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Potential Invasion Risk of Pet Traded Lizards, Snakes, Crocodiles, and Tuatara in the EU on the Basis of a Risk Assessment Model (RAM) and Aquatic Species Invasiveness Screening Kit (AS-ISK)

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Abstract: Because biological invasions can cause many negative impacts, accurate predictions are necessary for implementing effective restrictions aimed at specific high-risk taxa. The pet trade in recent years became the most important pathway for the introduction of non-indigenous species of reptiles worldwide. Therefore, we decided to determine the most common species of lizards, snakes, and crocodiles traded as pets on the basis of market surveys in the Czech Republic, which is an export hub for ornamental animals in the European Union (EU). Subsequently, the establishment and invasion potential for the entire EU was determined for 308 species using proven risk assessment models (RAM, AS-ISK). Species with high establishment potential (determined by RAM) and at the same time with high potential to significantly harm native ecosystems (determined by AS-ISK) included the snakes *Thamnophis sirtalis* (Colubridae), *Morelia spilota* (Pythonidae) and also the lizards *Tiliqua scincoides* (Scincidae) and *Intellagama lesueurii* (Agamidae).

1. Introduction

Invasive species are considered to be among the major causes of biodiversity loss [1–3], and therefore conservation agencies around the world devote significant attention to this issue [4]. Time, money, and considerable effort are spent each year in the eradication, control and mitigation of non-native species [5]. However, despite the increasing interest of ecologists and conservation biologists in invasions [6], there is no sign that the introduction rate of non-indigenous species is slowing down [7].

In general, vertebrates are introduced more intentionally compared to other organisms [8]. The spread of non-native vertebrates took place in several historically specific waves and different taxonomic groups were at the peak of occupying new territories at different times. Fish, birds and mammals were introduced into new countries mainly in the 19th century and in the second half of the 20th century. On the other hand, the peak of reptile introductions was at the turn of the 20th and 21st centuries [9–11]—although many recent cases may have been overlooked. These differences have been caused by specificity of vectors and reasons for introductions. While fish, birds, and mammals were

mostly introduced intentionally for the benefit, usually economic, of people [10], the main reason for reptile introductions is the pet trade (which makes up for about 45% of introductions), which can lead to their subsequent release or escape [12].

Increasing urbanization creates a desire for contact with nature for people living in towns and cities, and keeping pets is one way of fulfilling this need [13]. The popularity of reptiles as pets has been growing steadily since the second half of the 20th century [14,15]. Unfortunately, reptiles can have enormous negative ecological impacts, e.g., invasion of the brown tree snake (*Boiga irregularis*) on Guam island caused the extinction of 77% of the island's native birds and 75% of its native lizards [16]. Also, other direct impacts on humans (e.g., (venomous) snakes or power outages caused by these snakes) cost a total of around $12 million per year [5]. One of the well-studied reptile invasions through the pet trade pathway in Europe is the case of the pond slider (*Trachemys scripta*). From 1989 to 1997, 52 million individual pond sliders were exported from the USA to Europe [17]. Because of the massive number of imports, they were sold very cheaply in pet shops. However, the growth of the turtle was associated with the loss of its attractive coloration and an increase in aggression, which often led unexperienced breeders to release them in the wild, where they would compete with native species of freshwater turtles for prey and places for basking [18,19]. Also, as a predator they can contribute to a local decline of native invertebrates, fish, or amphibians [20]. It is not surprising, therefore, that the import of *T. s. elegans* was banned by the EU's Commission Regulation (EC) No 338/97 in 1997 (Official Journal of the European Union, 1997). Regardless of these two examples, reptiles have been widely overlooked in systematic invasion studies [21,22], and their establishment potential and invasion dynamics remain poorly understood [23].

The Czech Republic is the EU hub for the import and export of ornamental animals [24,25], and it is situated between three seas (Black, Baltic and North), which represents significant potential opportunity for the spreading of non-native species into other parts of Europe [26]. In previous articles, we evaluated invasion potential in the European Union for ornamental amphibians [27] and freshwater turtles [28] based on import data and offers from wholesalers from the Czech Republic. In this article, we complete an overview of ornamental herpetofauna by evaluating establishment potential and the impact on native ecosystems for the rest of the reptile taxonomical groups – lizards, snakes, crocodiles, and tuatara.

2. Materials and Methods

According to laws and regulations in force in the Czech Republic, the import of live animals and their products is registered by the Customs Administration of the Czech Republic. Therefore, to identify species of reptiles that are being offered in EU countries, we took species listed in materials of the Customs Administration and, additionally, surveyed the online price lists of five leading Czech wholesalers of ornamental animals and domestic producers of these animals to complete the list of potentially invasive reptiles. Furthermore, additional discussions were conducted with wholesalers and producers, who helped us clarify certain queries or provided supplementary information concerning the reptile trade, especially availability on the market. The survey was performed during the year 2016.

Altogether, 381 species from 20 families (Appendix A Table A1) were identified as being on the pet market in the EU. In accordance with Nentwig et al. [29] we restricted our study to species with a native distribution entirely outside the European continent, mainly from different zoogeographical regions.

To stay consistent with previous studies about ectothermic tetrapods, we chose all states of the EU as the target region, while overseas departments and regions of France and Great Britain were not included in our study as parts of the EU [27,28].

We used two hierarchical models for determining the establishment and invasion risk: the Risk Assessment Model (RAM) for exotic amphibians and reptiles developed by the Australian Bureau of Rural Sciences [21,30] and the Aquatic Species Invasiveness Screening Kit v2.0 (AS-ISK) developed by Center for Environment Fisheries and Aquaculture Science (CEFAS) [31].

The species identified as being widely traded were firstly assessed by RAM, which tested the probability of their establishment, i.e., the formation of a self-sustaining population in a new environment [32], and then all species were evaluated for their invasion potential, i.e., their spread in the new environment simultaneously producing significant changes in the composition, structure, or processes of the ecosystem [32], in the EU by AS-ISK. We decided to use this approach mainly due to the fact that RAM is a model developed specifically for the determination of establishment only, while a major part of independently scored questions in AS-ISK deals with the potential impacts of an evaluated species rather than its ability to be introduced or established.

RAM is based on four parameters: (i) climatic similarity between the source (native distribution of species) and target regions (termed *climate match risk* score), (ii) species' abilities to establish populations elsewhere (termed *prop.species* value), (iii) establishment success of species from the particular family (termed *family random effect*), and (iv) jurisdiction score, which accounts for expected variability in the establishment success rate due to the effect of a particular jurisdiction (country, state or province) and for all evaluated species is constant.

Climate match risk scores were computed using the program Climatch v1.0 (Bureau of Rural Sciences, 2008) with a Euclidean algorithm and 16 temperature and rainfall variables. This is based on comparison of data from climatic stations in the native range and data from climatic stations in the target region (EU in our case). Values of *prop.species* scores were computed originally for this study using the Kraus database [12]. When values for calculating *prop.species* or *prop.genus* were insufficient, we did not compute a *prop.family* value [22], but instead used approximation according to phylogenetically related genera i.e., the closest branches on an up-to-date phylogenetic trees. *Family random effects* were taken from Bomford [30]. If the value of *family random effect* was not listed, we substituted both potential extremes into the formula (−1.3 and 1.69), and then the range of values for risk score is presented. The risk score in RAM can reach values of 0–1, where establishment risk ranks are: low ≤ 0.16, moderate 0.17–0.39, serious 0.40–0.85 and extreme ≥ 0.86.

Not all traded species could be evaluated by the described procedure. The main problem was the impossibility of finding a map of occurrence or species living in such a small area which does not contain any climate station. Such species were therefore excluded from our analysis.

AS-ISK is an electronic toolkit which consists of 55 questions [31]. Some of the questions deal with biogeographical similarity, including the climate tolerance of the evaluated species, and some of the questions examine undesirable attributes, such as whether the species is poisonous or if it is a pathogen vector. However, most questions concern the species' biological and ecological characteristics that can facilitate a potential invasion. There are also six questions related to climate change. For evaluating the invasion potential of ornamental reptiles, we used the sum of the scores from the questions dealing with biological and ecological features (this includes undesirable (or persistence) traits, resource exploitation, reproduction, dispersal mechanisms, and tolerance attributes). Because of the character of the questions in the AS-ISK software, we can argue that the AS-ISK invasion score from this part of the program expresses the species' potential abilities to spread in a new environment and to alter the environment either directly or indirectly.

AS-ISK was originally developed for aquatic species. Thus, some questions (23., 44., 45. and 48.) concern characteristics related to life in a water environment. To stay consistent in our evaluation, which covers terrestrial species of reptiles, we used the term "Not applicable" as the answer for these questions across all evaluated species. The categorization (low, medium, or high invasion risk) of final numerical scores is not possible, because we did not use the AS-ISK overall score (i.e., BRA and BRA+CCA scores).

Each author of the article evaluated selected families by using both tools (RAM and AS-ISK). Before the start of the evaluation process, the authors attended three meetings for the unification of procedures and for clarifying specific issues. We searched for publications about the distribution and biology of assessed species, using their scientific names (and if necessary, their older synonyms) as search terms. Furthermore, relevant information provided on websites (www.iucn.org, https:

//nas.er.usgs.gov, www.animaldiversity.org), as well as literature cited therein, were used to compile published information available on selected species.

3. Results

The basics (a distribution map, or the presence of a climatic station in the area of distribution) for a climate match of the 381 evaluated species was not found or did not exist for 73 of the species (19.2%). This portion was significantly different among families (contingency tables: $\chi^2 = 42.83$, P < 0.0001), with varanidae (58%), gekkonidae (68%), and agamidae (72%) being the families with the lowest number of distribution records available, or with the absence of a climatic station in their limited range of occurrence.

Only 4 species (1.30% of those with available distribution maps or climatic stations) reached the RAM extreme risk rank (Table 1). The most numerous were species with a serious RAM risk rank—111 (36.04%)—followed by 106 species with a low RAM risk rank (34.41%) and 87 species with a moderate RAM risk rank (28.25%). We took the mean value of RAM scores if species had this value noted as a range.
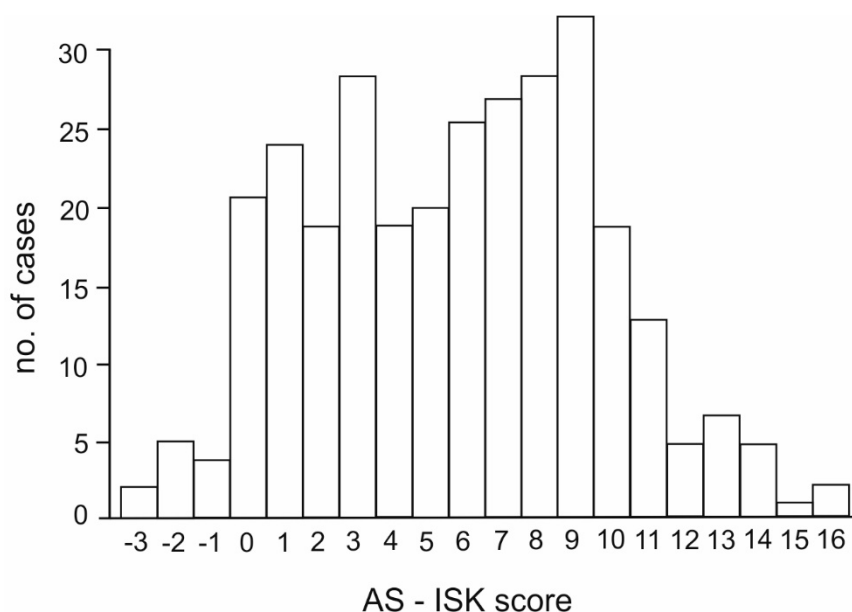
Table 1. Species of ornamental reptiles (excluding turtles) with highest potential to establish viable populations in the EU, based on the Risk Assessment model.

Species	Family	Risk Score	Risk Rank
Diplodactylus vittatus	Gekkonidae	0.940	extreme
Underwoodisaurus milii	Gekkonidae	0.920	extreme
Tiliqua scincoides	Scincidae	0.912	extreme
Intellagama lesueurii	Agamidae	0.885	extreme
Morelia spilota	Pythonidae	0.769	serious
Philothamnus semivariegatus	Colubridae	0.731	serious
Chamaeleo dilepis	Chamaeleonidae	0.730	serious
Uta stansburiana	Iguanidae	0.703	serious
Thamnophis sirtalis	Colubridae	0.662	serious
Chamaeleo calyptratus	Chamaeleonidae	0.624	serious
Barisia imbricata	Anguidae	0.582–0.663	serious
Sauromalus ater	Iguanidae	0.616	serious
Trioceros bitaeniatus	Chamaeleonidae	0.586	serious
Cyrtopodion scabrum	Gekkonidae	0.577	serious
Stenodactylus mauritanicus	Gekkonidae	0.575	serious

Values of AS-ISK were not evenly distributed (Kolmogorov-Smirnov test: D = 0.09, P < 0.05), with the greatest portion of species scores from six to nine (Figure 1). However, values of AS-ISK 13 and more were rare and reached by only fifteen species – these can be identified as having the greatest potential to harm native species in the EU (Table 2).

Table 2. Species of ornamental reptiles (excluding turtles) with highest potential to spread and negatively influence nature in the EU, based on AS-ISK (from the Biology/Ecology section only).

Species	Family	Risk Score
Python sebae	Pythonidae	16
Malayopython reticulatus	Pythonidae	16
Osteolaemus tetraspis	Crocodylidae	15
Agama agama	Agamidae	14
Eunectes notaeus	Boidae	14
Varanus salvator	Varanidae	14
Corallus hortulanus	Boidae	14
Holcosus undulatus	Teiidae	14
Hemidactylus frenatus	Gekkonidae	13
Lepidodactylus lugubris	Gekkonidae	13
Morelia spilota	Pythonidae	13
Boa constrictor	Boidae	13
Nerodia taxispilota	Colubridae	13
Thamnophis marcianus	Colubridae	13
Thamnophis sirtalis	Colubridae	13

Figure 1. Distribution of AS-ISK score (from Biology/Ecology section only) of ornamental reptile species (excluding turtles) for the EU area.

4. Discussion

We used a hierarchical approach to predict species' potential establishment and spread with a negative impact on native ecosystems in the EU. In the first step, we searched for species that are imported and can be released or escape into the wild (transport and introduction). Then, using RAM, we evaluated the establishment potential of these species, and by AS-ISK, their future negative impact on EU nature. This process is advantageous because it overcomes the known problem with risk assessment models—the production of a single unifying factor such as "weediness" or "invasiveness" [33], which often leads to confusion or at least the impossibility of correcting the identification and level of expression of traits involved in the invasion process [34]. On the other hand, the procedure described has its limits. Due to the enormous number of species that were evaluated, particular families were divided among authors. While the calculation of a RAM score is not subjective and the final score is a result of mathematical procedures with given rules, the final value of the AS-ISK score for the same species can differ when species are evaluated by several authors [35,36]. We tried to adjust this by holding three meetings of the authors prior to evaluation, where unification of procedure and clarifying specific issues were discussed. It must also be mentioned that we used a non-specific jurisdiction score in the RAM formula, therefore a RAM risk score cannot be viewed as a precise estimation of the probability of establishment, but rather provides a relative ranking of ornamental reptiles traded in the EU.

In contrast to species that invade new areas through accidental pathways, transport of pet-traded species can be controlled and documented [37–39]. Legislative regulations can be based on negative experiences with non-native species already present in the environment, or the ban of such species can be based on predictive models of "invasivity" as a prevention [4]. This approach, which is still precise, deals firstly with the transport step of the invasion process [40]. The second step in the invasion process is introduction [41], which for pet-traded species is usually a deliberate release or unintentional escape from enclosures [12,42]. Therefore, occurrence of non-indigenous species is associated with human activity and invasions are casually linked to demographic data. It has been shown that occurrence of non-native species is associated with the density of human settlement [43], proximity of communications [32], the number of pet shops [44], wealth of inhabitants [45], or the index of urbanization [46].

Legislative regulations can effectively ban the trade of some species, however other species replace banned species to satisfy market demands – therefore we cannot expect that the volume of traded reptiles will decrease in the future [47]. Besides abiotic factors, the establishment of non-native species is influenced mostly by the number of individuals that are released into the environment, underpinned by propagule pressure [48]. For example, the potential of certain turtles to become established, which are imported as pets into the EU after the ban of *Trachemys scripta*, is much higher for many species than for *Trachemys scripta* [28]. However, their real potential to establish themselves in the EU is limited because of an increased variety of traded species [49], probably resulting in lower numbers of imported individuals for each particular species. Precise data about numbers of imported and exported individuals are still not collected by public authorities in the Czech Republic, therefore we were not able to incorporate propagule pressure into our models.

The impact of non-native species in new environments can be direct or indirect [50]. In all assessed groups of reptiles, we expect rather direct impacts – mainly competition and predation. From the evaluated species, colubrid snake *Thamnophis sirtalis* and *Morelia spilota* from the Pythonidae family exhibit high RAM scores (i.e., the ability to become established in large areas of the EU) and at the same time, high AS-ISK scores, and thus from a pan-EU perspective, they represent the most dangerous imported species.

Thamnophis sirtalis is a medium-sized snake with an extensive range from Florida in the United States to the Northwest Territories in Canada [51]. The mode of their reproduction is viviparity [52], which allows reptiles to exist even in cold climates [53]. It is very adaptable and lives in a variety of habitats, including those modified by humans such as pastureland, rural gardens, ponds, drainage canals, and ditches, and is often found near water [51]. Niche overlap is therefore assumed mainly with snakes from the Natricinae subfamily which contains three species living in the EU: *Natrix natrix*, *Natrix maura* and *Natrix tessellate* [54]. Competition for food would be the most probable interaction with these snakes – the food of *T. sirtalis* consists predominantly of anurans, salamanders, and fish [55] which are the main prey of native species of snakes from the genus *Natrix* [56–58]. A great proportion of amphibians in the EU are endangered and protected, and thus predation is another potential threat to native ecosystems. Due to its resistance to the strongest amphibian toxins, *Thamnophis sirtalis* can act as a nonselective predator [59]. While members of the family Colubridae are among the most successful reptile invaders in Europe with 14 % of established species among non-native reptiles in European countries [60], *Thamnophis sirtalis* itself was not established in Europe with known temporary occurrence in Austria, Germany, Great Britain, and Sweden [12]. While there was one case in Germany of an attempt to become established near the city of Dortmund [61], the presence in other countries was random and episodic.

Morelia spilota is a large snake reaching from two to four meters in length from the Australian zoogeographical region, where it is the most widespread python [62]. *M. spilota* have a broad habitat tolerance – however, occurrence of shrubs and hollow logs is critical for this semiarboreal species [62,63]. It is climatically and ecologically adaptable – in Australia it occurs in areas that receive snowfall and is also often found near human habitation [64]. Long-term persistence in adverse conditions can be facilitated by exhibition of maternal care, when females coil around their eggs and guard them until they hatch. Females leave the eggs to bask, and heat obtained from basking is transferred to the clutch. Females may also raise the temperature of the eggs by shivering [65]. The diet of adult snakes consists mainly of mammals, while juveniles consume mammals as well as reptiles [66]. In some parts of the EU, this species may become a top predator. This species may have a lifespan from 15 to 20 years [65], which also increases its invasive potential. Despite snakes from genus *Morelia* being popular in the pet trade [67] no record of this species outside its native range exists [12].

Other species with high values of AS-ISK evaluated in this article are large animals with the potential to become top predators in their non-native range. However, their RAM scores are low or moderate, suggesting that their potential establishment may be local and mainly in parts of south European countries. At the opposite end, the highest RAM risk scores were for small- to medium-bodied

lizards. Among them, Australian medium sized lizards *Tiliqua scincoides* and *Intellagama lesueurii* also have relatively high AS-ISK scores (11 for both species). The AS-ISK score from part of the model dealing with biological and ecological features was over 10, suggesting potential strong effects on native ecosystems. Known ectothermic vertebrate pests that are already present in the EU, including the frogs *Lithobates catesbeianus* and *Xenopus laevis*, obtain this value [27].

A minority of introductions lead to establishment and spread of non-native species. For example, Europe is the continent with the most reptile introductions, but the smallest number of introductions (about 5%) lead to establishment here [12]. However, we generally underestimate the invasive potential and the negative impact of non-native species [68]. This is especially true for reptiles, which are commonly overlooked in invasion studies [21,22]. We should therefore treat each non-native reptile very carefully and in the EU, pet traded *Thamnophis sirtalis*, *Morelia spilota*, *Tiliqua scincoides*, and *Intellagama lesueurii* mainly deserve our attention.

Author Contributions: O.K. is authors of original idea. Made conceptualization, supervision and data curation. Also wrote draft of manuscript, creates methodology and visualization of results in form of tables and figures, works with literature resources. Other authors works on data analysis of assigned families in software RAM and AS-ISK and provides review of final version of manuscript draft.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Species of ornamental reptiles (excluding turtles) imported into EU with values of their RAM score (determining establishment potential in EU) and AS-ISK (determining potential to negatively influence nature in the EU).

Family	Species	Distribution Map Available/Presence of Climate Station	RAM	AS-ISK (Biology/Ecology Score Only)
Chamaleonidae	*Bradypodion setaroi*	yes	0.508	4
	Bradypodion thamnobates	yes	0.508	5
	Brookesia betschyi	yes	0.508	3
	Brookesia brygooi	yes	0.508	4
	Brookesia ebenaui	yes	0.508	0
	Brookesia griveaudi	yes	0.508	0
	Brookesia minima	yes	0.508	0
	Brookesia nasus	yes	0.508	0
	Brookesia peyrierasi	yes	0.508	0
	Brookesia stumpffi	yes	0.508	0
	Brookesia therezieni	yes	0.508	0
	Brookesia thieli	yes	0.508	1
	Chamaeleo calyptratus	yes	0.624	8
	Chamaeleo dilepis	yes	0.731	6
	Chamaeleo senegalensis	yes	0.544	3
	Furcifer bifidus	yes	0.450	3
	Furcifer lateralis	yes	0.450	10
	Furcifer oustaleti	yes	0.450	10
	Furcifer pardalis	yes	0.450	8
	Furcifer verrucosus	yes	0.450	10
	Furcifer wilsii	yes	0.450	2
	Rhampholeon acuminatus	no		
	Rhampholeon boulengeri	yes	0.520	−1

Table A1. *Cont.*

Family	Species	Distribution Map Available/Presence of Climate Station	RAM	AS-ISK (Biology/Ecology Score Only)
	Rhampholeon nchisiensis	no		
	Rhampholeon spectrum	yes	0.508	−3
	Rhampholeon spinosus	yes	0.508	−3
	Rhampholeon temporalis	yes	0.508	−2
	Rhampholeon viridis	yes	0.508	1
	Rieppelon brevicaudatus	yes	0.508	0
	Rieppeleon kerstenii	yes	0.529	1
	Trioceros bitaeniatus	yes	0.586	7
	Trioceros cristatus	yes	0.450	6
	Trioceros deremensis	yes	0.450	3
	Trioceros ellioti	yes	0.461	9
	Trioceros fuelleborni	yes	0.450	7
	Trioceros hoehnelii	yes	0.528	11
	Trioceros jacksonii	yes	0.542	11
	Trioceros melleri	yes	0.450	3
	Trioceros montium	no		
	Trioceros pfefferi	no		
	Trioceros quadricornis	no		
	Trioceros rudis	yes	0.456	8
	Trioceros werneri	yes	0.450	6
	Kinyongia boehmei	yes	0.450	5
	Kinyongia matschiei	yes	0.450	2
	Kinyongia multituberculata	yes	0.450	1
	Kinyongia tavetana	yes	0.450	1
	Kinyongia tenuis	yes	0.450	1
	Kinyongia uthmoelleri	yes	0.450	1
	Calumma boettgeri	yes	0.450	7
	Calumma brevicorne	yes	0.450	3
	Calumma gastrotaenia	yes	0.450	3
	Calumma guillaumeti	no		
	Calumma malthe	yes	0.450	2
	Calumma marojezense	yes	0.450	1
	Calumma nasutum	yes	0.450	4
Gekkonidae	*Aeluroscalabotes felinus*	yes	0.453	−2
	Blaesodactylus antongilensis	yes	0.241	0
	Blaesodactylus sakalava	yes	0.241	0
	Cnemaspis africana	no		
	Cnemaspis barbouri	no		
	Cnemaspis quattuorseriata	no		
	Coleonyx elegans	yes	0.220	5
	Coleonyx mitratus	yes	0.218	3
	Cyrtodactylus fumosus	no		
	Cyrtopodion scabrum	yes	0.577	8
	Elasmodactylus tetensis	yes	0.241	1
	Elasmodactylus tuberculosus	yes	0.241	3
	Eublepharis macularius	yes	0.251	8
	Geckolepis polylepis	yes	0.241	5
	Gehyra vorax	yes	0.241	0
	Gekko badenii	yes	0.162	4
	Gekko gecko	yes	0.106	6
	Gekko grossmanni	yes	0.162	6

Table A1. *Cont.*

Family	Species	Distribution Map Available/Presence of Climate Station	RAM	AS-ISK (Biology/Ecology Score Only)
	Gekko monarchus	no		
	Gekko ulikovskii	yes	0.162	6
	Gekko vittatus	yes	0.162	6
	Gonatodes albogularis	no		
	Goniurosaurus lichtenfelderi	no		
	Hemidactylus ansorgii	no		
	Hemidactylus brookii	no		
	Hemidactylus fasciatus	yes	0.369	9
	Hemidactylus frenatus	yes	0.370	13
	Hemidactylus imbricatus	yes	0.388	11
	Hemidactylus platyurus	no		
	Hemidactylus prashadi	yes	0.369	10
	Hemidactylus ruspolii	no		
	Hemidactylus squamulatus	no		
	Hemidactylus tanganicus	no		
	Hemitheconyx caudicinctus	yes	0.106	2
	Holodactylus africanus	no		
	Homopholis fasciata	yes	0.502	2
	Lepidodactylus lugubris	yes	0.355	13
	Lygodactylus capensis	no		
	Lygodactylus gutturalis	no		
	Lygodactylus kimhowelli	no		
	Lygodactylus klemmeri	yes	0.162	8
	Lygodactylus luteopicturatus	no		
	Lygodactylus miops	yes	0.162	4
	Lygodactylus scheffleri	no		
	Lygodactylus williamsi	yes	0.127	1
	Matoatoa brevipes	yes	0.162	0
	Pachydactylus bibroni	no		
	Pachydactylus rangei	no		
	Paroedura androyensis	yes	0.453	7
	Paroedura bastardi	yes	0.453	5
	Paroedura masobe	yes	0.453	1
	Paroedura picta	yes	0.453	7
	Phelsuma dubia	no		
	Phelsuma laticauda	yes	0.453	
	Phelsuma lineata	yes	0.403	6
	Phelsuma madagascariensis	yes	0.403	5
	Phelsuma quadriocellata	yes	0.403	3
	Ptychozoon kuhli	no		
	Ptyodactylus guttatus	no		
	Ptyodactylus hasselquistii	yes	0.061	10
	Ptyodactylus ragazzi	no		
	Rhacodactylus auriculatus	yes	0.106	0
	Rhacodactylus chahoua	yes	0.106	3
	Rhacodactylus ciliatus	yes	0.106	1
	Sphaerodactylus sputator	yes	0.213	6
	Stenodactylus petrii	yes	0.496	1
	Stenodactylus sthenodactylus	yes	0.369	5
	Tarentola annularis	yes	0.327	9
	Tarentola delalandii	yes	0.047	1

Table A1. *Cont.*

Family	Species	Distribution Map Available/Presence of Climate Station	RAM	AS-ISK (Biology/Ecology Score Only)
	Tarentola mauretanica	yes	0.274	1
	Teratoscincus roborowskii	yes	0.213	1
	Teratoscincus scincus	yes	0.213	1
	Tropiocolotes steudneri	no		
	Tropiocolotes tripolitanus	yes	0.505	1
	Underwoodisaurus milii	yes	0.920	7
	Ebenavia inunguis	yes	0.241	3
	Uroplatus ebenaui	yes	0.241	6
	Uroplatus guentheri	yes	0.241	2
	Uroplatus fimbriatus	yes	0.241	5
	Uroplatus henkeli	yes	0.241	3
	Uroplatus phantasticus	yes	0.241	6
	Chondrodactylus turneri	no		
	Phyllopezus pollicaris	yes	0.247	8
	Stenodactylus mauritanicus	yes	0.575	1
	Diplodactylus vittatus	yes	0.940	3
Iguanidae	*Anolis carolinensis*	yes	0.308	11
	Basiliscus vitttatus	yes	0.226	9
	Corytophanes cristatus	yes	0.271	7
	Crotaphytus bicinctores	yes	0.326	5
	Crotaphytus collaris	yes	0.376	5
	Ctenosaura quinquecarinata	no		
	Ctenosaura similis	yes	0.433	7
	Dipsosaurus dorsalis	yes	0.524	2
	Gambelia wislizenii	yes	0.236	5
	Iguana Iguana	yes	0.371	1
	Leiocephalus schreibersi	yes	0.326	0
	Phrynosoma platyrhinos	yes	0.340	3
	Sauromalus ater	yes	0.616	−2
	Sceloporus magister	yes	0.286	7
	Sceloporus malachiticus	yes	0.175	−1
	Tropidurus hispidus	no		
	Uta stansburiana	yes	0.703	3
	Anolis coelestinus	yes	0.467	4
	Anolis cristatellus	yes	0.370	9
	Anolis cybotes	yes	0.467	7
	Anolis equestris	yes	0.439	8
	Anolis gingivinus	yes	0.467	7
	Anolis hendersoni	yes	0.467	7
	Anolis noblei	yes	0.467	10
	Anolis pogus	yes	0.431	9
	Anolis roquet	yes	0.467	6
	Anolis sagrei	yes	0.396	5
	Basiliscus plumifrons	yes	0.226	2
	Brachylophus fasciatus	yes	0.470	0
	Crotaphytus insularis	yes	0.206	2
	Chalarodon madagascariensis	yes	0.467	4
	Leiocephalus personatus	yes	0.389	-2
	Oplurus cyclurus	yes	0.467	0
	Oplurus fierinensis	yes	0.467	0
	Oplurus grandidieri	yes	0.467	2
	Oplurus quadrimaculatus	yes	0.467	0
	Chameleolis barbatus	yes	0.467	4

Table A1. *Cont.*

Family	Species	Distribution Map Available/Presence of Climate Station	RAM	AS-ISK (Biology/Ecology Score Only)
Pythonidae	*Aspidites ramsayi*	yes	0.131	3
	Bothrochilus boa	yes	0.060	8
	Broghammerus reticulatus	yes	0.060	16
	Broghammerus timoriensis	yes	0.060	2
	Leiopython albertisii	yes	0.060	2
	Liasis mackloti	yes	0.078	9
	Morelia amethistina	yes	0.078	9
	Morelia boeleni	yes	0.078	2
	Morelia spilota	yes	0.769	13
	Morelia viridis	yes	0.072	5
	Python breitensteini	yes	0.071	10
	Python brongersmai	yes	0.071	8
	Python regius	yes	0.060	9
	Python sebae	yes	0.132	16
Boidae	*Calabaria reinhardtii*	yes	0.084	10
	Acrantophis dumerili	yes	0.084	9
	Epicrates cenchria	yes	0.060	8
	Eunectes notaeus	yes	0.206	14
	Corallus caninus	yes	0.059	6
	Corallus hortulanus	yes	0.103	14
	Gongylophis colubrinus	no		
	Boa constrictor	yes	0.171	13
Crocodylidae	*Osteolaemus tetraspis*	yes	0.201	15
Alligatoridae	*Paleosuchus palpebrosus*	yes	0.096	12
Anguidae	*Barisia imbricata*	yes	0.58–0.66	2
Agamidae	*Acanthocercus atricollis*	yes	0.397	6
	Agama aculeata	yes	0.465	5
	Agama agama	yes	0.208	14
	Agama doriae	yes	0.403	0
	Hydrosaurus amboinensis	yes	0.351	4
	Hydrosaurus weberi	yes	0.351	2
	Japalura tricarinata	yes	0.462	2
	Leiolepis belliana	yes	0.113	1
	Leiolepis guttata	yes	0.113	1
	Leiolepis reevesii	yes	0.113	−2
	Physignathus cocincinus	yes	0.208	4
	Intellagama lesueurii	yes	0.885	11
	Pogona vitticeps	yes	0.151	10
	Pseudotrapelus sinaitus	yes	0.087	7
	Chlamydosaurus kingi	yes	0.116	6
	Trapelus savignii	yes	0.429	5
	Acanthosaura lepidogaster	yes	0.455	4
	Uromastyx acanthinura	yes	0.073	6
	Uromastyx benti	yes	0.058	−1
	Draco maculatus	yes	0.455	3
	Calotes jubatus	yes	0.455	2
	Japalura splendida	no		
	Uromastyx geyri	no		
	Uromastyx dispar	no		
	Uromastyx ornata	no		
	Acanthosaura capra	no		
	Draco volans	no		
	Calotes emma	no		
	Gonocephalus chamaeleontinus	no		

Table A1. *Cont.*

Family	Species	Distribution Map Available/Presence of Climate Station	RAM	AS-ISK (Biology/Ecology Score Only)
Scincidae	*Acontias percivalii*	yes	0.279	9
	Bellatorias frerei	yes	0.131	9
	Egernia depressa	yes	0.126	9
	Corucia zebrata	yes	0.064	1
	Chalcides sexlineatus	yes	0.278	11
	Lamprolepis smaragdina	yes	0.281	5
	Mochlus sundevalli	yes	0.416	9
	Mabuya multifasciata	yes	0.324	11
	Mabuya quinquetaeniata	no		
	Lepidothyris fernandi	yes	0.411	9
	Scincus scincus	yes	0.356	9
	Trachylepis affinis	no		
	Trachylepis elegans	yes	0.293	7
	Trachylepis margaritifera	yes	0.293	8
	Trachylepis perrotetii	no		
	Tiliqua gigas	yes	0.226	10
	Tiliqua scincoides	yes	0.912	11
	Tribolonotus gracilis	yes	0.064	9
	Tropidophorus baconi	no		
	Eumeces schneideri	yes	0.438	7
	Eumeces algeriensis	yes	0.405	10
	Voeltzkowia rubrocaudata	yes	0.264	9
Gerrhosauridae	*Zonosaurus karsteni*	yes	0.018–0.271	8
	Zonosaurus laticaudatus	yes	0.018–0.271	10
	Zonosaurus madagascariensis	yes	0.018–0.271	6
	Zonosaurus maximus	yes	0.018–0.271	7
	Zonosaurus ornatus	yes	0.018–0.271	10
	Zonosaurus quadrilineatus	yes	0.018–0.271	6
	Gerrhosaurus flavigularis	no		
	Gerrhosaurus major	yes	0.036–0.430	9
	Gerrhosaurus nigrolineatus	no		
	Tracheloptychus petersi	yes	0.018–0.271	8
Varanidae	*Varanus acanthurus*	yes	0.119	9
	Varanus beccarii	no		
	Varanus boehmei	yes	0.119	9
	Varanus exanthematicus	yes	0.037	9
	Varanus jobiensis	yes	0.119	9
	Varanus macraei	no		
	Varanus melinus	no		
	Varanus prasinus	yes	0.119	9
	Varanus rudicolis	no		
	Varanus salvator	yes	0.119	14
	Varanus timorensis	yes	0.119	8
	Varanus yuwonoi	no		
Lacertidae	*Acanthodactylus longipes*	yes	0.458	11
	Adolfus jacksoni	yes	0.391	3
	Heliobolus spekii	yes	0.474	3
	Holaspis guentheri	yes	0.325	5
	Latastia longicaudata	yes	0.492	10
	Takydromus sexlineatus	yes	0.325	5
Teiidae	*Ameiva ameiva*	no		
	Holcosus undulatus	yes	0.368	14
	Aspidoscelis deppei	yes	0.366	3
	Cnemidophorus lemniscatus	no		

Table A1. *Cont.*

Family	Species	Distribution Map Available/Presence of Climate Station	RAM	AS-ISK (Biology/Ecology Score Only)
	Tupinambis merianae	yes	0.150	12
	Tupinambis rufescens	yes	0.145	12
Cordylidae	*Cordylus beraduccii*	yes	0.018–0.271	3
	Cordylus tropidosternum	yes	0.018–0.271	3
	Platysaurus guttatus	no		
	Platysaurus intermedius	yes	0.019–0.275	5
	Platysaurus torquatus	yes	0.018–0.271	3
Colubridae	*Ahaetulla nasuta*	yes	0.056	10
	Ahaetulla prasina	yes	0.056	8
	Coelognathus helena	no		
	Coelognathus radiatus	no		
	Chrysopelea ornata	no		
	Boiga cynodon	yes	0.075	8
	Boiga dendrophila	no		
	Coluber constrictor	yes	0.067	12
	Cyclophiops major	yes	0.060	8
	Dasypeltis fasciata	yes	0.115	6
	Dasypeltis medici	yes	0.157	8
	Dasypeltis scabra	yes	0.401	8
	Dromicodryas bernieri	yes	0.134	7
	Elaphe bimaculata	yes	0.099	11
	Elaphe carinata	no		
	Erpeton tentaculatum	yes	0.056	8
	Euprepiophis mandarinus	yes	0.332	8
	Gonyosoma oxycephala	yes	0.342	4
	Homalopsis buccata	yes	0.134	7
	Lampropeltis alterna	yes	0.073	8
	Lampropeltis getula	yes	0.122	11
	Lampropeltis pyromelana	yes	0.116	8
	Lampropeltis triangulum	no		
	Lamprophis fuliginosus	yes	0.482	9
	Langaha madagascariensis	yes	0.134	7
	Leioheterodonn geayi	yes	0.134	8
	Leioheterodon madagascariensis	yes	0.134	7
	Leioheterodon modestus	yes	0.134	7
	Liophidium chabaudi	yes	0.134	6
	Madagascarophis citrinus	no		
	Madagascarophis colubrinus	yes	0.134	8
	Nerodia taxispilota	yes	0.100	13
	Oligodon chinensis	yes	0.151	9
	Oligodon formosanus	yes	0.135	6
	Oocatochus rufodorsatus	yes	0.073	10
	Opheodrys aestivus	yes	0.139	9
	Oreocryptophis porphyracea	no		
	Orthriophis moellendorffi	yes	0.290	6
	Orthriophis taeniurus friesi	no		
	Psammophis mossambicus	yes	0.140	9
	Psammophylax multisquamis	no		
	Pseudelaphe flavirufa	yes	0.059	6
	Rhadinophis frenatum	yes	0.345	6

Table A1. *Cont.*

Family	Species	Distribution Map Available/Presence of Climate Station	RAM	AS-ISK (Biology/Ecology Score Only)
	Rhamphiophis rostratus	no		
	Rhamphiophis rubropunctatus	no		
	Rhinocheilus lecontei	yes	0.149	9
	Rhynchophis boulengeri	yes	0.342	6
	Spalerosophis diadema	no		
	Thamnophis marcianus	yes	0.369	13
	Thamnophis sauritus	yes	0.358	12
	Thamnophis sirtalis	yes	0.662	13
	Xenochrophis vittata	yes	0.290	7
	Telescopus beetzi	no		
	Heterodon nasicus	yes	0.178	11
	Dendrelaphis cyanochloris	yes	0.056	7
	Dendrelaphis formosus	yes	0.056	10
	Dinodon flavozonatum	yes	0.344	6
	Pantherophis vulpinus	yes	0.155	10
	Philothamnus semivariegatus	yes	0.731	9
Viperidae	*Atheris ceratophora*	yes	0.018–0.254	2
	Bitis arietans	yes	0.101–0.671	11
	Bitis nasicornis	yes	0.019–0.264	4
	Bitis rhinoceros	yes	0.018–0.254	9
	Cerastes cerastes	yes	0.035–0.395	7
	Crotalus atrox	yes	0.057–0.524	7
	Crotalus cerastes	yes	0.026–0.326	8
	Cryptelytrops albolabris	no		
	Cryptelytrops fasciatus	yes	0.018–0.254	4
	Cryptelytrops insularis	yes	0.018–0.254	4
	Cryptelytrops purpureomaculatus	yes	0.018–0.254	2
	Trimeresurus fucatus	yes	0.018–0.254	4
	Trimeresurus nebularis	yes	0.018–0.254	4
	Trimeresurus poperium	yes	0.018–0.254	3
	Trimeresurus puniceus	yes	0.018–0.254	4
	Tropidolaemus subannulatus	yes	0.018–0.254	7
	Tropidolaemus wagleri	yes	0.018–0.254	3
	Viridovipera gumprechti	yes	0.018–0.254	0
	Viridovipera vogeli	yes	0.018–0.254	0
	Deinagkistrodon acutus	yes	0.020–0.267	10
	Agkistrodon contortrix	yes	0.082–0.620	8
Elapidae	*Acanthopis praelongus*	yes	0.126	−1
	Aspidelaps lubricus	yes	0.405	1
	Dendroaspis angusticeps	yes	0.418	3
	Naja atra	yes	0.216	3
	Naja kaouthia	yes	0.381	5
	Naja naja	yes	0.170	9
Xenopeltidae	*Xenopeltis unicolor*	yes	0.190	7
Sphenodontidae	*Sphenodon punctatus*	yes	0.072–0.607	4

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