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Invasion Potential of Ornamental Terrestrial Gastropods in Europe Based on Climate Matching

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Abstract: Invasive species are one of the main causes of biodiversity loss worldwide. Pet trade is a well-known pathway for the introduction of non-native species. Prevention is the most effective, least time-consuming, and least financially demanding way to protect biodiversity against the spreading of invasive species. The main part of prevention is the early detection of a potentially high-risk species, as well as the successful implementation of prevention strategies in legislation and practice. This study summarizes the pre-introduction screening of pet-traded terrestrial gastropod species and their potential occurrence in the EU territory. Based on the list of species traded in the Czech Republic, one of the most important global hubs of the pet trade, 51 species (49 snails and 2 slugs) were analysed. Due to a lack of certain native occurrence data, only 29 species (28 snails and 1 slug) from 10 families were modelled using MaxEnt software. Twenty species from seven families have potential occurrence in the EU territory. Based on MaxEnt modelling, we considered the following species to be high-risk candidates for the EU: *Anguispira alternata*, *A. strongylodes*, *Laevicaulis alte*, *Megalobulismus oblongus*, *Rumina decollata*, and *R. saharica*. Based on this estimation, we present considerations with which to further improve the risk assessment and recommend continuous monitoring of the pet trade market.

Keywords: MaxEnt; invasive species; pet trade; snail; slug; biodiversity loss

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1. Introduction

Anthropogenic activities have a substantial influence on biodiversity, as shown in [1–3]. Human globalization has overcome natural geographical barriers limiting the spread of organisms, which are removed from their native range in large numbers [4–6]. In this, gastropods are not an exception. Even if certain species have only been reported from greenhouses [7–9], various terrestrial gastropods (so-called "land snails and slugs") are classified as invaders or at least potentially invasive species due to their significantly negative impact on native biota and entire ecosystems [6,10–12]. Invasive land snails are occupying free niches, out-competing native species, e.g., for food resources or predation on native species, and also serve as hosts and vectors of non-native pathogens [13,14].

Lissachatina fulica (Bowdich, 1822) is an invasive species in many countries worldwide [10,11]. It negatively impacts plant production, the diversity of invertebrates and native plant species, and serves as a vector of parasites and pathogens [15,16]. Another example is *Cornu aspersum* (Müller, 1774), a species native to the Mediterranean region and Western Europe. In California and Florida, *C. aspersum* is an agricultural and garden pest causing great socio-environmental losses annually [17].

Irresponsible management practices support biological invasions. For instance, *Euglandina rosea* (Férussac, 1821), *Gonaxis* spp. and *Rumina decollata* (Linnaeus, 1758) were intentionally introduced to control previously introduced pest snails; however, paradoxically, they preyed on native species instead of invasive ones [18–20], causing the extinction of several endemic gastropod species in some Pacific islands [6].

Terrestrial gastropods have a relatively low ability for active dispersal [21–23]. Over longer distances, they spread through passive dispersal using various vectors [24]. Live gastropods are transported in the digestive tract of their predators such as birds [25,26], by adhesion on the body surface of vertebrates [27], or by attaching to transferred material such as food and nesting material [28,29]. Many examples of the spreading and subsequent establishment of terrestrial gastropods out of their native range are associated with human activities such as the unintentional transport of commodities, agriculture, pet trade, medical reasons, and farming for human consumption [6,11,30–32]. Many invasive species have been introduced via different pathways and for various purposes that are poorly studied, such as *Arion subfuscus* (Draparnaud, 1805), *Bradybaena similaris* (Férussac, 1822), *Deroceras reticulatum* (Müller, 1774), *Sarasinula plebeia* (Fischer, 1868), and *Elisolimax flavescens* (Keferstein, 1866) [33–36]. Mostly, the continuously increasing local and international pet trade has been identified as one of the major sources of invasive species worldwide [1,37–40].

Wittenberg and Cock [41] suggested four basic strategies for handling non-native species: (1) prevention, (2) early detection, (3) eradication, and (4) control. Among these strategies, prevention involves the identification of potential future invaders before their introduction, and early detection and eradication of harmful invasions soon after establishment are often seen as the most effective approaches [42]. The prevention of new introductions is the most successful; moreover, since early detection is difficult, controlling the species can be very expensive, and its total eradication may be impossible in many cases. Even where an optimal non-native species policy involves a combination of all aforementioned strategies [43], the role of prevention is crucial. Prevention integrates environmental modelling and risk assessment, general public education, monitoring of introduction pathways, and the improvement of legislation (e.g., regulation of trade) [44,45]. In the case of environmental modelling, a climate-matching analysis comparing selected environmental parameters such as temperature, moisture, and precipitation between the native range and target area is commonly used [40,46,47].

Even if the prevention of biological invasions is the most important way to protect the environment, the efficiency of supporting restrictions is somewhat controversial because detailed analyses of high-risk species and related risks are lacking in certain cases [48,49]. The European Union (EU), as a party to the Convention on Biological Diversity, regulates the transportation, marketing, keeping, and breeding of invasive species threatening EU countries according to Regulation (EU) 1143/2014 on the prevention and management of the introduction and spread of invasive alien species. The Union List of invasive alien species of EU concern (Commission Implementing Regulation (EU) 2016/1141, 2017/1263 and 2019/1262) currently lists 30 animal species, including crustaceans, fish, amphibians, reptiles, birds, and mammals, as well as 36 plant species. It is obvious that many problematic species have been omitted from this list, such as, for example, the over 250 species of alien mollusc that Hulme [50] claims to be in Europe.

In comparison to aquatic species [51–53], the pet trade as an introduction pathway and the market are poorly studied regarding terrestrial gastropods, while related risks are highlighted only sporadically [54]. The Czech Republic is considered one of the leading countries contributing to the global pet trade market. This country is known as a significant importer, exporter, and producer of pet animals for ornamental keeping and as a gateway to Europe [55,56]. For this reason, we decided, based on the surveyed availability of terrestrial gastropod species on the ornamental market in the Czech Republic [57], to analyse their probability to establish new populations in the territory of the EU via climate matching.

2. Materials and Methods

The definition of the term "invasive (alien) species" is not uniform and clear. For the purposes of this analysis, we followed ecological terminology [58]: an invasive species is defined as a non-native species rapidly multiplying and spreading out of its native range with a negative impact on native biota.

The list of traded species (Table 1) was adopted from Bohatá and Patoka [57], and the current taxonomy of each species was adopted from https://www.molluscabase.org/ (accessed on 4 January 2023). Fifty-one species (49 snails and 2 slugs) from 11 families were analysed using climate matching for the European Union territory and the Schengen Area [51] using MaxEnt (v.3.4.1; https://biodiversityinformatics.amnh.org/open_source/maxent, accessed on 5 January 2023) [59]. Pet owners, traders, and breeders usually sort ornamental gastropods according to their "breeding difficulty" (including adaptability, opportunistic feeding, reproduction, etc., according to landsnails.org, https://aquariumbreeder.com/, accessed on 4 January 2023).

Based on previously published information on species native occurrence [11,62], environmental layers including temperature, moisture, and precipitation were selected, and maps showing the potential occurrence of each species were modelled. Available GPS coordinates of native occurrence were obtained from the Global Biodiversity Information Facility (GBIF; https://www.gbif.org, accessed on 5 January 2023), according to published records, e.g., [63], and online databases (ADW https://animaldiversity.org/, Terrestrial Mollusc Tool https://idtools.org/id/mollusc, WMSDB https://www.bagniliggia.it/WMSD/WMSDhome.htm, all accessed on 5 January 2023). Environmental layers were obtained from the CliMond database (v.1.2; https://www.climond.org/, accessed on 5 January 2023) with a spatial resolution of 10 arcmins ($\sim$1 km^2). The CliMond datasets were applied for a reliable climate-matching model of invasive species with a suitable spatial precision result [64]. The datasets were assembled in QGIS 3.8.2 Zanzibar (https://qgis.org/en/site/, accessed on 5 January 2023) to ASCII format and used in the MaxEnt algorithm.

MaxEnt is a maximum entropy model that is well suited for species distribution mapping [65,66] and is widely used to predict non-native species' distribution [67,68]. The final set of environmental predictions included 27 bioclimatic layers (Bio1–Bio19, Bio28–Bio35) (Table 2). For the models, 80% of presence records were randomly selected and used in model training while the remaining 20% were used in model testing. The number of records was different in each evaluated species and was always based on available data from the GBIF database. The model described a continuous probability surface of habitat suitability in the target area of European Union territory. For the cumulative output, a continuous map was generated for each evaluated species and visualised in QGIS 3.8.2 Zanzibar (https://qgis.org/en/site/, accessed on 5 January 2023). According to statistical evaluation of model testing, threshold values for the predicted areas of each species were applied based on balance training omission [65,69,70]. Areas reaching or exceeding the specific threshold were interpreted as areas where there is no evidence of climatic constraints for the survival of the evaluated species (coloured red on the map).

Species threshold values were calculated during the modelling of the predicted potential occurrence maps for each evaluated species (Table 3). The models had a training area under the receiver operator curve (AUC) value of over 0.95 (Table 3), suggesting the high predictability of the model [71]. The AUC value determines the validity of the model and the probability that a random selection from the presence records had a model score greater than a random selection from the absence records [67]. Species threshold values and AUC values for each species are provided in Table 3.

The degree of potential risk was evaluated based on the size of the predicted occurrence of the species: S—a small area was defined according to the prediction of potential occurrence in Macaronesia in the southern part of the evaluated territory of the EU only; M—medium-sized area covering less than 5% of the territory; L—large area covering more than 5% of the territory.

Table 1. The list of pet-traded terrestrial gastropods, species description, family, breeding difficulty (easy, medium, hard, following landsnails.org), native geographic distribution (AT—Afrotropical, AU—Australasian, NA—Nearctic, NT—Neotropical, OL—Oriental, PA—Palaearctic), status (x—no records found, I—invasive, alien, MI—misidentification with invasive species, NN—non-native, P—pest); the source is indicated by upper index letters: [a] https://www.aphis.usda.gov, [b] http://www.iucngisd.org, [c] https://doi.org/10.1093/mollus/eyy062, [d] https://idtools.org/id/mollusc, [e] https://www.cabidigitallibrary.org, [f] https://explorer.natureserve.org (all accessed on 5 January 2023).

Species	Author	Family	Breeding Difficulty	Native Geographic Distribution	Status
Acavus haemastoma	(Linnaeus, 1758)	Acavidae	medium	OL	x
Acavus superbus	(Pfeiffer, 1850)	Acavidae	medium	OL	x
Helicophanta bicingulata	(Smith, 1882)	Acavidae	medium	AT	x
Helicophanta magnifica	Férussac, 1819	Acavidae	medium	AT	x
Oligospira waltoni	(Reeve, 1842)	Acavidae	medium	OL	x
Achatina achatina	(Linnaeus, 1758)	Achatinidae	easy	AT	P [a]
Achatina balteata	(Reeve, 1849)	Achatinidae	easy	AT	P [a]
Achatina craveni	(Smith, 1881)	Achatinidae	easy	AT	P [a]
Achatina schweinfurthi	(von Martens, 1874)	Achatinidae	medium	AT	P [a]
Achatina tincta	(Reeve, 1849)	Achatinidae	easy	AT	P [a]
Achatina weynsi	(Dautzenberg, 1900)	Achatinidae	easy	AT	P [a]
Archachatina degneri	(Bequaert and Clench, 1936)	Achatinidae	easy	AT	P [a]
Archachatina marginata	(Swainson, 1821)	Achatinidae	easy	AT	P [a]
Archachatina papyracea	(Pfeiffer, 1845)	Achatinidae	-	AT	P [a]
Archachatina purpurea	(Gmelin, 1790)	Achatinidae	easy	AT	P [a]
Archachatina puylaerti	(Mead, 1998)	Achatinidae	easy	AT	P [a]
Archachatina rhodostoma	(Philippi, 1849)	Achatinidae	easy	AT	P [a]
Archachatina ventricosa	(Gould, 1850)	Achatinidae	-	AT	P [a]
Ceras dautzenbergi	(Dupuis and Putzeys, 1901)	Achatinidae	easy	AT	x
Cochlitoma varicosa	(Pfeiffer, 1861)	Achatinidae	-	AT	P [a]
Limicolaria aurora	(Jay, 1839)	Achatinidae	easy	AT	P [a]
Limicolaria flammea	(Müller, 1774)	Achatinidae	easy	AT	P [a]
Limicolaria martensiana	(Smith, 1880)	Achatinidae	easy	AT	P [a]
Lissachatina albopicta	(Smith, 1878)	Achatinidae	easy	AT	P [a]
Lissachatina allisa	(Reeve, 1849)	Achatinidae	easy	AT	P [a]
Lissachatina fulica	(Bowdich, 1822)	Achatinidae	easy	AT	I [b]
Lissachatina immaculata	(Lamarck, 1822)	Achatinidae	easy	AT	P [a]
Lissachatina reticulata	(Pfeiffer, 1845)	Achatinidae	easy	AT	P [a]
Lissachatina zanzibarica	(Bourguignat, 1879)	Achatinidae	easy	AT	P [a]
Paropeas achatinaceum	(Pfeiffer, 1846)	Achatinidae	easy	OL	NN [f]
Pseudachatina downesii	(Sowerby I, 1838)	Achatinidae	hard	AT	P [a]
Rumina decollata	(Linnaeus, 1758)	Achatinidae	easy	PA	I [a]
Rumina saharica	(Pallary, 1901)	Achatinidae	easy	PA	MI, NN [12,60]
Subulina octona	(Bruguière, 1789)	Achatinidae	easy	NT	NN [7]

Table 1. *Cont.*

Species	Author	Family	Breeding Difficulty	Native Geographic Distribution	Status
Ariophanta exilis	(Müller, 1774)	Airophantidae	easy	OL	x
Hemiplecta distincta	(Pfeiffer, 1850)	Airophantidae	medium	OL	x
Macrochlamys amboinensis	(von Martens, 1864)	Airophantidae	easy	OL	NN [c]
Hadra webbi	(Pilsbry, 1900)	Camaenidae	easy	AU	x
Oospira vanbuensis	(Bavay and Dautzenberg, 1899)	Clausiliidae	easy	OL	x
Phaedusa paviei	(Morlet, 1893)	Clausiliidae	easy	OL	x
Anguispira alternata	(Say, 1817)	Discidae	easy	NA	x
Anguispira strongylodes	(Pfeiffer, 1855)	Discidae	easy	NA	x
Pleurodonte isabella	(Férussac, 1822)	Pleurodontidae	easy	NT	x
Caracolus excellens	(Pfeiffer, 1853)	Solaropsidae	easy	NT	x
Caracolus marginella	(Gmelin, 1791)	Solaropsidae	easy	NT	x
Caracolus sagemon	(Beck, 1837)	Solaropsidae	easy	NT	x
Megalobulimus oblongus	(Müller, 1774)	Strophocheilidae	-	NT	NN [d]
Laevicaulis alte	(Férussac, 1822)	Veronicellidae	easy	AT	I [12,61]
Leidyula sloanii	(Cuvier, 1816)	Veronicellidae	easy	NT	P [e], NN [f]
Zachrysia guanensis	(Poey, 1858)	Zachrysiidae	medium	NT	P [d]
Zachrysia provisoria	(Pfeiffer, 1858)	Zachrysiidae	-	NT	I [e]

Table 2. Bioclimatic layers and the contributing variables used in their calculation (https://www.climond.org/, accessed on 5 January 2023).

Number	Variable	Minimum Temp (°C)	Maximum Temp (°C)	Rainfall (mm month^{-1})	Pan Evaporation (mm d^{-1})
Bio01	Annual mean temperature (°C)	×	×		
Bio02	Mean diurnal temperature range (mean (period max–min)) (°C)	×	×		
Bio03	Isothermality (Bio02 ÷ Bio07)	×	×		
Bio04	Temperature seasonality (C of V)	×	×		
Bio05	Max temperature of warmest week (°C)		×		
Bio06	Min temperature of coldest week (°C)	×			
Bio07	Temperature annual range (Bio05–Bio06) (°C)	×	×		
Bio08	Mean temperature of wettest quarter (°C)	×	×	×	
Bio09	Mean temperature of driest quarter (°C)	×	×	×	
Bio10	Mean temperature of warmest quarter (°C)	×	×		
Bio11	Mean temperature of coldest quarter (°C)	×	×		
Bio12	Annual precipitation (mm)			×	
Bio13	Precipitation of wettest week (mm)			×	

Table 2. *Cont.*

Number	Variable	Minimum Temp (°C)	Maximum Temp (°C)	Rainfall (mm month^{-1})	Pan Evaporation (mm d^{-1})
Bio14	Precipitation of driest week (mm)			×	
Bio15	Precipitation seasonality (C of V)			×	
Bio16	Precipitation of wettest quarter (mm)			×	
Bio17	Precipitation of driest quarter (mm)			×	
Bio18	Precipitation of warmest quarter (mm)	×	×	×	
Bio19	Precipitation of coldest quarter (mm)	×	×	×	
Bio28	Annual mean moisture index			×	×
Bio29	Highest weekly moisture index			×	×
Bio30	Lowest weekly moisture index			×	×
Bio31	Moisture index seasonality (C of V)			×	×
Bio32	Mean moisture index of wettest quarter			×	×
Bio33	Mean moisture index of driest quarter			×	×
Bio34	Mean moisture index of warmest quarter	×	×	×	×
Bio35	Mean moisture index of coldest quarter	×	×	×	×

Table 3. The risk results for 29 species evaluated using MaxEnt. The climate matching (CM) for these bioclimatic layers (Bio1–Bio19, Bio28–Bio35) (Sup. 1) is based on the size of the predicted occurrence of the species: S—small area is defined by prediction of potential occurrence in Macaronesia in the southern part of the evaluated territory of the EU only; M—medium-sized area covering less than 5% of the territory; L—large area covering more than 5% of the territory; N—no risk. Species threshold values (the lowest probability value that is the minimum value for suitable habitat) were calculated during the modelling of predicted potential occurrence maps for each evaluated species. The models had a training AUC value over 0.95, suggesting high prediction accuracy.

Species	Family	CM (1–19, 28–35)	Threshold Balance	AUC
			CM (1–19, 28–35)	CM (1–19, 28–35)
Acavus superbus	Acavidae	M	0.757	0.994
Helicophanta bicingulata	Acavidae	L	1.168	0.998
Helicophanta magnifica	Acavidae	S	1.770	0.997
Achatina achatina	Achatinidae	N	1.226	0.997
Achatina balteata	Achatinidae	S	3.130	0.976
Achatina schweinfurthi	Achatinidae	N	0.771	0.985
Archachatina marginata	Achatinidae	M	1.094	0.993
Archachatina ventricosa	Achatinidae	M	2.372	0.999
Cochlitoma varicosa	Achatinidae	L	1.751	0.998
Limicolaria flammea	Achatinidae	S	2.164	0.963

Table 3. *Cont.*

Species	Family	CM (1–19, 28–35)	Threshold Balance	AUC
			CM (1–19, 28–35)	CM (1–19, 28–35)
Limicolaria aurora	Achatinidae	S	2.118	0.988
Limicolaria martensiana	Achatinidae	N	1.609	0.993
Lissachatina allisa	Achatinidae	M	2.177	0.988
Lissachatina fulica	Achatinidae	S	1.196	0.997
Lissachatina reticulata	Achatinidae	S	1.633	0.995
Rumina decollata	Achatinidae	L	1.694	0.982
Rumina saharica	Achatinidae	L	2.128	0.997
Subulina octona	Achatinidae	N	0.611	0.999
Hemiplecta distincta	Airophantidae	N	0.937	0.998
Hadra webbi	Camaenidae	L	1.068	0.990
Phaedusa paviei	Clausiliidae	L	3.337	0.998
Anguispira alternata	Discidae	L	1.422	0.955
Anguispira strongylodes	Discidae	L	1.358	0.995
Caracolus marginella	Solaropsidae	N	0.617	0.999
Caracolus sagemon	Solaropsidae	N	0.968	0.998
Megalobulimus oblongus	Strophocheilidae	L	2.722	0.980
Laevicaulis alte	Veronicellidae	L	3.806	0.98
Zachrysia guanensis	Zachrysiidae	N	0.993	0.999
Zachrysia provisoria	Zachrysiidae	N	1.066	0.999

3. Results

Only 29 species out of 51 terrestrial gastropods pet-traded in the Czech Republic (shown in Table 3) were evaluated, as the data were deficient for the rest. Nine of them, i.e., *Achatina achatina* (Linnaeus, 1758); *Achatina schweinfurthi* von Martens, 1874; *Limicolaria martensiana* (Smith 1880); *Hemiplecta distincta* (Pfeiffer, 1850); *Caracolus marginella* (Gmelin, 1791); *Caracolus sagemon* (Beck, 1837); *Zachrysia guanensis* (Poey, 1858); *Z. provisoria* (Pfeiffer, 1850); and *Subulina octona* (Bruguière, 1789), were without predicted potential occurrence in the European Union (EU) territory. According to our results, the remaining 20 species belonging to seven families may potentially occur in the EU. Ten species, i.e., *Cochlitoma varicosa* (Pfeiffer, 1861); *Helicophanta bicingulata* (Smith, 1882); *Hadra webbi* (Pilsbry, 1900); *Phaedusa paviei* (Morlet, 1893); *Anguispira alternata* (Say, 1817); *Anguispira strongylodes* (Pfeiffer, 1855); *Megalobulimus oblongus* (Müller, 1774); *Rumina decollata* (Linnaeus, 1758); *Rumina saharica* (Pallary, 1901); and *Laevicaulis alte* (Férussac, 1822) were predicted to cover a large area of the EU territory (Figure 1). Four species, i.e., *Archachatina marginata* (Swainson, 1821); *Archachatina ventricosa* (Gould, 1850); *Acavus superbus* (Pfeiffer, 1850); and *Lissachatina allisa* (Reeve, 1849) were predicted to cover a medium-sized area (Figure 2), and six species, i.e., *Achatina balteata* (Reeve, 1849); *Limicolaria flammea* (Müller, 1774); *L. aurora* (Jay, 1839); *Lissachatina fulica* (Bowdich, 1822); *L. reticulata* (Pfeiffer, 1845); and *Helicophanta magnifica* (Férussac, 1819) were predicted to occupy a small area of the EU (Figure 3).

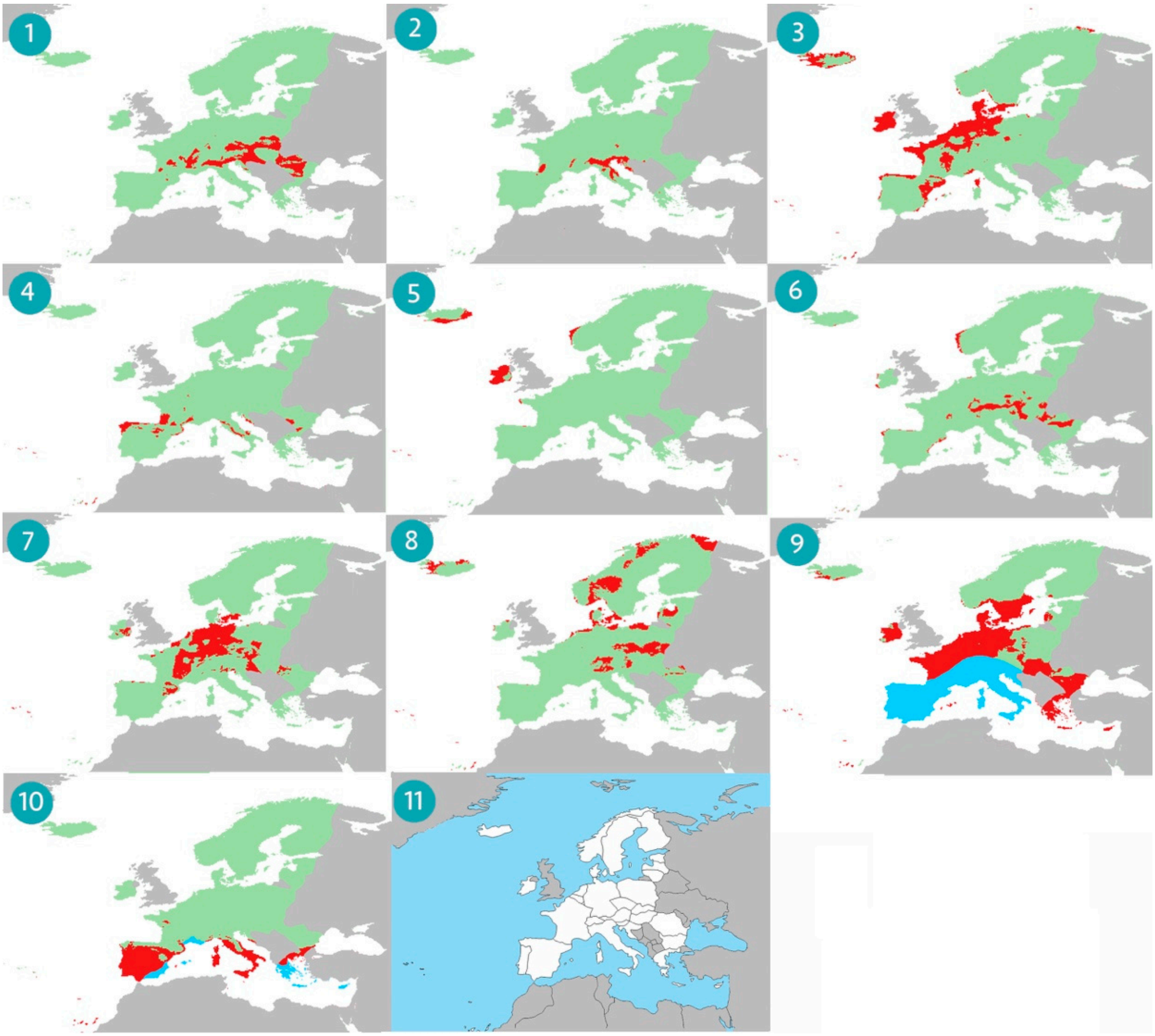

Figure 1. The prediction computed using the MaxEnt model of the pet-traded gastropods with potential occurrence in a "large area" of EU (= covered more than 5% of the territory). The maps show native range in blue and suitability in red, representing a high probability of establishment for these species: (**1**) *Anguispira alternata*, (**2**) *A. strongylodes*, (**3**) *Cochlitoma varicosa*, (**4**) *Hadra webbi*, (**5**) *Helicophanta bicingulata*, (**6**) *Laevicaulis altea*, (**7**) *Megalobulimus oblongus*, (**8**) *Phaedusa paviei*, (**9**) *Rumina decollata*, and (**10**) *R. saharica*; (**11**) map of European Union.

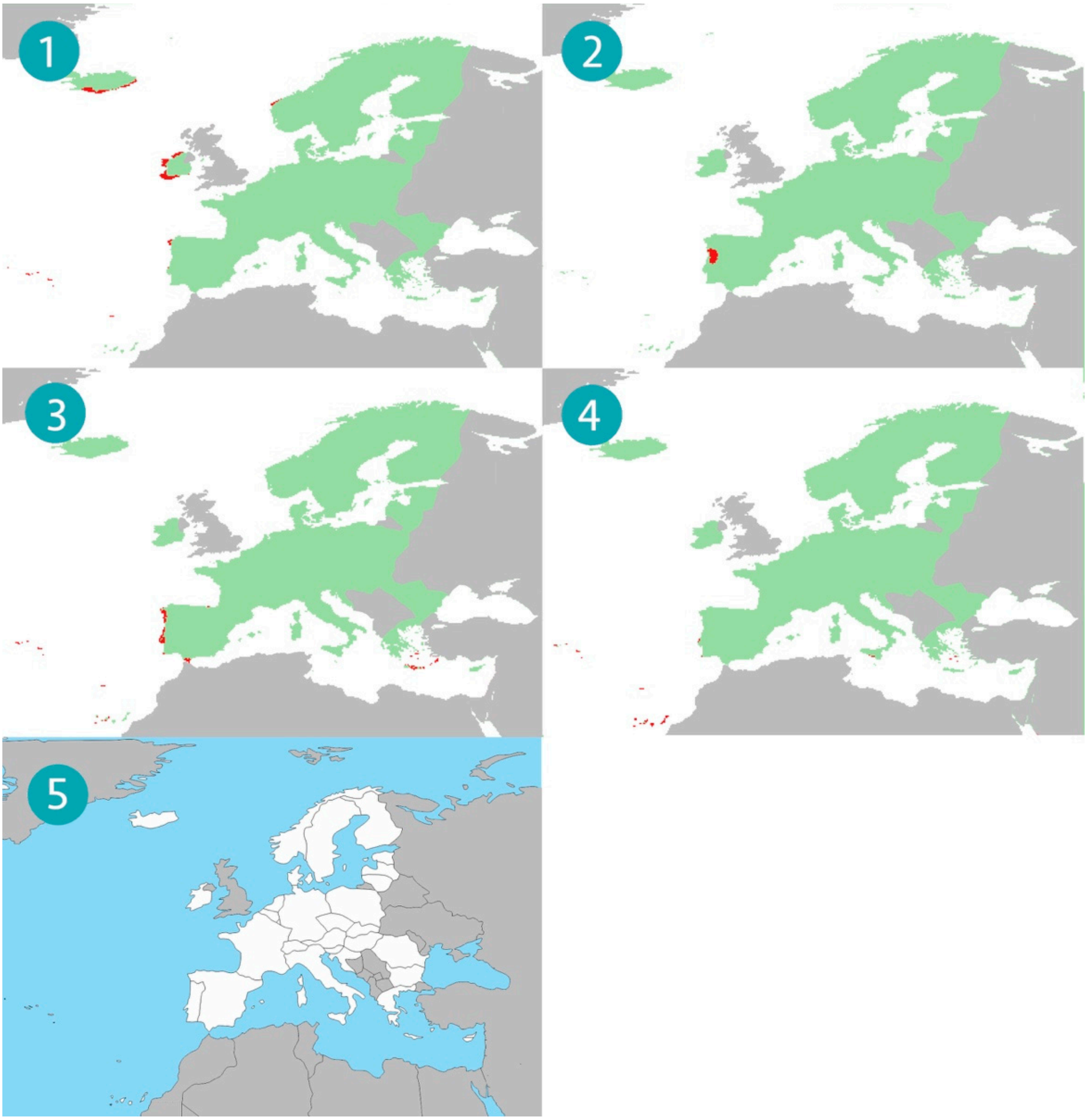

Figure 2. The prediction computed using the MaxEnt model of the pet-traded gastropods with potential occurrence in a "medium area" of EU (= covering less than 5% of the territory). The maps show suitability in red, representing a high probability of establishment for these species: (**1**) *Acavus superbus*, (**2**) *Archachalina ventricosa*, (**3**) *A. marginata*, and (**4**) *Lissachatina allisa*; (**5**) map of European Union.

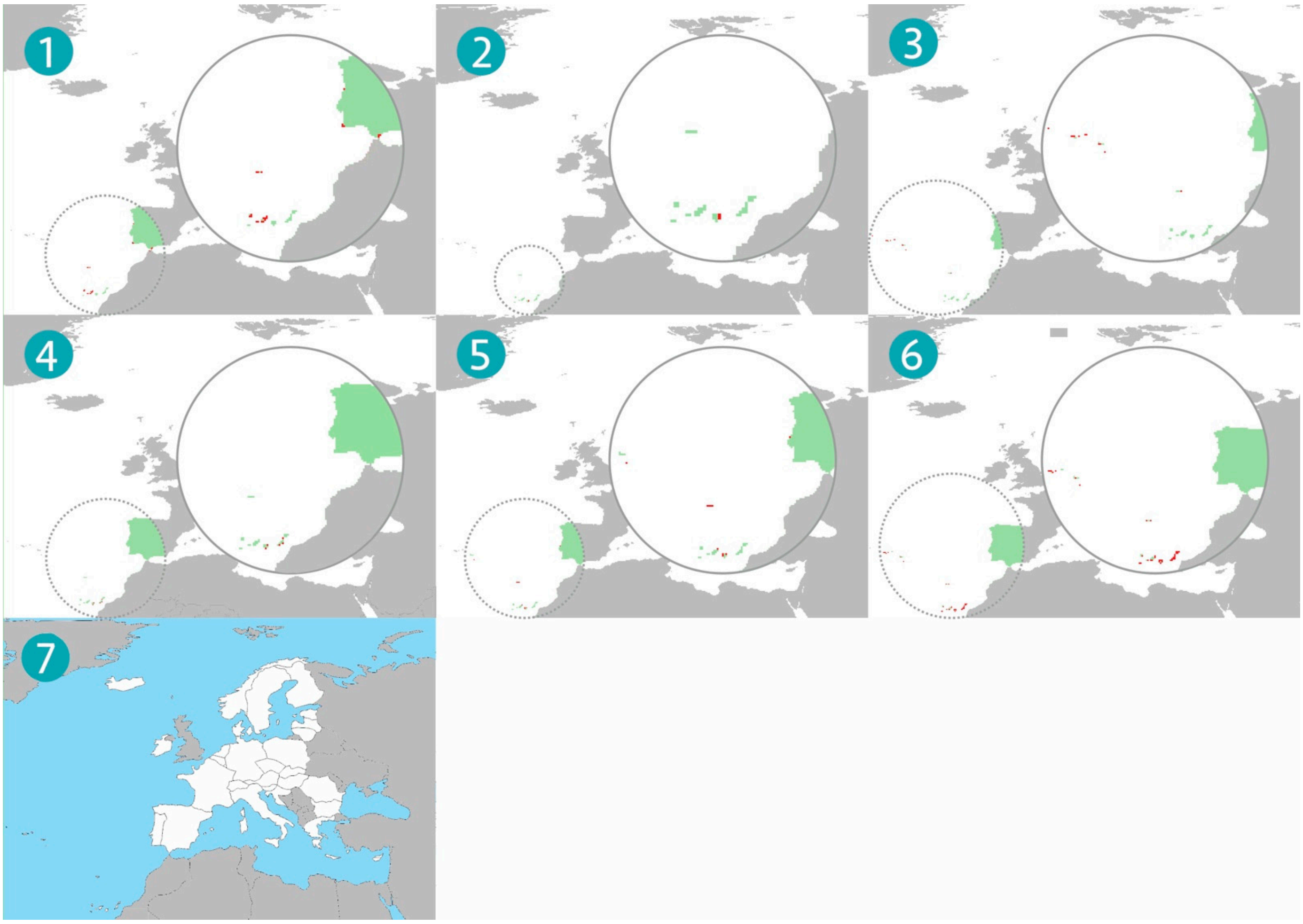

Figure 3. The prediction computed using the MaxEnt model of the pet-traded gastropods with potential occurrence in a "small area" of EU (= covering only Macaronesia in the southern part of the territory). The maps show suitability in red, representing a high probability of establishment for these species: (**1**) *Achatina balteata*, (**2**) *Helicophanta magnifica*, (**3**) *Limicolaria aurora*, (**4**) *L. flammea*, (**5**) *Lissachatina fulica*, and (**6**) *L. reticulata*; (**7**) map of European Union and Macaronesia belonging to the EU.

4. Discussion

Among the 29 evaluated terrestrial gastropod species, 20 species were found to have the potential to establish new populations in the EU territory. This supports the assumption that the pet trade is an important pathway and vector for invasive species [31,48,72,73].

Characteristics of popular pet-traded animals are breeding, handling, and care maintenance based on one or more characteristics such as tolerance to various factors, unspecialised diet, high fecundity, simple rearing, and reproduction modes. Together with climatic characteristics such as temperature and moisture, these properties can be seen as important predictors of the invasive success of evaluated species [12,61]. The best example of this phenomenon is seen for the well-known species (even to the general public) *L. fulica* [12], which has been introduced in numerous countries worldwide (Global Invasive Species Database GISD ISSG http://www.iucngisd.org, accessed on 5 January 2023). The MaxEnt model used for *L. fulica* showed the potential distribution of the species in a small area in the EU. This self-fertilizing species is listed among the 100 most invasive species [10] according to its invasion history and significantly negative impacts on biodiversity and economy worldwide. Nielsen et al. [12] classified this species as having moderate risk with an increasing establishment probability due to climate change. Moreover, this species is not the only one from the family Achatinidae expected to have an impact on the biodiversity and economy of many countries [12]. In the USA, the import and interstate transport of all species from the genus *Achatina* were banned (USDA APHIS https://www.aphis.usda.gov, accessed on 5 January 2023). However, the designation of the genus "*Achatina*" is misleading because numerous synonyms and misnomers exist (MolluscaBase https://www.molluscabase.org/). Since there are plenty of examples of invasive species being introduced from North America into Europe and vice versa, as shown in [74–76], one can conclude that, to these species, the finding of, and acclimation to, available niches and climatic conditions is not a barrier. Therefore, one can assume that the same species may have the potential to invade the same climatic niches in both aforementioned regions.

From the family Discidae, two species are traded as ornamentals: *Anguispira alternata* and *A. strongylodes*. According to Nielsen et al. [12], molecular genetic analyses revealed confusing morphological characteristics used in species determination in *A. alternata* and *A. strongylodes*. The MaxEnt model confirmed the potential occurrence of both species in a large area in the EU. Although they have a high probability of establishment in Norway, Nielsen et al. [12] determined the risk to be in the medium category given the expected low impact on native biodiversity.

Only one species of the family Strophocheilidae is traded as an ornamental: the predicted potential occurrence of *Megalobulimus oblongus* was shown in large areas of the EU. In South America, this species is threatened by environmental changes and by non-native species such as *L. fulica*. The most effective method for controlling *L. fulica* is manual capture [77]. In addition to the competition, *M. oblongus* is threatened by this control method due to its confusion with *L. fulica* [77,78]. If *M. oblongus* establishes and spreads in a new area, this would be an example of an interesting phenomenon, namely, the so-called "Biodiversity Conservation Paradox" [79,80], when an endangered species, in its native range, behaves as an invader in a non-native range. However, Nielsen et al. [12] classified *M. oblongus* as a low-risk species.

Rumina decollata and *R. saharica* from the family Achatinidae are representatives of Palearctic fauna. The medium-sized facultatively self-fertilizing predatory species *R. decollata* is spreading across the world mainly through the subtropical zone but also in the European temperate zone, negatively affecting native malacofauna [11,12]. *R. saharica*, a self-fertilizing subtropical predatory snail inhabiting southern Europe, has not yet been confirmed to negatively impact biodiversity; however, the misidentification of *R. saharica* and *R. decollata* is possible, while the spread of its native range has been confirmed [12,60]. MaxEnt modelling confirmed the potential occurrence on a large area of the EU for both these species, and Nielsen et al. [12] classified these gastropods as species of moderate risk for *R. decollata* and low risk for *R. saharica*.

The occurrence of *Paropeas achatinaceum*, originally from tropical and subtropical Southeast Asia, has been recorded in the USA [81], in Europe [9], and in Japan (Invasive Species of Japan https://www.nies.go.jp/biodiversity/invasive). Hence, the same pattern of invasion due to similar climate conditions cannot be excluded at least in parts of the EU. Although the MaxEnt model of *P. achatinaceum* was not evaluated due to a lack of suitable occurrence data, we emphasized that this species is spreading around the world and has obvious invasion potential [12]. Although Hulme [50] lists another representative of this family, *Subulina octona*, as a potential invasive species in Europe, further references substantiating its occurrence in the European wilderness were not found. Juřičková [7] confirmed the occurrence of this tropical species in Europe, but only in greenhouses and hothouses. Even if Nielsen et al. [12] evaluate this species as low risk in Norway and our MaxEnt modelling has not confirmed a potential occurrence elsewhere in the EU, changing climatic conditions should nevertheless be further monitored.

The American Malacological Society identified members of the family Veronicellidae as taxa with potential major pest significance to the USA, similar to those of the family Achatinidae [61]. *Laevicaulis alte* and *Leidyula sloanii* are examples of pet-traded animals with negative impacts on biodiversity, ecosystem functions, agriculture, etc. [12,61]. *Laevicaulis alte* is self-fertilizing and can lay fertilized eggs multiple times after only a single mating [12]. MaxEnt modelling showed the potential distribution of *L. alte* in a large area of the EU. *Leidyula sloanii* was not evaluated due to a lack of occurrence data. From a Norwegian perspective, the occurrence of both of these species was evaluated as potentially possible, even if a low probability was estimated [12].

Tropical and subtropical species without an invasion history on a large area of the EU include *Cochlitoma varicosa*, *Helicophanta bicingulata*, *Hadra webbi*, and *Phaedusa paviei*. Considering the extent of the area, we recommend their further monitoring and evaluation.

The legislative act focusing on the prevention of new introductions of invasive species in the EU is Regulation No. 1143/2014 and the Union list of invasive alien species. However, the reasons for the species listed and not listed are debatable and not well-defined in certain cases. No gastropods or other molluscs are listed. We have highlighted the seven species identified as high-risk (*Anguispira alternata*, *A. strongylodes*, *Rumina decollata*, *R. saharica*, *Megalobulimus oblongus*, *Laevicaulis alte*, and *Lissachatina fulica*) for the consideration of policymakers for the next revision of the Union list.

However, sufficient and credible data about many pet-traded terrestrial gastropods are unavailable, partly due to inconsistent taxonomy, overlapping species occurrence, and the difficult determination of subjected species. For these reasons, and due to changing climate conditions and the variation in the adaptability of the found species, we suggest further improving the risk assessment and monitoring of pet-traded animals in general, and for the ornamental terrestrial gastropods in particular. We recommend our findings to the attention of conservationists, wildlife managers, policymakers, and other stakeholders.

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