Unveiling *Batrachochytrium dendrobatidis* distribution in Europe: Identifying threats and potential refuges for amphibians

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INTRODUCTION

Amphibians face significant threats due to climate change but also the widespread of the agent of the chytridiomycosis fungal disease *Batrachochytrium dendrobatidis* (Bd), posing severe risks to amphibians' survival. This study was aimed to uncover the influencing factors driving the geographic spread of Bd (Tytar et al., 2023) using species distribution models (SDM, BART algorithm). Our objective was to identify conditions that affect the geographic distribution of this pathogen using species distribution models (SDMs) with a special focus on Eastern Europe. SDMs can help identify hotspots for future outbreaks of Bd but perhaps more importantly identify locations that may be environmental refuges ("coldspots") from infection. In general, climate is considered a major factor driving amphibian disease dynamics, but temperature in particular has received increased attention. Here, 42 environmental raster layers containing data on climate, soil, and human impact were used. Later on, the results of this study were confirmed by verification of the built models through countrywide screening of samples collected from all over Ukraine (Jakóbik et al., 2024, preprint).

Figure 1. *Bufotes viridis* (Laurenti, 1768) (green toad, left) and *Hyla orientalis* (Bedriaga, 1890) (eastern tree frog, right) from Pishcha village, Volyn region, Ukraine, from which Bd was confirmed by PCR test (Jakóbik et al., 2024).

MATERIALS & METHODS

We analyzed only Bd records from European localities. Global niche descriptions do not account for local invasive range specifics. Studies using invasive range records alone have shown accurate predictions for invasive species expansion.

SDMs were built in Maxent using:

1) 19 bioclimatic WorldClim variables indicating precipitation and temperature trends;
2) 16 climate and 2 topographic variables from ENVIREM relevant to species distributions;
3) Topography data from EarthEnv for spatial heterogeneity;
4) Land cover metrics from EarthEnv;
5) Soil variables from Sun Yatsen University.

To address predictor collinearity, we used the 'removeCollinearity' function in the 'virtualspecies' R package. A presence-only approach was chosen, employing Bayesian additive regression trees (BARTs) to compute habitat suitability (0 to 1). The 'Boruta' algorithm in R created a custom predictor set for a consensus model, with input prepared using 'flexsdm' R package functions.

Models were evaluated using AUC and TSS. A 50% habitat suitability threshold was used to analyze the impact of key variables. Habitat suitability maps in GeoTIFF format were processed in SAGA GIS, and statistical data were analyzed using PAST software and/or R.

Results and discussion

Analyzing 42 diverse environmental layers comprising climate, soil, and human impact data, revealed that 'Continentality' and 'Cultivated and Managed Vegetation' were the prominent predictors of Bd distribution, especially impacting Western Europe. Our models identified Eastern Europe (including Central and Eastern Ukraine, Belarus, and Latvia) as potential environmental refugium. Our analysis indicated that suitable areas in Ukraine for Bd are predominantly situated in the western parts of the country, particularly within and around the Carpathian region and the marshy forest area of the Polissia zone. Given that the Carpathians and forest regions harbor the highest amphibian species diversity in Ukraine, these findings underscore the significance of protecting these regions for amphibian conservation efforts. This research serves as a foundation for future chytridiomycosis investigations and, also, underscores the urgent need for collaborative efforts among scientists, policymakers, conservationists, and the public to protect amphibian populations, especially from fungal diseases through preventive measures. Taking into account the results of ground verification – the applied method of GIS-modelling for predicting of potential distribution of Bd is useful and effective to be included in management of amphibian populations in the wild.

Figure 2. **(A)** Partial response curve for 'Open water' (%); **(B)** Partial response curve for 'Cultivated and Managed Vegetation' (%).

Figure 3. **(A)** Partial response curve for Min. Temperature of Coldest Month (°C × 10); **(B)** partial response curve for Continentality (°C).

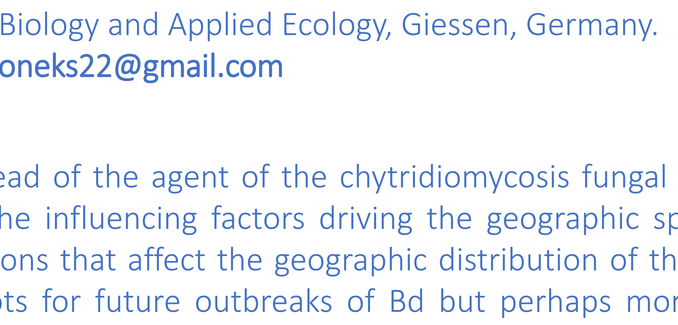

Figure 4. Map of sampled regions in Ukraine (A) and selected localities in Volyn (B), Chornobyl Zone (C) and Chernivtsi (D) regions. Pie charts show proportions of samples positive for Bd, chart size is proportional to sample sizes. Habitat suitability values from Tytar et al. (2023) are overlaid on the map in A. The map was taken from another article, dedicated to screening of the country on presence of Bd (Jakóbik et al., 2024, preprint), where O. Nekrasova and O. Marushchak are co-authors.

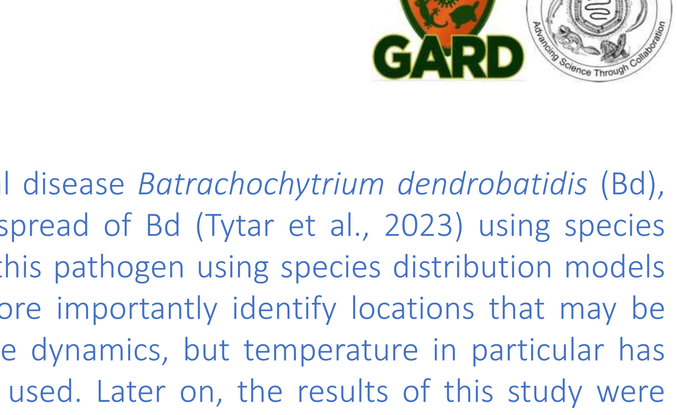

Figure 5. Habitat suitability map for Bd in Ukraine; the legend shows habitat suitability ranging from high (red) to low (blue). 1—Carpathian region; 2—forested (Polissia) zone; 3—wetlands along the Dnipro River; 4—wetlands in the Lower Danube area, 5—Crimea.

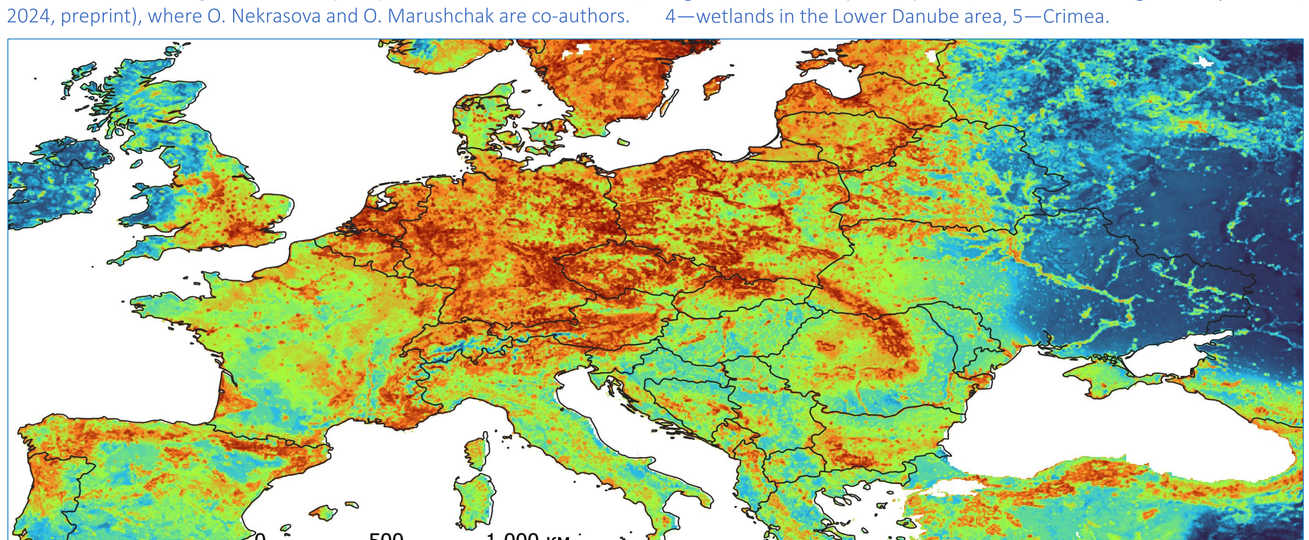

Figure 6. Habitat suitability map for Bd in Europe; the legend shows habitat suitability ranging from high (red) to low (blue).

Conclusions

- "Continentality" and "Cultivated and managed vegetation" are the main factors influencing the distribution of the amphibian fungus Bd.
- Western Ukraine, especially the Carpathians, is a suitable environment for Bd. What our research confirmed for the first time (Jakóbik et al., 2024, preprint).
- Eastern Europe may be a refuge for amphibia from Bd - "Coldspot".
- Further research and biosecurity measures are needed to protect amphibians from Bd.

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