MODELLING THE RANGE EXPANSION OF PUMPKINSEED *LEPOMIS GIBBOSUS* ACROSS EUROPE, WITH SPECIAL FOCUS ON LATVIA AND UKRAINE

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Introduction. The pumpkinseed *Lepomis gibbosus* (Linnaeus, 1758) is a North American sunfish (*Centrarchidae*) that has been introduced to Europe in the late 19th century, and established in at least 28 countries across Europe and Asia Minor, however considered invasive in part but not all of its introduced range (Copp & Fox, 2007). Currently the species is not considered to spread to more northerly latitudes (the northernmost known reproducing population is situated in southern Norway), however *L. gibbosus* is predicted to become invasive to these areas under conditions of climate warming (Britton et al., 2010). While more than a century has passed since its initial introduction to Europe, the range expansion of this fish has continued across the continent (Yavno et al., 2020). Exploring limiting environmental factors may help to understand the key drivers of the suggested range expansion of the species and may at the same time help to establish efficient monitoring programs including risk assessments of *L. gibbosus* invasion. Our objective was to predict the possible geographic range of the fish based on presence records and environmental variables likely to be associated with habitat suitability. Thus findings of this study can inform enhanced surveillance efforts in Latvia and Ukraine where *L. gibbosus* has not yet been recorded but where the environment appears to be favorable for its establishment. The basic approach applied here is based on species distribution models (SDMs) often called ecological niche models (ENMs), where species' presence or absence are correlated with environmental variables prevailing in the respective locations in order to project the potential distribution of a species under current and/or future climatic conditions. These projections are based on statistical and/or machine learning algorithms, aiming at the best estimation of the species-environment relationship.

Materials and methods. Occurrence data was collected from the literature, FishBase (http://www.fishbase.org/) and an extensive search of social media (Facebook, Twitter etc.), resulting in a total of 1,263 and 1,386 non-duplicate records across Europe and North America, respectively. To calculate sampling bias, we used the nearest neighbor distance (NND) method to narrow the data, where occurrence points that were ≤0.2 units away from each other were removed to avoid errors due to spatial autocorrelation. In this study, 82 climatic (http://www.worldclim.com/) and topographic variables (http://www.earthenv.org/) were analysed in order to identify key factors that discriminate areas, where *L. gibbosus* is present from those where the species is absent. Highly correlated (>0.7) predictors were removed using the 'virtualspecies' package in R, resulting in a selection of 16: aspect, BIO1 = annual mean temperature, BIO2 = mean diurnal range, BIO3 = isothermality, BIO5 = max temperature of the warmest month, BIO7 = annual temperature range, BIO12 = annual precipitation, BIO13 = precipitation of the wettest month, BIO14 = precipitation of the driest month, BIO18 = precipitation of the warmest quarter, BIO19 = precipitation of the coldest quarter, elevation, precipitation in July, solar radiation in January, solar radiation in July, terrain wetness index. Six SDM methods were employed using the 'sdm' and 'embarcadero' packages in R. The area under the receiver operating characteristic (ROC) curve (AUC) was used for assessing the discriminatory capacity of the models: AUC>0.8 is considered excellent. A final consideration is whether to restrict the model to one based on native range data or data from the invaded range, or include both. This is important because the assumption of niche conservatism over space is not always met: niches of invasive species can differ from their natives, especially if there has been a long historical distribution of a species in its invaded range, just as in the case of *L. gibbosus*. We compared both niches in environmental space using one-way ANOSIM (https://palaeo-electronica.org) and found moderate but statistically significant dissimilarities ($R = 0.24$. $p<0.05$). Therefore, to avoid this bias, capable of affecting transferability, only invaded range data was incorporated in the modelling.

Results. The most accurate technique was the Bayesian additive regression trees (BART) algorithm (AUC = 0.87), while the least accurate technique was 'bioclim' (AUC = 0.64). In terms of variable importance, the highest contributing variables appear to be annual mean temperature, annual temperature range (a proxy for continentality), solar radiation in January (a characteristic period with low position of the sun, and consequently, with low radiation intensity). The hump-shaped relationship of these temperature-related factors with the predicted habitat suitability suggests them to be limiting factors at their extremes. Amongst water-related factors, precipitation in June appears to be the most essential. Increasing altitudes accounted for a lower number of sites with better habitat suitability. One assumption is that lower altitudes can be associated with a stronger influence of land use and other human disturbances (Holcomb et al., 2016) of which invasive species can take advantage (Pollux & Korosi, 2006). According to an ensemble model, predicted habitat suitability in Ukraine ranges between 0.10 and 0.69, with south of the country being especially favourable for the species. Expansion is expected to occur in the Dnister catchment and to a lower extent in the Lower Pripyat and its tributaries further to the west. In Latvia conditions are far less satisfactory: habitat suitability ranges between 0.06 and 0.21, with the Kurzeme province being most promising.

Conclusion. Environmental niche modeling together with an updated record of *L. gibbosus* in Europe enable to characterize the environmental conditions relevant to its distribution within the invaded range, and may help to establish efficient monitoring programs including invasion risk assessments.

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