Research Article

Range expansion of the alien red-eared slider *Trachemys scripta* (Thunberg in Schoepff, 1792) (Reptilia, Testudines) in Eastern Europe, with special reference to Latvia and Ukraine

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Abstract

An increasing number of thermophilic invasive species are spreading and becoming naturalized in Eastern Europe, at least partially due to recent climate change. This can be exemplified by current expansion of the red-eared slider, *Trachemys scripta*, in Latvia and Ukraine. We collected 44 records of the species in Latvia and 79 in Ukraine. Two of the three subspecies have been found – *T. s. elegans* and *T. s. scripta*. In both countries courtship behavior and egg-laying have been observed. Individuals successfully surviving the winter in the wild have been recorded. Due to climate change, it is likely that this species has the potential to establish itself in Latvia and Ukraine.

Key words: alien species, climate change, turtle, the pond slider, species distribution modelling

Introduction

Climate change in recent years has allowed more thermophilic alien species to naturalize and actively invade Eastern Europe (Pupins and Pupina 2011; Nekrasova 2013; Cerasoli et al. 2019; Kuybida et al. 2019; Nekrasova et al. 2019a, b, c, 2021a, b; Marushchak et al. 2021). One of the reasons for the emergence of new alien species is the trade in exotic animals and their uncontrolled release into nature. Freshwater turtles are among the most traded reptiles. Until the 1990's, the trade of freshwater turtles focused mostly on the American red-eared slider *Trachemys scripta* (Thunberg in Schoepff, 1792). In the period 1989–1997, more than 52 million red-eared sliders were exported from the USA (Telecky 2001). Today red-eared sliders are one of only two reptiles included in the list of the "World's Worst Invasive Alien Species" (Global Invasive Species Database 2021) and considered one of the 100 worst invasive alien species in Europe (Scalera 2009). In Ukraine, several alien turtle species have been discovered, *T. scripta, Testudo horsfieldii, Mauremys rivulata, M. caspica* (Nekrasova 2013; Kukushkin et al. 2017) and, perhaps *Testudo graeca* (Nekrasova and

Tytar 2012). In Latvia *T. scripta, M. rivulata, M. caspica, Pelodiscus sinensis,* and *T. horsfieldii* (Pupins and Pupina 2011) were recorded.

Among the noted species *T. scripta* represents the greatest threat for local biodiversity because this species can transmit diseases to which native turtles are susceptible, occupy similar ecological niches of native turtles, competing for their food resources, displacing them from their favored basking sites, participating in their breeding-courtship attempts between the autochthonous turtles, and overall reducing their survival (Cadi and Joly 2004; Pupins 2007; Semenov 2009; Cerasoli et al. 2019; Espindola et al. 2019; Pupins et al. 2019; Nekrasova et al. 2021b). According to the Handbook of global freshwater invasive species (Ficetola et al. 2012), pond sliders are recorded in Finland, Latvia and Lithuania (but not in Estonia), Poland, Slovakia, Hungary, Romania, Bulgaria, Russia and other countries (Cadi and Joly 2004; Semenov 2009; Pupins and Pupina 2011; Kukushkin et al. 2017; Kornilev et al. 2020). Numerous findings of exotic turtles continued to appear at the beginning of the 21st century in the regions of Ukraine – Odesa, Crimea, Transcarpathia areas next to the border with Hungary and Romania (Nekrasova 2013; Kurtyak and Kurtyak 2013; Kukushkin et al. 2017).

Recently, the red-eared slider has been found in a number of regions in Ukraine due to breeding in captivity and release into various wetlands (mostly urban; Nekrasova et al. 2021b). Despite the availability of some distribution maps at different scales (Rödder et al. 2009; Banha et al. 2017) there are no distribution maps concerning the species in Eastern Europe, particularly Latvia and Ukraine. Yet, for biodiversity conservation and species management purposes, it would be important to predict how far the red-eared slider can advance. The availability of spatially explicit maps of risk of establishment may allow to set up specific preventive measures in different regions, like trade regulation or appropriate communication campaigns (Masin et al. 2014). In this study we attempted to summarize findings of the red-eared slider in outdoor settings both in Latvia and Ukraine and, by using a species distribution modeling (SDM) approach, to identify areas where the species could survive under current climatic conditions.

Materials and methods

We compiled original research, literature (Supplementary material Appendix 1) and verified reports from colleagues that provided turtle photos (Pupins 2007; Kark et al. 2009; Ficetola et al. 2012; Nekrasova et al. 2019b). We focused particularly on collecting data from social networking sites and media sharing services, which support textual and visual content and geotagging (Supplementary material, Dabasdati.lv. https://dabasdati.lv/lv [In Latvian]; GBIF 2021). Thus, we collected 44 records of *T. scripta* in Latvia (formed a database Pupins M., Čeirāns A., Table S1) and 79 in Ukraine (formed a database Nekrasova O., Table S2, Figure 1). Only a portion of

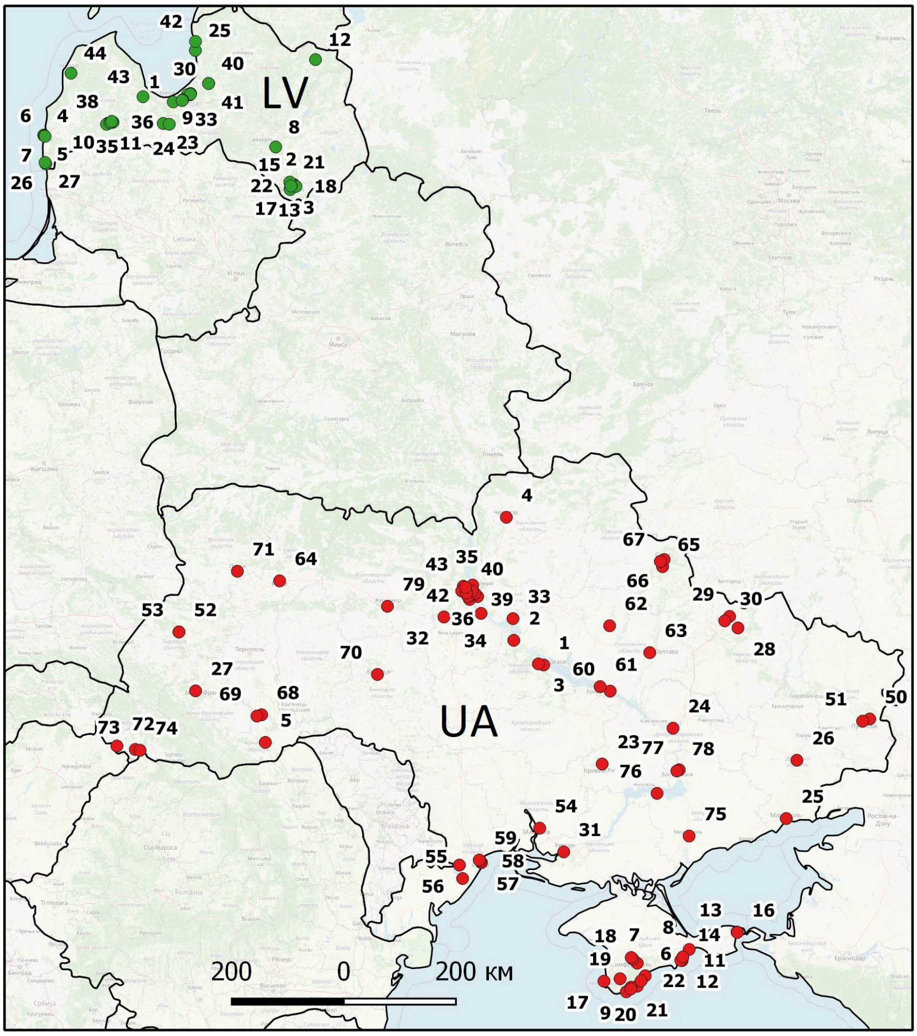

Figure 1. Distribution of records of the red-eared slider in Latvia (LV green dots) and Ukraine (UA red dots); numbers correspond to information in the Tables S1–S2 of the Supplementary material.

this data has been published before (Pupins 2007; Pupins and Pupina 2011; Čeirāns et al. 2019). Records lacking coordinates were georeferenced in OziExplorer (http://www.oziexplorer.com), Google Earth Pro (v7.3.0) (https://www.google.com/intl/uk/earth/) and visualized in QGIS (v3.14.15-Pi) (https://www.qgis.org).

To explore the potential distribution of *T. scripta* in our study area we employed Bayesian Additive Regression Trees (BART), a machine learning technique consisting of a Bayesian approach to Classification and Regression Trees (CART), capable of producing highly accurate predictions without overfitting to noise or to particular cases in the data. Models of this method estimate the probability of a given output variable (a binary classification of habitat suitability or species presence) based on decision "trees" that split predictor variables with nested, binary rule-sets (Carlson 2020). Running SDMs with BARTs has recently been greatly facilitated by the development of an R package, "embarcadero". The algorithm computes habitat suitability values ranging from 0, for fully nonsuitable habitat, to 1, for fully suitable habitat. Model performance was assessed using measures of accuracy: the area under the receiver-operator curve (AUC) (Fielding and Bell 1997), and the true skills statistic (TSS) (Allouche et al. 2006).

As input, SDMs require georeferenced biodiversity observations and geographic layers of environmental information. Because the use of restricted data (similar to not capturing the full species' environmental range) reduces strongly the combinations of environmental conditions under which the models are calibrated and reduces the applicability of the model for predictive purposes (Pearson and Dawson 2003; Thuiller et al. 2004), we used the full set of European invasive records from the GBIF data base (*Trachemys scripta*, GBIF 2021), updated by our personal field investigations. These occurrence points (n = 1,147) varied in spatial density due to variable sampling intensity. As a result, and to avoid overemphasizing heavily on sampled areas, the BART algorithm selects points for model calibration using subsampling to reduce sampling bias and spatial autocorrelation, which would produce models of lower rather than higher quality (Beck et al. 2013). The niche for the species (not discriminating for subspecies) was described based on climate. We transformed 30 climate data from the CliMond global dataset (Kriticos et al. 2014, see Table S3). This dataset consists of climatic variables in raster format covering temperature, rainfall, solar radiation, and seasonality conditions that reportedly influence reptile ranges (Martínez et al. 2020); following Araújo et al. (2006), a 10′ grid resolution was chosen. Because collinearity among environmental predictors will increase uncertainty in model parameters and decrease statistical power we used principal components analysis (PCA) in SAGA GIS (Conrad et al. 2015) to reduce collinearity (Petitpierre et al. 2017), giving a new, simpler environmental space defined in fewer, and fully orthogonal axes. Significance of the components was identified using the broken stick method (Jackson 1993). PCA reduced collinearity amongst the 30 variables from the CliMond dataset (Table S3); the first four components were identified as significant, which together accounted for almost 90% of the variation (according to standard techniques https://www.climond.org/BioclimData.aspx, Kriticos et al. 2014, Tables S4–S5). To differentiate between suitable and non-suitable environments in terms of invasion risk two thresholds were used: the minimum training presence (Pearson et al. 2007) and the more conservative one percentile threshold. These are the thresholds at which all or all but 1% of the training presences are required to be included within projected suitable environments, respectively. Contour lines depicting the threshold values separating suitable from unsuitable areas for the species were produced in SAGA GIS. Maps of habitat suitability in the GeoTIFF format were processed and visualized in SAGA GIS.

Results and discussion

We collected 123 findings of *T. scripta* in Latvia and Ukraine (Figure 1; Tables S1–S2). Turtles were found mostly in stagnant water bodies.

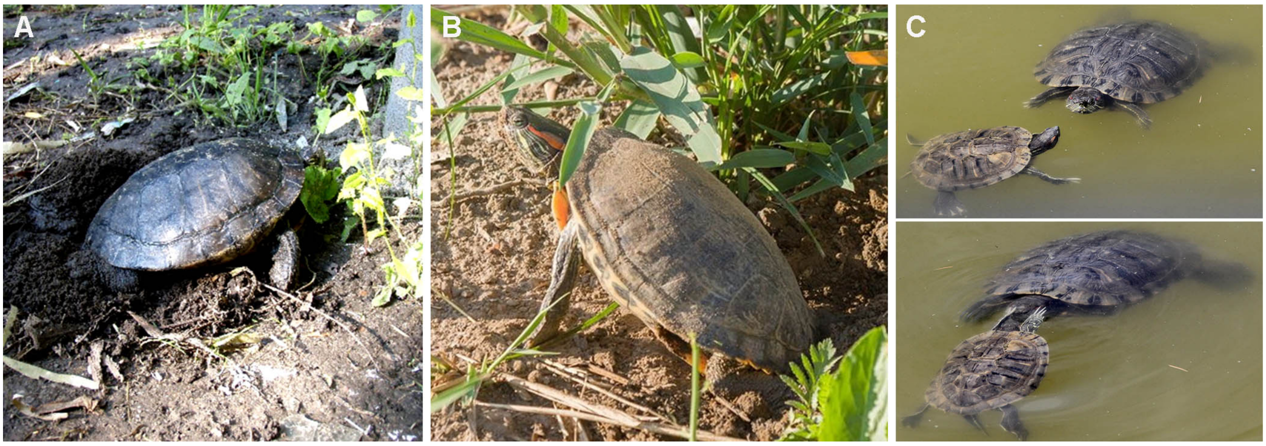

Figure 2. Red-eared slider laying eggs: A – Latvia, Daugavpils; B – Ukraine, Donetsk Region, Mariupol (Photo – O. Lazarenko); Courtship behavior: C – Ukraine, Odessa, Athletic Park.

In Latvia, pond sliders were first found in 1999 (Table S1) and in 2006, when six adult animals were recorded in Nitaure, a village in Amata municipality, where they had successfully over-wintered. In addition to the records of Pupins (2007) and Pupins and Pupina (2011), 11 new findings of *T. s. scripta* (Schoepff, 1792) and 33 of *T. s. elegans* (Wied-Neuwied, 1839) were added to our database (Figure 1; Table S1).

In Ukraine, the turtle was found in drainage waters of Kyiv (Ukraine) in the late 1990s, namely at the Bortnychi sewage water treatment plant (50.3837N; 30.6642E), where juveniles and adults were recorded (Table S2). Interestingly, at any time of the year various exotic species of fish and plants could also be found in the warm waters (about +19–+20 °C) of this sewage water treatment plant, for instance guppy (*Poecilia reticulata* Peters, 1859) (Nekrasova et al. 2021a, b).

Two of the three subspecies of *T. scripta* were found in Latvia and Ukraine – *T. s. elegans* and *T. s. scripta*. The more common one was *T. s. elegans* – 75% of the records in Latvia and 97.5% of the records in Ukraine. It is possible that the *T. s. troostii* subspecies also occurs in both study areas, but it is rather difficult to identify it.

In Ukraine the red-eared slider is often kept in captivity and is a fairly popular pet. This may be evidenced by a simple Google Search query using the key words "buy" and "red-eared slider" (in Ukrainian) that returned 1,350 results (4th of August 2021). Unfortunately, turtles are commonly released into the wild to nearby ponds and lakes, thus invading urban ecosystems. In the wintertime, turtles in these habitats usually don't survive and this becomes noticeable in the spring. For instance, dead turtles were found on the 21st of March 2013 in ponds of Myrhorod (Poltava Region) and on the 13th of April 2015 in fish ponds of Didorivka (a suburb of Kyiv).

Occasional records have been made of egg-laying and courtship behavior. In Latvia (Daugavpils) an individual was recorded laying eggs after successfully over-wintering in a fenced outdoor pool (Figure 2A); these eggs were fertilized but the turtles did not hatch. Similarly, a female

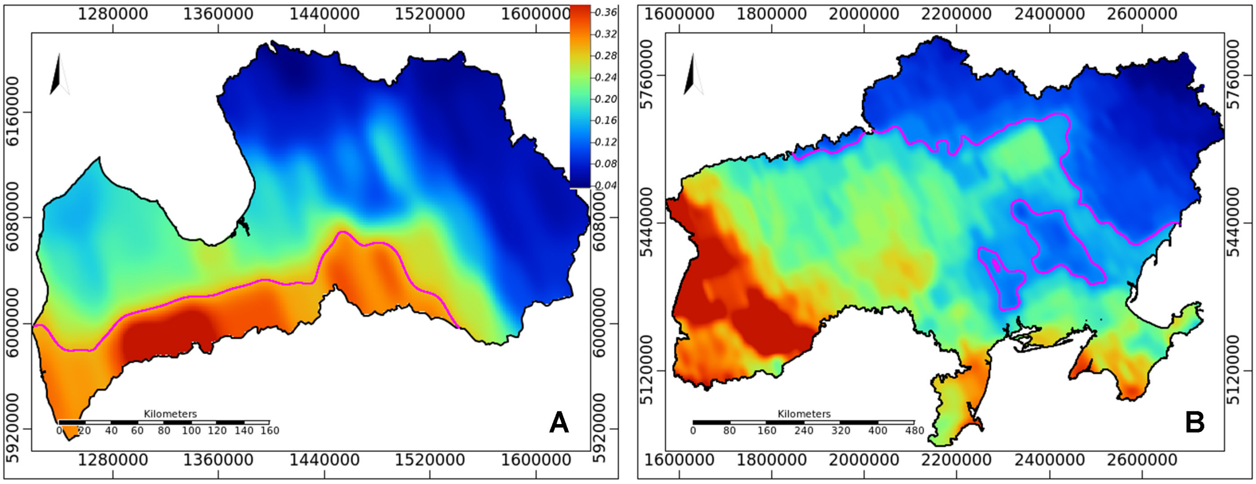

Figure 3. Predicted habitat suitability for the red-eared slider. Warmer colours indicate higher bioclimatic suitability for the species. The contour line in color fuchsia depicts the one percentile threshold: A – Latvia; B – Ukraine. Areas of the highest habitat suitability (> 0.3–0.5) are colored in red and areas of the lowest (< 0.2) – in blue (SagaGis).

T. scripta was observed laying eggs on the 28th of June 2017 in Mariupol (Donetsk Region) (personal communication – O. Lazarenko, Figure 2B; Table S2), but the fate of the clutch is unknown. Courtship behavior in Ukraine has been recorded in ponds of the Athletic Park in Odesa on the 21st of June 2020 (Figure 2C).

In urban ecosystems *T. scripta* was found alongside with a native species, *Emys orbicularis* (Linnaeus, 1758). In these ecosystems in southern Ukraine *T. scripta* is numerically dominant over *E. orbicularis*. For instance, of the 80 turtles found on the 8th of May 2020 in the Athletic Park 94% were *T. scripta*. Within this system of lakes in the park, koi fish (a domesticated variety of the common carp) are also found. These exotic fish, together with red-eared slider, are assumed to have been successfully wintering here for at least 10 years. In Europe, strong competition occurs between *T. scripta* and *E. orbicularis*, since they occupy similar habitats and ecological niches (Cadi and Joly 2004). For Europe habitat suitability maps showed a strong correlation (Pearson's r = 0.68) between the species, meaning high chances of co-occurrence and the potential for interspecific competition (Pupins et al. 2019).

These PCA-derived variables were used for the modelling instead of the original set of environmental information (Tables S3–S5). In terms of discrimination accuracy the BART model showed acceptable performance: AUC = 0.825 and TSS = 0.513 (Swets 1988; Jiménez-Valverde et al. 2011).

Analyzing the models, we came to the conclusion that the minimum training presence logistic threshold, which provides minimum requirements for the species climate preferences, indicated all sites in Latvia and Ukraine as suitable in terms of the bioclimatic niche for the red-eared slider, although on the average habitat suitability (HS) conditions for the species are higher in Ukraine (HS 0.219 against HS 0.106 in Latvia), meaning the risk of invasion is potentially higher in Ukraine. Employing the more conservative one percentile threshold shows that in Latvia the areas more suitable for the species are in the south and south-west of the country, whereas in Ukraine these are located primarily in the west and south. Moreover, this species successfully winters in the south of Ukraine. Therefore, specific preventive measures should be planned and undertaken here. These include both legal measures to control pet trade and campaigns to explain the problems caused by imported turtles and to encourage people to change their attitudes towards nature and support biodiversity conservation (Ficetola et al. 2012; Masin et al. 2014).

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References

Allouche O, Tsoar A, Kadmon R (2006) Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). *Journal of Applied Ecology* 43: 1223–1232, https://doi.org/10.1111/j.1365-2664.2006.01214.x

Araújo MB, Thuiller W, Pearson RG (2006) Climate warming and the decline of amphibians and reptiles in Europe. *Journal of Biogeography* 33: 1712–1728, https://doi.org/10.1111/j.1365-2699.2006.01482.x

Banha F, Gama M, Anastácio PM (2017) The effect of reproductive occurrences and human descriptors on invasive pet distribution modelling: *Trachemys scripta elegans* in the Iberian Peninsula. *Ecological Modelling* 360: 45–52, https://doi.org/10.1016/j.ecolmodel.2017.06.026

Beck J, Ballesteros-Mejia L, Nagel P, Kitching IJ (2013) Online solutions and the "Wallacean shortfall": What does GBIF contribute to our knowledge of species' ranges? *Diversity and Distributions* 19: 1043–1050, https://doi.org/10.1111/ddi.12083

Cadi A, Joly P (2004) Impact of the introduction of the red-eared slider (*Trachemys scripta elegans*) on survival rates of the European pond turtle (*Emys orbicularis*). *Biodiversity & Conservation* 13: 2511–2518, https://doi.org/10.1023/B:BIOC.0000048451.07820.9c

Carlson CJ (2020) Embarcadero: Species distribution modelling with Bayesian additive regression trees in R. Methods in Ecology and Evolution 11: 850–858, https://doi.org/10.1111/2041-210X.13389

Čeirāns A, Pupiņš M, Škute A (2019) Guidelines for combating invasive Amur Sleeper (*Perccottus glenii*) and the Red-eared Slider (*Trachemys scripta elegans*) in the most endangered amphibian and reptilian populations in Latvia, Daugavpils University, 43 pp [In Latvian]

Cerasoli F, Iannella M, Biondi M (2019) Between the hammer and the anvil: how the combined effect of global warming and the non-native common slider could threaten the European pond turtle. *Management of Biological Invasions* 10: 428–448, https://doi.org/10.3391/mbi.2019.10.3.02

Conrad O, Bechtel B, Bock M, Dietrich H, Fischer E, Gerlitz L, Wehberg J, Wichmann V, Böhner J (2015) System for Automated Geoscientific Analyses (SAGA) v. 2.1.4. *Geoscientific Model Development Discussions* 8: 2271–2312, https://doi.org/10.5194/gmdd-8-2271-2015

Espindola S, Parra JL, Vázquez-Domínguez E (2019) Fundamental niche unfilling and potential invasion risk of the slider turtle *Trachemys scripta*. *PeerJ* 7: e7923, https://doi.org/10.7717/peerj.7923

Ficetola GF, Rödder D, Padoa-Schioppa E (2012) Slider terrapin (*Trachemys scripta*). In: R. Francis (ed), Handbook of global freshwater invasive species. Earthscan, Taylor & Francis Group, Abingdon, UK, pp 331–339

Fielding AH, Bell JF (1997) A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental Conservation* 24: 38–49, https://doi.org/10.1017/S0376892997000088

GBIF (2021) *Trachemys scripta* (Thunberg In Schoepff, 1792) in GBIF.org. GBIF Occurrence Download, https://doi.org/10.15468/dl.rvtkb3 (accessed 19 June 2021)

Global Invasive Species Database (2021) Species profile: *Trachemys scripta elegans*. http://www.iucngisd.org/gisd/speciesname/Trachemys+scripta+elegans (24 June 2021)

Jackson D (1993) Stopping rules in principal components analysis: comparison of heuristic and statistical methods. *Ecology* 74: 2204–2214, https://doi.org/10.2307/1939574

Jiménez-Valverde A, Peterson A, Soberón J, Overton J Aragón P, Lobo JM (2011) Use of niche models in invasive species risk assessments. *Biological Invasions* 1: 2785–2797, https://doi.org/10.1007/s10530-011-9963-4

Kark S, Solarz W, Chiron F, Clergeau P, Shirley S (2009) Alien birds, amphibians and reptiles of Europe. In: DAISIE (ed), Handbook of Alien Species in Europe. Springer, Dordrecht, pp 105–118, https://doi.org/10.1007/978-1-4020-8280-1_8

Kornilev YV, Lukanov S, Pulev A, Slavchev M, Andonov K, Vacheva E, Vergilov V, Mladenov V, Georgieva R, Popgeorgiev G (2020) The alien pond slider *Trachemys scripta* (Thunberg in Schoepff, 1792) in Bulgaria: Future prospects for an established and reproducing invasive species. *Acta Zoologica Bulgarica* 72: 571–581, http://acta-zoologica-bulgarica.eu/older-articles/00SIO_1_09

Kukushkin OV, Doronin IV, Tuniyev BS, Ananjeva NB, Doronina MA (2017) Introduction of Amphibians and Reptiles at the Caucasus and the Crimea: an Overview and Some Actual Data. *Current Studies in Herpetology* 17: 157–197, https://doi.org/10.18500/1814-6090-2017-17-3-4-157-197 [in Russian]

Kurtyak FF, Kurtyak MF (2013) Red-eared slider *Trachemys scripta elegans* (Wied, 1839) (Reptilia; Testudines), as an Invasive threat in Transcarpathian Region. *Scientific bulletin of Uzhgorod University, Ser. Biology* 34: 58–62 [in Ukrainian]

Kuybida VV, Nekrasova OD, Kutsokon YK, Lopatynska VV (2019) Summer Fish Kills in the Kaniv Reservoir. *Hydrobiological Journal* 55: 103–106, https://doi.org/10.1615/HydrobJ.v55.i1.110

Kriticos DJ, Jarošik V, Ota N (2014) Extending the suite of Bioclim variables: a proposed registry system and case study using principal components analysis. *Methods in Ecology and Evolution* 5: 956–960, https://doi.org/10.1111/2041-210X.12244

Martínez DVE, Ríos-Muñoz CA, Vega-Flores KM (2020) Why geography matters: Sources and considerations of environmental information in the process of ecological niche and/or species distribution modelling. *Revista Latinoamericana de Herpetología* 3: 5–32, http://herpetologia.fciencias.unam.mx/index.php/revista/article/view/157

Marushchak OY, Nekrasova OD, Tytar VM, Smirnov NA, Korshunov OV, Pupins M, Mykytynets GI, Skute A, Henle K, Kaiser H (2021) A GIS approach to the study of colour anomalies in amphibians of Ukraine reveals the deleterious effect of human impacts. *Herpetology Notes* 14: 1239–1251

Masin S, Bonardi A, Padoa Schioppa E, Bottoni L, Ficetola GF (2014) Risk of invasion by frequently traded freshwater turtles. *Biological Invasions* 16: 217–231, https://doi.org/10.1007/s10530-013-0515-y

Nekrasova OD (2013) To the study of the herpetofauna in the Sukhyi Estuary Valley (Ukraine). In: Pisanets EM (ed), Proceeding of the Ukrainian Herpetological Society, pp 109–117 [in Russian]

Nekrasova OD, Tytar VM (2012) On the possibility of the habitat of the Mediterranean spur-thighed tortoise *Testudo graeca* L. on the territory of Ukraine. In: The abstracts of scientific. conf. "Animals: ecology, biology and conservation", December 2012, Russia, Saransk, pp 270–273 [in Russian]

Nekrasova O, Yanish Y, Tytar V, Pupins M (2019a) GIS-modeling of the Range Shifts of the Sub-fossil and Extant European Pond Turtle (*Emys orbicularis*) in Eastern Europe in Holocene. *Diversity* 11: 121, https://doi.org/10.3390/d11080121

Nekrasova OD, Tytar VM, Kuybida VV (2019b) GIS modeling of climate change vulnerability of amphibians and reptiles in Ukraine. NAS of Ukraine, Shmalgausen Institute of Zoology NAS, 204 pp, [in Ukrainian]

Nekrasova O, Tytar V, Pupins M (2019c) Distribution models of invasive red-eared slider (*Trachemys scripta elegans*) in the eastern part of the range of the species (Ukraine and the Baltic Countries). In: Program & Abstracts of XX European Congress of Herpetology, September 2–6, 2019, Milan, Italy, pp 229

Nekrasova O, Tytar V, Pupins M, Čeirāns A, Marushchak O, Skute A (2021a) A GIS Modeling Study of the Distribution of Viviparous Invasive Alien Fish Species in Eastern Europe in Terms of Global Climate Change, as Exemplified by *Poecilia reticulata* Peters, 1859 and *Gambusia holbrooki* Girarg, 1859. *Diversity* 13: 385, https://doi.org/10.3390/d13080385

Nekrasova O, Marushchak O, Pupins M, Skute A, Tytar V, Čeirāns A (2021b) Distribution and Potential Limiting Factors of the European Pond Turtle (*Emys orbicularis*) in Eastern Europe. *Diversity* 13: 280, https://doi.org/10.3390/d13070280

Pearson RG, Dawson TE (2003) Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? *Global Ecology and Biogeography* 12: 361–372, https://doi.org/10.1046/j.1466-822X.2003.00042.x

Pearson RG, Raxworthy CJ, Nakamura M, Townsend Peterson A (2007) Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. *Journal of Biogeography* 34: 102–117, https://doi.org/10.1111/j.1365-2699.2006.01594.x

Petitpierre B, Broennimann O, Kueffer C, Daehler C, Guisan A (2017) Selecting predictors to maximize the transferability of species distribution models: Lessons from cross-continental plant invasions. *Global Ecology and Biogeography* 26: 275–287, https://doi.org/10.1111/geb.12530

Pupins M (2007) First report on recording of the invasive species *Trachemys scripta elegans*, a potential competitor of *Emys orbicularis* in Latvia. *Acta Universitatis Latviensis Biology* 723: 37–46

Pupins M, Pupina A (2011) First records of 5 allochthonous species and subspecies of Turtles (*Trachemys scripta troostii, Mauremys caspica*, *Mauremys rivulata*, *Pelodiscus sinensis*, *Testudo horsfieldii*) and new records of subspecies *Trachemys scripta elegans* in Latvia. *Management of Biological Invasions* 2: 69–81, https://doi.org/10.3391/mbi.2011.2.1.09

Pupins M, Tytar V, Nekrasova O, Ceirans A (2019) Modelling co-occurrence patterns of the invasive Pond Slider (*Trachemys scripta*) and the native European Pond Turtle (*Emys orbicularis*) in Europe. In: Proceedings Joint ESENIAS and DIAS Scientific Conference and 9th ESENIAS Workshop "Species, ecosystems and areas of conservation concern under threat from the invasive alien species" September 3–6, 2019, Ohrid, Republic of North Macedonia, pp 89

Rödder D, Schmidtlein S, Veith M, Lötters S (2009) Alien invasive slider turtle in unpredicted habitat: a matter of niche shift or of predictors studied? *PLoS ONE* 4: e7843, https://doi.org/10.1371/journal.pone.0007843

Scalera R (2009) Species account of 100 of the Most Invasive Alien Species in Europe. Handbook of Alien Species in Europe, Springer, Berlin, 374 pp

Semenov DV (2009) Slider Turtle, *Trachemys scripta elegans*, as Invasion threat (Reptilia; Testudines). *Russian Journal of Biological Invasions* 1: 36–44 [in Russian], https://doi.org/10.1134/S2075111710040077

Swets JA (1988) Measuring the Accuracy of Diagnostic Systems. *Science*: 240: 1285–1293, https://doi.org/10.1126/science.3287615

Telecky T (2001) United States import and export of live turtles and tortoises. *Turtle and Tortoise Newsletter* 4: 8–13

Thuiller W, Brotons L, Araújo MB, Lavorel S (2004) Effects of restricting environmental range of data to project current and future species distributions. *Ecography* 27: 165–172, https://doi.org/10.1111/j.0906-7590.2004.03673.x

Supplementary material

The following supplementary material is available for this article:

Table S1. Occurrence points of *Trachemys scripta* in Latvia.

Table S2. Occurrence points of *T. scripta* in Ukraine.

Table S3. Bioclimatic variables in the CliMond dataset (Kriticos et al. 2014) used for the modelling.

Table S4. Eigenvalues of the correlation matrix table, we can see that the first four principal components explain ~ 90% of the variance.

Table S5. Component loadings of each variable.

Appendix 1. List of references for Tables S1–S5.

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http://www.reabic.net/journals/bir/2022/Supplements/BIR_2022_Nekrasova_etal_SupplementaryMaterial.xlsx