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Species Distribution Modelling: *Bombina bombina* (Linnaeus, 1761) and its Important Invasive Threat *Perccottus glenii* (Dybowski, 1877) in Latvia under Global Climate Change

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Amphibians are greatly affected by invasive species through direct predation and competition. Being triggered by climate change, the invasion of *Perccottus glenii* (the Chinese sleeper) in Eurasia may have detrimental consequences for the fire-bellied toad (*Bombina bombina*). The invader can feed upon *B. bombina* toads and juveniles and compete for food. We used correlative species distribution models (SDMs) to infer competitive interaction between the invader and native species. As a result, a significant level of correlation (r=0.636) between both SDMs was found. It means that there is a considerable overlap of areas of similar habitat suitability related to the species and a potential for competition. For strategical management of both species in Latvia for nature

conservation purposes, we mapped areas in the country according to two main criteria: 1) the lesser chances of negative interactions between species, and 2) a possibility to avoid unwanted contact and/or competition between the fish and the toad.

Keywords: *Bombina bombina*, *Perccottus glenii*, climate change, invasive species, *Maxent*.

Introduction

Humans have spread non-native animals and plants around the world at an unprecedented rate in the last century. The establishment and spread of exotic species form a major threat to biodiversity worldwide. Amphibians have been greatly affected by introduced species through direct predation and competition. Recent studies have found that many factors of decline, such as habitat modification, chemical contaminants, UV-B and disease, work synergistically to exacerbate the negative effects of invasive species on native amphibians (AmphibiaWeb, 2018; Korzikov, 2016).

Invasive species are considered competitive to native species. The strength of such competition depends on the extent species niches overlap. Understanding of interactions between invasive species and other species is challenging but essential for quantifying effects on local communities. It helps develop practical approaches to biodiversity long-term management as well. Understanding of spatial patterns of invasion and the identification of the areas most at risk of invasion are particularly important. These two investigation steps may be used to determine preventive measures that are cheaper and/or more effective than those applied at later invasion stages (Leung et al., 2002; Hulme, 2006).

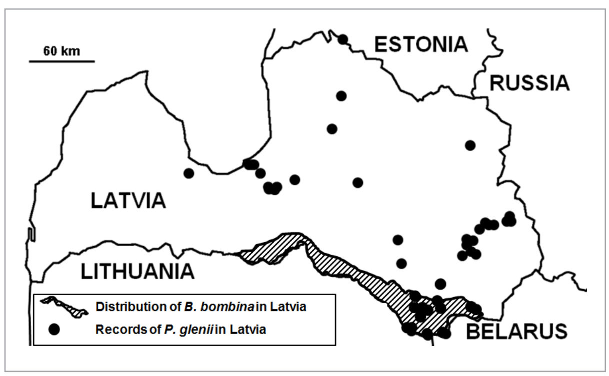
Much of the current knowledge on community interactions comes from laboratory and field studies. Anyway there is a need to develop novel approaches. The importance of predicting species distributions is rapidly increasing as global climate changes and their influence on native ecosystems intensify. Scientists or biodiversity conservation managers may need to locate and protect rare or endangered species populations, or identify habitat that may be threatened by invasive species. These are two of many reasons for the need of accurate predictive tools (West et al., 2016). Species distributions vary according to an array of biological and physical conditions underlying the fundamental niche (Hutchinson, 1957). Correlative species distribution models (SDMs) also provide a tool that enhances our understanding of this niche in geographic space. Today SDMs are the prime tools used to assess the species spatial distribution and explore their habitat suitability requirements (Franklin, 2009; Miller, 2010). The maximum entropy model (Phillips et al., 2006) is one of the most widely used presence-only SDMs.

Although exotic and native species may coexist in many modern habitats, conservation efforts typically focus on single-species management (York et al., 2011). In this study, we investigate the widespread and rapid invasion of *Perccottus glenii* (Dybowski, 1877) (the Chinese sleeper) in Eurasia triggered by climate change and its potential impact on native biota using the maximum entropy modelling approach.

P. glenii is widely distributed in Central and Eastern Latvia (Pupina et al., 2015). The territories occupied by this species are also inhabited by the fire-bellied toad (*Bombina bombina* L., 1761) (Pupina, Pupins, 2008). The latter one is a rare and protected amphibian species in the European Union (Bern Convention, 1979) and in Latvia (Ministru, 2000) (Fig. 1). *B. bombina*

Fig. 1

Overlapping areas of *B. bombina* and *P. glenii* distribution in Latvia (Pupina et al., 2015; unpublished data of the authors)



inhabits only south-eastern Latvia on the extremely northern border of its European range. Here this species experiences hard press of cold Latvian climate and, therefore, can be very sensitive to climate change.

Negative interactions are likely to occur between this fish invader and the fire-bellied toad, as in Baltic countries "fish of all kinds are by far the most important predators for *B. bombina*" which "do not spawn if fish are presented in the water" (Fog et al., 2011).

According to modern studies, *B. bombina* tadpoles are predated and traumatized by *P. glenii* in invaded ponds in Latvia (Pupina et al., 2015; Pupina, Pupins, 2016, original data of the authors) (Fig. 2).

Fig. 2

B. bombina tadpole heavily traumatized (amputation of tail) by *P. glenii* in an invaded pond in Latvia (Fog et al., 2011, photo by the authors)

"Observations from Latvia indicate that *P. glenii* prey on *B. bombina* tadpoles and newly metamorphosed specimens and may even eat adults" (Fog et al., 2011). During the last 30 years, the most stable Latvian *B. bombina* population was registered every year in a "Round pond" – one of the best Latvian biotopes for this species. This biotope was invaded by *P. glenii* in 2006, when the species was observed in a quantity up to 20 individuals per 1 m^2. After summer desiccation of the pond, more than 80 *P. glenii* per 1 m^2 (total body length was about 6–9 cm) were found here (Pupins, Pupina, 2006). In 2006–2007, *B. bombina* tadpoles or vocalizing males were not observed here (Pupina, Pupins, 2008).

The biggest *P. glenii* specimen registered in Latvia (Trikarta lake, Daugavpils) had a body length of 30.8 cm including caudal fin and weight of 693.6 g (Pupina et al., 2016). Potentially, such big individuals can prey on adult amphibians of most Latvian species (Fig. 3).

Therefore, according to the official Plan of *B. bombina* conservation in Latvia, *P. glenii* is considered to be an important threat for the species (Pupins, Pupina, 2006).

Both the fish and the toad species have been modeled individually at the landscape level (Peterson et al., 2009; Reshetnikov, Ficetola, 2011; etc.). However,

Fig. 3

Big Chinese sleeper registered by authors in Daugavpils, Latvia

their distribution has not been comparatively modeled for the same landscape for exploring potential overlap of habitats, predation and competition.

It was especially important to take into account the various trends in the distribution of animal species in changing climatic conditions. The Latvian State Agency for assessing the climate change impact in the country "Latvian Environment, Geology and Meteorology Agency" (Latvian State Agency, 2018) indicates that, according to the results of their analysis of temperature changes, local warming can only increase over time (according to different scenarios).

Methods

The algorithm used in this paper, *Maxent*, has proven good performance and accuracy for SDM studies (Elith et al., 2011). *Maxent* is a machine learning algorithm. Its main advantage in comparison with other methods is that it only needs the species presence point data, besides the environmental layers. Pseudo-absence points are randomly generated and used instead of true absences. *Maxent* provides output data in various formats. The logistic format (values range from 0 to 1) is recommended, because it allows an easier and potentially more accurate interpretation of habitat suitability compared with the other approaches (Baldwin, 2009). The performance of the *Maxent* models is evaluated by the receiver operating characteristic (ROC) approach and calculating the area under the ROC curve (AUC) as a measure of prediction success. Values greater than 0.5 indicate a better-than-random performance event, and higher values of 0.7–0.8, 0.8–0.9, and 0.9–1.0 are considered of "good", "very good" and "excellent" performance, respectively (Swets, 1988).

We used the Worldclim climate data set – a set of global climate layers (gridded climate data). Thus, 5 arcmin resolutions were used. They included temperature, precipitation and 19 bioclimatic variables derived from monthly temperature and rainfall values in order to generate biologically meaningful variables. These are often used in SDMs and related modeling techniques. The bioclimatic variables represent annual trends, seasonality, extreme and/or limiting environmental factors (Hijmans et al., 2001, 2005).

Our database on *B. bombina* consisted of 2,277 georeferenced point data (Tytar, Nekrasova, 2016; Tytar et al., 2018a; Tytar et al., 2018b) and 445 for *P. glenii* (Kutsokon, 2017). All data were extracted from a variety of online and published sources, including GBIF.org (2018), Sillero et al. (2014), Reshetnikov (2010, 2013), Kutsokon et al. (2014), Pupina et al. (2015), Pupina, Pupins (2008, 2016), and authors' original unpublished data. To avoid overemphasizing on heavily sampled areas, we selected points for model calibration using a subsampling regime to reduce sampling bias and spatial autocorrelation (Nuñez, Medley, 2011). We generated models using all available occurrence points and measured spatial autocorrelation among model's pseudo-residuals by calculating Moran's *I* at multiple distance classes using the SAM v4.0 software (Rangel et al., 2006). After that, the spThin package in R (Aiello-Lammens et al., 2015) was used to subsample our datasets. Occurrence records were separated by the first distance lags and were found to be positively spatially autocorrelated.

The resulting habitat suitability grids were clipped in SAGA GIS (Conrad et al., 2015) to the boundaries of Latvia and then processed and analyzed concerning their level of similarity/correlation. Statistical data were analyzed using the PAST software package (Hammer et al., 2001).

Results and Discussion

B. bombina is a very rare and strictly protected species of Latvia batrachofauna represented by only a few populations with low numbers of individuals within this country. Before 2004, only two very small (~10 vocalizing males in each) populations were known from its territory: the "Bauska" population in Bauska District and the "Ilgas" population from Daugavpils District (Pupina, Pupins, 2007). Since 2006, the number of new *B. bombina* populations' finds has increased (Pupina, Pupins, 2008; 2013). However, this species is still very rare and requires special protection measures (Pupins, Pupina, 2006).

In our opinion, the distribution of this amphibian species in the northern border of its range may be related to climate change, vegetation cover and other factors

(Kuzmin et al., 2008; Tytar, Nekrasova, 2016; Tytar et al., 2018a, 2018b).

The study of aquatic species' effects on the fire-bellied toads' abundance has shown that invasive fish species *P. glenii* can heavily affect *B. bombina* populations (Fog et al., 2011; Pupina et al., 2015; Pupina, Pupins, 2008; 2016). "Invasive fish species are serious threats. Carps, eel and other fish prevent breeding success of *Bombina* completely. Not only do the tadpoles not survive; adults refrain from spawning the water contains fish. The toads will emigrate to other localities if possible." (Fog et al., 2011). *P. glenii* continues invading new ponds in Latvia: in 2017–2018, we found the species in 16 new ponds in South-Eastern Latvia. In all these cases, *B. bombina* was not found in the ponds. We predict that invasions of *P. glenii* can influence the distribution of *B. bombina* and reduce its range and the number of populations in Latvia.

The thinning procedure greatly reduced sampling bias and spatial autocorrelation, resulting in evenly distributed occurrence points across geographical space. Finally, we retained 1,742 and 97 occurrence records for the fire-bellied toad and the Chinese sleeper, respectively. These numbers of records were considered sufficient to generate robust SDMs (Hernandez et al., 2006).

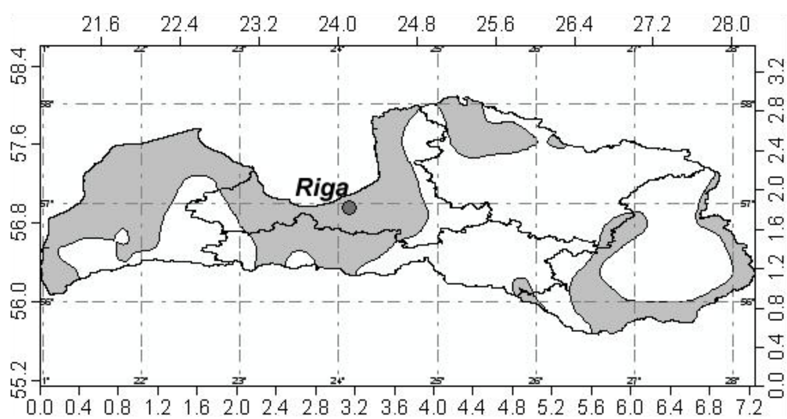
The average AUC scores (± standard deviations, SD) for our *Maxent* models were 0.856±0.002 SD and 0.838±0.012 SD for *B. bombina* and *P. glenii*, respectively, which can be considered to be a "very good" fit and indicate a high discriminatory capacity of the models in both cases (i.e., the *Maxent* models were significantly better than random).

SDMs can be useful to infer competitive interaction (e.g., Wellenreuther et al., 2012), particularly if the considered species occupy the same niche. We assume that such interaction will have the potential to be stronger in areas where predicted habitat suitability for both species is high. At the very least, it means that in such places there are greater chances for them to contact with each other.

Using the "Scatterplot" function in SAGA GIS, we found a statistically significant level of pixel-by-pixel correlation (r=0.636; t=15.3, n=347) between both SDMs. There is a considerable overlap of areas of similar habitat suitability related to the species and a potential for competition. For strategical management purposes, we considered mapping areas in Latvia where differences between predicted bioclimatic habitat requirements for both species vary from the lowest to the highest values. This can help to select conservation areas of high values avoiding unwanted contact and/or competition between the fish and the toad, especially in cases of *B. bombina* (re)introduction to support the protected species populations. The map (Fig. 4) denotes areas where differences between predicted bioclimatic habitat requirements

Fig. 4

Map of areas in Latvia (gray shaded) where differences between predicted bioclimatic habitat requirements of *B. bombina* and *P. glenii* are above the median and where there are lesser chances for negative interactions between the both species



of both species in Latvia are above the median and where negative interactions between them are less likely to occur.

In conclusion, we note that predictions may be a risky venture, but this does not stop managers and policy makers from asking scientists and experts to set priorities or give guidelines on it for rapid response and control of invasive species (Holcombe et al., 2010). Predictions based on SDMs are a simple tool to assess the potential spread of a certain species. They are particularly important for invasive species at early stages of the invasion process that might not have filled all of their niches being yet far from establishing a full-scaled impact on native species.

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