted by habitat loss and degradation resulting from wetland drainage, agriculture, and urbanization. As a consequence, over much of their range, these species persist in small populations isolated from conspecifics by habitat fragmentation.

Sources for taxonomy are from the IUCN Red List of Threatened Species, version 2014.3 (http://www.iucnredlist.org).

The logistic probabilities provide a relative indication of the likelihood of occurrence by the species, but they do not define predicted occurrence in the binary, presence/absence manner typically required by managers. To establish which areas are climatically suitable for the species, we used the 10 percentile training presence logistic threshold. This has the effect of conservatively identifying a region of highest fit that does not allow outlying points of presence to expand the predicted area of occupancy beyond a core region. Binary maps of species occurrence were created by reclassifying the integer raster datasets, where all values above the given threshold were assigned a value of 1 and all other values were assigned a value of 0.

Final versions of habitat suitability maps were considered to benefit by a simple smoothing filter as one of the means for coping with observation bias (Home et al., 2007) and generalizing raster outputs: 3 x 3 neighborhood filtering implemented in DIVA GIS (www.diva-gis.org/) was applied for this purpose.

Creating contour data layers from grid data layers was accomplished with SAGA 2.1.4_Win32, a system for automated geo-scientific analysis (http://www.saga-gis.org/).

Environmental Data Collection and Processing

Temperature, precipitation and solar radiation have been proved that have significant correlations with the distributions of reptile species and activities of reptile individuals (Nicholson et al., 2005). Topographical factors have been stated as necessary factors for SDMs (Guisan et al., 1999). The topography predictor variables

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[1] The study region, model building and evaluation have been described in a previous paper (Tytar et al., 2015).

selected were: topographical wetness index (TWI) and aspect. Aspect is a proxy for the amount of solar radiation on the ground surface, the TWI combines a measure of the upslope area and slope to predict the hydrology of a given location (Sorenson et al., 2005). Small values represent upper catenary positions (dry), and high values represent lower catenary (wet) positions.

Bioclim climate data are derived from the monthly temperature and rainfall values (Hijmans et al., 2005). It generates more biologically meaningful variables about temperature and precipitation. Bioclim climate data contains 19 factors represent annual trends, seasonality and extreme or limiting environmental conditions.

The Human Footprint (HF) data set (Sanderson et al., 2002) was taken as a measure of anthropogenic impact. The HF layer combines layers representing human population pressure (population density), human land use and infrastructure (built-up areas, night-time lights, land use/land cover), and human access (roads, railroads, navigable rivers). The resultant layer is normalized by biome to reflect the continuum of human influence on the natural environment. The HF score ranges from zero to 100.

All environmental data layers were spatial resolution rasters (~1 km) with the same extent and cell alignment, arranged by the *QDSM* plugin in *QGIS* 2.6.1 freeware (www.qgis.org).

Due to the high levels of correlations between many environmental variables, we filtered the initial variable set of 23 predictors based on the results of multi-colinearity analysis. by calculating the Variance Inflation Factor (VIF): $\mathrm{VIF} = 1/(1-R^2)$, where R^2 is the coefficient of determination. VIF values higher than 10 are considered to lead to problematic levels of multi-collinearity (Craney, Surles, 2002). Factors with VIF values that exceeded 10 were not used in the model. The 9 selected factors are shown in table 1.

Table 1. Predictors, remaining after the multi-colinearity analysis

Predictor	VIF
bio 3: Isothermality (*bio 2*/*bio* 7*)	2.0
bio 4: Temperature Seasonality (STD** x 100)	2.5
bio 6: Min Temperature of Coldest Month, °C	2.4
bio 13: Precipitation of Wettest Month, mm	3.3
bio 14: Precipitation of Driest Month, mm	4.1
bio 19: Precipitation of Coldest Quarter, mm	5.3
Aspect	1.0
Topographical wetness index (TWI)	1.2
Human Footprint (*HF*)	1.0

* *Bio 2*: Mean Monthly Temperature Range; *bio 7*: Temperature Annual Range (°C*10).

** STD — standard deviation.

Results and discussion

Factors associated with (species) habitat distribution

The modeling identified a number of environmental variables that had high contribution to generating the potential distribution prediction of reptiles in the study area. As it is the case with reptiles in general, their large-scale distribution is mainly environmentally dependent, due to physiological features, their behavior and ultimately fitness is influenced directly by environmental conditions (Huey, 1982; Huey, Kingsolver, 1989).

Based on percent contribution, of all 9 variables initially used in the modeling process, the most important ones and those that best explained the environmental requirements of the species, were isothermality (*bio 3*), temperature seasonality (*bio 4*), minimum temperature of the coldest month (*bio 6*) and human impact, measured by the Human Footprint (*HF*); precipitation of the wettest month (*bio 13*) and precipitation of the coldest quarter (*bio 19*) were of importance only for *Vipera berus* (table 2). The percent contribution of precipitation of the driest month (*bio 14*), aspect and topographical wetness index (*TWI*) in all cases was below 10 %, so they were not included to table 2.

Isothermality (*bio 3*) was a major contributor to models for all the 10 reptile species, particularly *Zamenis longissimus* (67.7 %) and *Lacerta viridis* (60.8 %). All considered in the study species displayed a similar bell-shaped response of increased suitability as isothermality increases above a certain value, indicated by the response curves generated using only the corresponding variable. Response curves also gave an indication of the range under which the variable reaches its optimum suitability. For *Zamenis longissimus*, for instance,

Table 2. The percent contribution of environmental variables (factors) in predicting the species geographic distribution models

Species	Factors associated with (species) habitat distribution > 10 %					
	bio 3	*bio 4*	*bio 6*	*bio 13*	*bio 19*	HF
Anguis fragilis	24.4	–	17.3	–	–	36.4
Coronella austriaca	43.2	24.3	–	–	–	–
Emys orbicularis	27.8	32.4	11.1	–	–	16.5
Lacerta agilis	31.8	14.4	22.1	–	–	21.4
Lacerta viridis	60.8	19.9	–	–	–	–
Zootoca vivipara	14.7	–	11.9	–	–	57.8
Natrix natrix	22.9	18.3	19.8	–	–	29.0
Natrix tessellata	48.4	24.2	10.8	–	–	10.0
Vipera berus	16.5	–	17.9	15.0	40.4	–
Zamenis longissimus	67.6	16.9	–	–	–	–
Importance for *n* species:	10	7	7	1	1	6

optimum suitability is expected to be reached at 28.20 within a narrow range of 28.02 to 28.32 (using the 10 percentile training presence logistic threshold of 0.4097) (fig. 1).

Secondly, temperature seasonality (*bio 4*) was an important contributor to modeling potential distribution of 7 species, especially *Emys orbicularis* (32.4 %). Response curves for this variable also displayed a similar bell-shaped response. Both these predictors express the homogeneity of temperatures throughout the year, meaning that apparentley most species try to avoid extreme temperature oscillations.

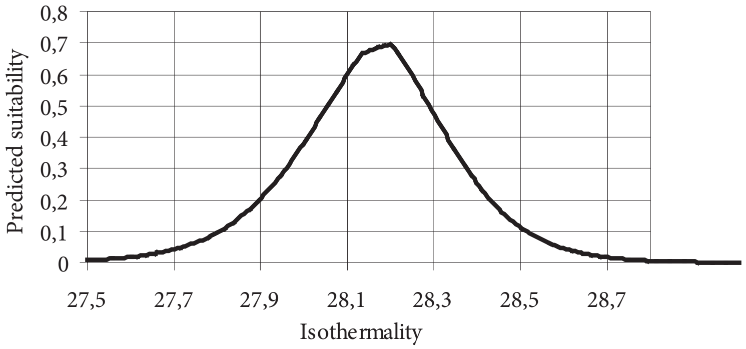

Fig. 1. Response curve of isothermality (*bio 3*), used for predicting the potential distribution of *Zamenis longissimus* at the local scale (Western Podillya in Ukraine).

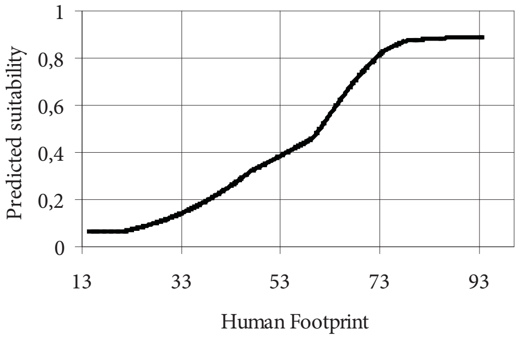

Fig. 2. Response curve of the Human Footprint (*HF*), used for predicting the potential distribution of *Zootoca vivipara* at the local scale (Western Podillya in Ukraine).

Next to temperature seasonality is the importance of the minimum temperature of the coldest month (*bio 6*). This factor is obviously related to winter survival, and for 7 species the percent contribution of the minimum temperature of the coldest month ranges between 10.8 (for *Natrix tessellata*) and 22.1 % (for *Lacerta agilis*).

Of the non-bioclimatic variables a profound contribution in predicting the species geographic distribution models for 6 species has been displayed by the Human Footprint. The *HF* percent contribution reaches values ranging from 10.0 % (for *Natrix tessellata*) to 57.8 % (for *Zootoca vivipara*). Curiously enough, for these species the *HF* positively affects predicted presence probability, as evidenced by the corresponding response curves. In the case of *Zootoca vivipara*, for example, the response to increasing values of the *HF* resembles a sigmoid curve (fig. 2).

Previous studies have demonstrated that anthropogenic factors have the capacity to affect natural species populations (Benayas et al., 2006; French et al., 2010), mostly in a negative way. The Human Footprint used in the modeling includes multiple factors related to human disturbance (e. g. human population size, land use, infrastructure and the degree of human access). One assumption is that these human effects greatly modify and generate new environments that are favorable for certain species. Another assumption, as evidenced by recent studies, can be linked to net primary productivity (NPP) (Luck, 2007). It appears that humans preferentially settle in areas of mid to high productivity. This pattern is consistent with relationships between NPP and species richness, where it appears that richness is typically maximal at high or midrange values of NPP. Hence, it is not surprising that positive correlations between human population density and species richness for various taxonomic groups have been recorded (for instance, Araújo, 2003).

Potenial distributions of the species

Based on the maximum entropy modeling algorithm and using 9 environmental variables (VIF < 10), we obtained 10 raster outputs modeling the distribution of the considered species. According to table 3, all the species distribution models were better than random (AUC > 0.5). For most of the species, models performances were “good” (AUC > 0.8) and “excellent” (AUC > 0.9). For only one species, *Vipera berus*, the model performance was “fair” (AUC > 0.7), apparently because of the small number of occurrences (n = 6).

In terms of the percent of suitable habitat in relation to the study area (table 3) the species can be ranked in a descending order of nature conservation priority: *Zamenis longissimus* > *Lacerta viridis* > *Zootoca vivipara* > *Natrix tessellata* > *Coronella austriaca* > *Emys orbicularis* > *Anguis fragilis* > *Natrix natrix* > *Lacerta agilis*. We do not consider *Vipera berus* because of the relatively poor model performance.

Table 3. Summary statistics for *Maxent* habitat suitability models

Species	Suitable habitat, %*	AUC ± SE**
Anguis fragilis	25.8	0.8840 ± 0.006
Coronella austriaca	22.1	0.9144 ± 0.004
Emys orbicularis	23.0	0.9350 ± 0.004
Lacerta agilis	37.5	0.8623 ± 0.004
Lacerta viridis	9.4	0.9652 ± 0.002
Zootoca vivipara	13.7	0.9426 ± 0.005
Natrix natrix	32.9	0.8898 ± 0.004
Natrix tessellata	15.2	0.9435 ± 0.002
Vipera berus	44.3	0.7670 ± 0.012
Zamenis longissimus	4.6	0.9723 ± 0.003

* % of study area > 10 percentile training presence logistic threshold.
** SE — standard error.

Fig. 3. Areas (downward diagonal filled polygons) in Western Podillya (Ukraine), where the average predicted habitat suitability for reptile species exceeds 0.5 (Districts: *1* — Terebovlianskyi, *2* —Husiatynskyi, *3* — Buchatskyi, *4* — Chortkivskyi, *5* — Chemerovetskyi, *6* — Horodenkivskyi, *7* — Zalishchytskyi, *8* — Borshchivskyi, *9* — Kamianets-Podilskyi, *10* — Zastavnivskyi, *11* — Khotynskyi).

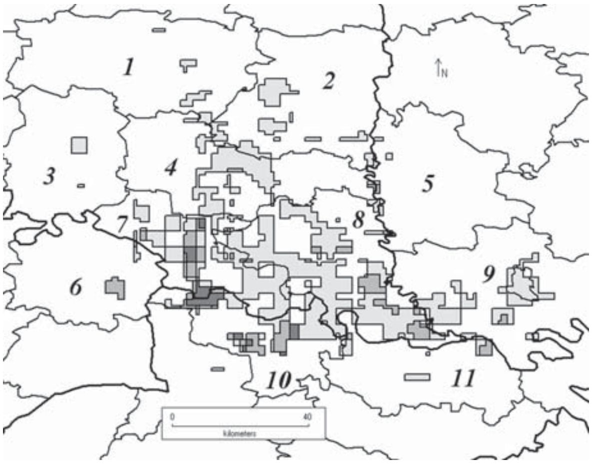

Fig. 4. Areas (polygons) in Western Podillya (Ukraine), where there is a predicted probability for the accommodation *9, 8* or *7* reptile species (gradient from dark gray — *9* species to light — *7* species). Districts numbered as in fig. 3.

We combined the predictions into an "ensemble" map by calculating the average of the predicted habitat suitability in each pixel for the considered species using a threshold of 0.5. Contours enclosing such areas (polygons) are depicted in fig. 3. These areas are likely very suitable for the species in general and suggest that surveys should be conducted prior to management actions to determine whether any of the species are present and the degree to which they may be impacted. In this respect relatively large and promising areas are located in Zalishchytskyi, Borshchivskyi and Zastavnetskyi Districts[2], especially alongside the Dnister, within Chortkivskyi District and around the historic city of Kamianets-Podilskyi.

By overlaying the binary maps derived for separate species that indicate either presence or absence, a summarizing species richness map was produced (fig. 4), emphasizing areas (polygons), where there is a predicted probability for accommodating 9, 8 or 7 reptile species. As seen, assumed areas of exceptional reptile species richness are located primarily in Zalishchytskyi and Zastavnetskyi Districts, the largest one (with the centroid in 25.740064° E, 48.648091° N) sharing the territory of both administrative units to the north and south of the river Dnister. Centroids of the other eight polygons, assumed to accommodate 9 species,

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[2] A rayon (also raion) is a type of administrative unit of several post-Soviet states (such as part of an oblast).

are: 25.950000° E, 48.495847° N; 25.845833° E, 48.508347° N; 25.858333° E, 48.525014° N; 25.829166° E, 48.541681° N; 25.979166° E, 48.554181° N; 25.702206° E, 48.763984° N; 25.733333° E, 48.845847° N. Given the lack of complete information about the distribution of the considered species, these locations could be the first to be surveyed for selecting potential conservation areas and also be used to verify by ground proof conclusions made in the course of the modeling. We also suggest a focus should be made on patches located alongside the Zbruch river and the canyon area of Kamianets-Podilskyi. Such informed conservation measures should improve the effectiveness of reserve networks and, ultimately, will contribute to better protection for biodiversity at the local level.

Conclusion

Additional information on the distribution of reptiles (as, for instance, *Vipera berus*), the current status of populations, and the natural history of species in the Western Podillya in Ukraine are necessary to develop a conservation program with specific objectives, so that guided decisions can help to mitigate negative effects in the populations. Furthermore, the protected areas and municipalities in the Western Podillya in Ukraine must develop monitoring plans in their areas that contain detailed information on the presence or absence of the species. In this respect SDMs can connect species occurrence with environmental conditions and be useful tool. SDMs could also become a tool to investigate empirical relationships between species occurrences and anthropogenic factors, which may be ambiguous or even benefit certain species. Finally, SDMs can be used to identify sets of conservation areas, where habitat suitability and factors enhancing species richness are in place. Improving data availability and comparing predicted distributions with ground-truthing results obtained by undertaking accordant field investigations are necessary for future progress in this field of informed biodiversity conservatio

The authors deeply thank O. Vikyrchak and M. Drebet for their help in collecting the occurrence data.

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Received 27 May 2015
Accepted 29 Octoder