

Distribution of Viviparous American Fish Species in Eastern Europe on the Example of *Gambusia Holbrooki* Girarg, 1859 and *Poecilia Reticulata* Peters, 1859 in the Context of Global Climate Change [†]

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Abstract: Potential distribution of tropical fish species in Eastern Europe—*Gambusia holbrooki* Girarg, 1859 (introduced for biological control) and *Poecilia reticulata* Peters, 1859 (aquarium species, found in waste waters of big cities) tend to be of particular interest in terms of global climate change. After GIS modeling of our own data and findings listed in the GBIF databases (2278 points for *G. holbrooki* and 1410 points for *P. reticulata*) by using the Maxent package, 18 uncorrelated variables of 35 Bioclim climatic parameters from CliMond dataset, it was found out that by 2090 guppies will appear in the south of Ukraine (Danube river's estuary, as well as in several places in the Caucasus and Turkey with habitat suitability >0.3–0.5). *G. holbrooki* will also slightly expand its range in Europe. Limiting factors for *G. holbrooki* distribution are: bio1 (Annual mean temperature, optimum +12–+23 °C) and bio19 (Precipitation of coldest quarter (mm)). Limiting factors for guppies are: bio1 (optimum +14–+28 °C), bio4 (Temperature seasonality), bio3 (Isothermality). Guppies, unlike *G. holbrooki*, prefer warmer waters (correlation 0.02). Such thermophilic fish species do not compete with the native ichthyofauna, but they can occupy niches in anthropogenically transformed habitats, playing an important role as agents of biological control.

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1. Introduction

Considering the prospects associated with the appearance of invasive species of animals on a new continent, some of the possible consequences of such actions are usually missed. It is often expected that the distribution and naturalization of invasive species can be controlled. But this is not always possible since in open biosystems (natural and anthropogenic), in addition to human activity, the influence of changing climatic conditions takes place. However, the influence of all these negative factors in the complex can lead to the suppression of native animal species [1] and the emergence of species new to the

local environment, which can actively displace not only representatives of the ichthyofauna, but also batrachofauna [2]. Therefore, the main questions that we must ask ourselves are as follows: (1) what environment is preferable (optimal) for an invasive species and in which regions naturalization and appearance of the species is possible; (2) what consequences of this appearance could be for native species and the environment in general. Of great interest is the appearance (or prospects of appearance) in temperate latitudes of thermophilic poikilothermic animals with their own strategy of viviparity, which gives them the opportunity to reproduce even in unfavorable conditions, for example, in human transformed territories. They also thrive and reproduce in both fresh and brackish water. Representatives of the genera *Gambusia* and *Poecilia* came to Europe as agents of a biological method for controlling the malaria mosquito at the beginning of the 20th century (they were released into the reservoirs of Western Europe). In addition, previously they also were bred in quantities in aquarium farms as aquarium fish. Two closely related species of this genus were introduced in Europe for the above mentioned purpose: *Gambusia affinis* (Baird et Girard, 1853) and *Gambusia holbrooki* (Girard, 1859), but the latter species is the most widespread and occurs in Ukraine.

Gambusia holbrooki is a viviparous freshwater fish species (Poeciliidae family) originating from southern areas of North America. The species demonstrates great plasticity in the preference of comfortable water temperatures, thriving at +31–+38 °C, but being able to survive both below and above these values [3]. This planktivorous species was used as an agent of biological control and was introduced in 1921 to the Iberian Peninsula for the first time to combat mosquito populations that played significant role in distribution of malaria. Later on the fish expanded area of its invasion to Italy in 1922 and other Mediterranean countries like Greece, Croatia, Spain etc. [3]. Currently this invasive species is well known from about 50 countries worldwide [4,5]. Besides being used for control of mosquito populations, this species is known to have negative effects on local populations of aboriginal amphibian and fish species [6,7], which makes studying of its potential distribution in terms of global climate change of particular importance in order to preserve local biodiversity.

Poecilia reticulata is another viviparous freshwater fish species from North America that became invasive in Europe over recent decades. The wild form of the guppy was introduced to Europe in the 19th century. It was also used in the fight against malaria, so it was introduced to many places. Being popular polymorphic aquarium species and due to their better resistance to colder water (up to +12 °C), guppies became invasive as a result of many accidental releases from aquaria [8,9]. Their ability to store sperm for months made it possible even for a one single gravid female to start a new population [10]. A wild population of guppies permanently lives in the Moskva river in the area of warm water discharge in Lyubertsy (Kuryanovsk drains) and in other places of this river [11,12]. Recently, in the Upper Volga basin, numerous self-reproducing populations of guppies have been noted in the regions of large cities (Tver, Yaroslavl, Rybinsk) in the areas of heated water discharge, as well as in settling ponds in facilities for the purification of domestic wastewater [13,14]. In their homeland, the island guppy populations live in brackish and seawater, they are bright in color and large in size. Optimal conditions for guppies include: clean water with a temperature of about +24 °C (lives in the range of +16–+30 °C), the presence of zones with vegetation and free for swimming, a varied diet with a substantial proportion of live food. There are no data on the biology of this species from the Moskva river. It is known that there it reaches a high number and can be caught with a net in large numbers. For water bodies of the Upper Volga, there is an indication that it does not occur in water bodies with a temperature lower than +17 °C [14].

Such assumptions about the appearance and distribution of these species in Eastern Europe are most relevant in connection with their potential usage as agents of biological control against the emergence of new carriers of various diseases-blood-sucking insects

[15]. Therefore, the purpose of our work was to study both climatic indicators of environmental optima for these invasive species, and the possibility of the spread of these species over Eastern Europe in space and time.

2. Materials and Methods

Occurrence data was collected from the original datasets [16], collection materials (I. I. Schmalhausen Institute of Zoology, National Academy of Sciences of Ukraine, Kyiv, Ukraine), GBIF databases [18,19]-all non-duplicate. To account for sampling bias, we used the nearest neighbor distance ('ntbox' package in R [20]) method to thin the data, where occurrence points that were ≤ 0.1 units away from each other were removed to avoid errors due to spatial autocorrelation. As a result, the number of points has significantly decreased: from 26,140 total points to 2278 for *G. holbrooki* and to 1410 points from 4200 points for *P. reticulata*.

Ecological niche modeling and species distribution modelling (SDM) methods have been used to determine the potential home range of invasive species in new environments (MaxEnt [21] with 35 replicates, DivaGis (Bioclim). We used bioclimatic variables from the CliMond dataset [22,23]. Of 35 bioclimatic variables, highly correlated (>0.7) predictors were removed using the 'virtualspecies' package in R, resulting in a selection of 18 for 1975 (1970–2000), 2030 (2021–2040), 2090 (2081–2100). The area under the receiver operating characteristic (ROC) curve (AUC) was used for assessing the discriminatory capacity of the models: $AUC > 0.9$ is considered excellent. GIS-modelling was accomplished using SagaGis, DivaGis, QGis [24]. Statistical processing of the obtained data was carried out using Statistica for Windows v.8.0.

3. Results

3.1. Limiting Factors for *P. reticulata* Distribution

As a result of GIS modeling, it was revealed that the limiting and important factors (percent contribution) for the distribution of guppies are: bio4 (Temperature seasonality)-21.9%, bio3 (Isothermality)-10.6%, bio23 (Radiation seasonality (C of V))-8.1%. Annual mean temperature (bio1) has optimum $+14$ – $+28$ °C (marked in green, Figure 1a). In this "ecological envelope" 68.1% of the guppies are found in the temperature range $+10$ – $+28$ °C (Figure 1a), DivaGis, Bioclim). The temperature of $+10$ °C may have appeared as a result of extrapolation to northern areas, where warm drains are located (in large cities, etc.). According to our observations of "wild" populations of guppies in warm water bodies of the Bortnychi aeration station in Kyiv (2011–2020; 50.3837 N, 30.6642 E, Ukraine), these fish are quite unpretentious in terms of water quality and are generally demanding to the water temperature. The total body length in males is 1.85–3.24 cm, and in females-2.00–5.50 cm. Guppies breed all year round and even in winter in warm sewage waters, in December 2020 (water temperature $+16$ °C) mainly juvenile individuals were registered.

3.2. Limiting Factors for *G. holbrooki* Distribution

On the contrary, mosquitofish can coexist in open water bodies outside the warm wastewaters of large cities and anthropogenic areas, in western and southern parts of Europe, as well as in Ukraine-in the Odessa region and Crimea [17]. As a result of GIS modeling, it was revealed that the most important factors (percent contribution) that limit the distribution of *G. holbrooki* in Europe are: bio21 (Highest weekly radiation (W m⁻²))-26.2%, bio19 (Precipitation of coldest quarter (mm))-18.6% Annual mean temperature (bio1, 14.7%) has the optimum $+12$ – $+23$ °C (marked in green, Figure 1b). In this ecological envelope 68.7% of *G. holbrooki* finds are in the temperature range of $+11$ – $+24$ °C (Figure 1b), DivaGis, Bioclim). This fish is also able to reproduce throughout the year as long as the water temperature is above $+15$ °C (April–November). An interesting fact is that at a water temperature below $+10$ °C *G. holbrooki* burrows into the silt and falls into a suspended anabiosis. During severe winters when reservoirs are bound by ice, *G. holbrooki* perishes

in great numbers. For instance, this species died en masse as a result of the cold winter in Sochi in 2020 [25].

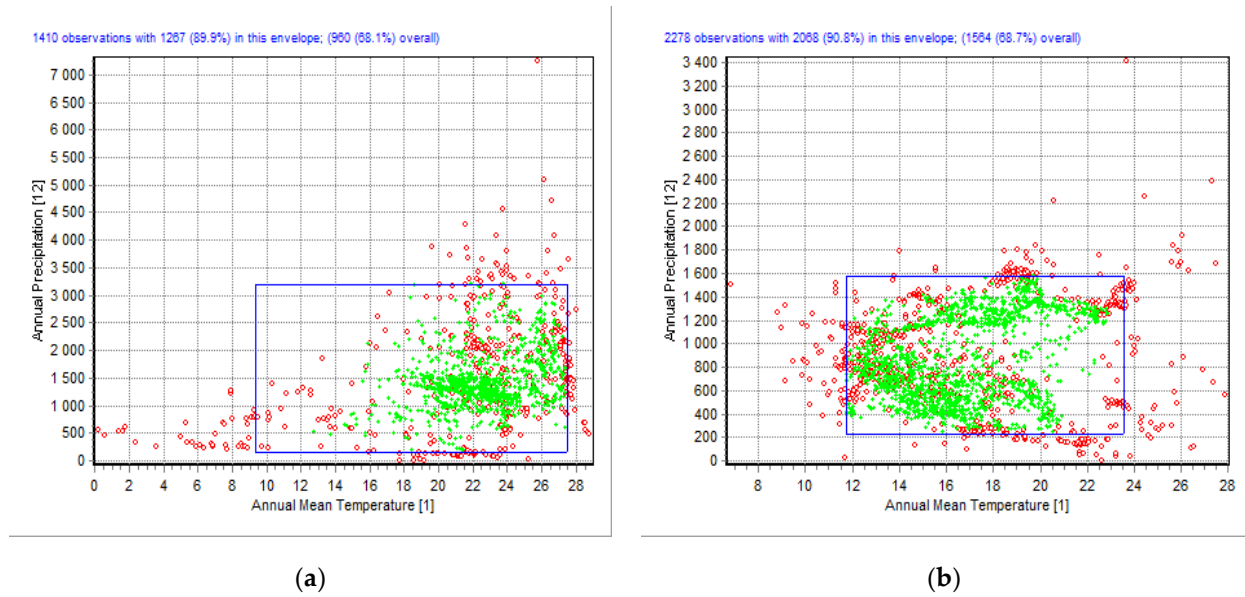


Figure 1. “Ecological envelope” (DivaGis): (a)-*P. reticulata*; (b)-*G. holbrooki*.

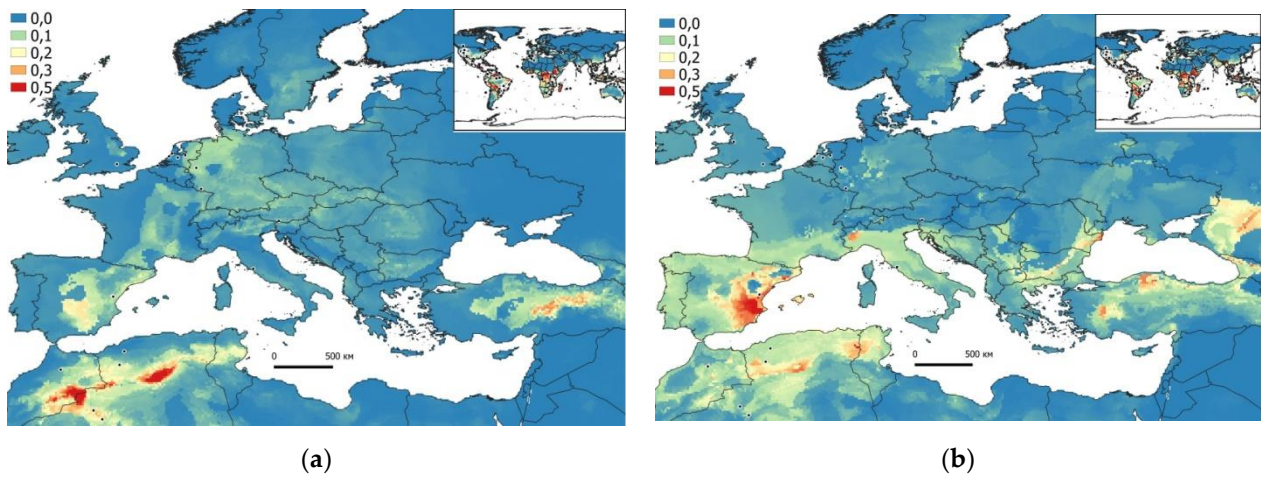


Figure 2. Potential (probabilistic) model of *P. reticulata* expansion built in the Maxent program based on the CliMond (a—1975 (1970–2000); b—2090 (2081–2100)) climatic data and GBIF data (2019). Areas of the highest habitat suitability (>0.3–0.5) are colored in red and areas of the lowest (<0.1)-in blue.

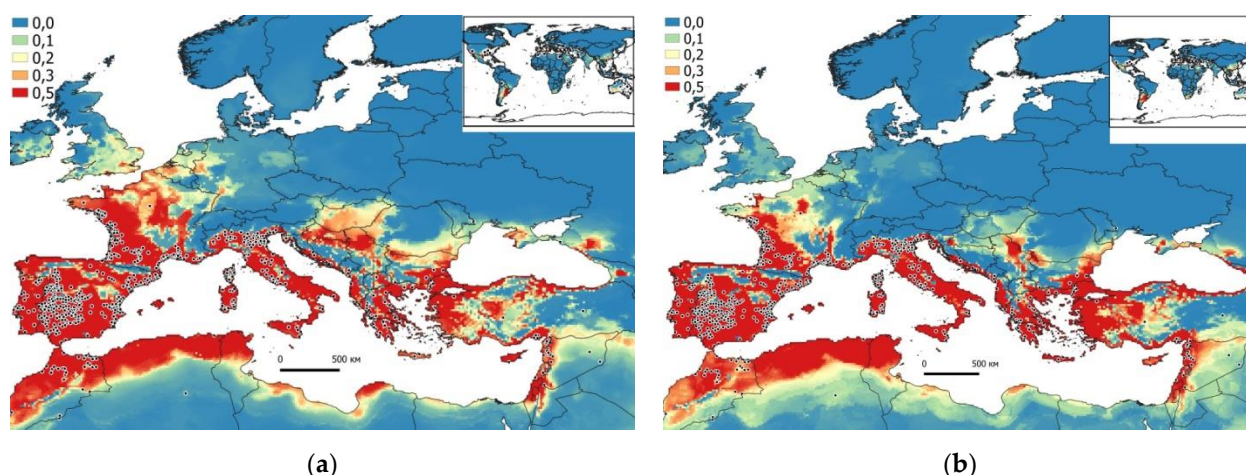


Figure 3. Potential (probabilistic) model of *G. holbrooki* world expansion built in the Maxent program based on the CliMond (a—1975 (1970–2000); b—2090 (2081–2100)) climatic data and GBIF data (2019). Areas of the highest habitat suitability (>0.3–0.5) are colored in red and areas of the lowest (<0.1)-in blue.

Despite the fact that these American viviparous fish species are thermophilic, they occupy different ecological niches, which certainly do not coincide with native northern fish species. To compare the SDM models (Maxent, 2030 (2021–2040)) of two species of American fish we using the regression module in DivaGis; the resulting correlation coefficient was only 0.02.

4. Discussion

As a result of GIS modeling, climatic factors have been identified that allow new alien species to inhabit southern Europe in the future. However, in our opinion, despite the fact that in the “warm countries” of Europe, these fish, especially mosquitofish, can pose a threat, by consuming eggs of fish and amphibians of the ‘Critically Endangered (CR)’ yellow-spotted tree frog (see *Litoria castanea* in IUCN Red List of Threatened Species); the ‘Endangered (EN)’ green and gold frog (see *Litoria raniformis* in IUCN Red List of Threatened Species); and the ‘Vulnerable (VU)’ golden bell frog (see *Litoria aurea* in IUCN Red List of Threatened Species) in Australia (NSW National Parks & Wildlife Service, 2004 [26]). In the more northern regions of Eastern Europe in a changing climate such thermophilic fish species do not compete with the native ichthyofauna, but they can occupy their niche in new habitats, playing an important role in ecosystems and for biological control (especially in anthropogenic areas) in a changing climate.

5. Conclusions

As a result of GIS modeling of collected data it was found out that by 2090 (2081–2100, Figure 2b) the appearance of guppies in the south of Ukraine is possible (the estuary of the Danube river, as well as in several places in the Caucasus, Turkey, lower part of the Don river (>0.3–0.5, Figure 3b). *G. holbrooki* will also slightly expand its range in Europe, as well as in Ukraine, namely in Crimea peninsula, western part of the Black Sea region and the Danube estuary (Figure 3b).

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Abbreviations

The following abbreviations are used in this manuscript:

SDM	species distribution model
ROC	receiver operating characteristic
AUC	receiver operating characteristic curve
CR	Critically Endangered
EN	Endangered
VU	Vulnerable

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