Establishment risk from pet-trade freshwater turtles in the European Union

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ABSTRACT

The pet-turtle market has grown in recent years and become an important pathway for the introduction of alien species in Europe. The import of *Trachemys scripta elegans* has been banned by European Commission Regulation due to its species' expanding territory and negative impact on native species. Since the demand from hobby breeders persists, however, blocking imports of this popular subspecies opens up the possibility for the introduction of other potentially invasive turtles. We determined those turtle species most common in the pet trade within the Czech Republic, which is the most important producer, importer and exporter of ornamental aquatic animals in the EU. The determination of establishment risk for the EU as a whole was then individually evaluated for turtle species based on known establishment models. *Chelydra serpentina*, *Apalone spinifera*, *Apalone mutica*, and *Sternotherus odoratus* were considered most problematic, because these species have serious establishment risk and are imported to the EU in substantial numbers. Also localities in the EU were identified where probability is highest for establishment of non-native turtles.

RÉSUMÉ

Le risque d'implantation des tortues d'eau douce, issues du commerce d'animaux de compagnie, dans l'Union européenne

Mots-clés :
*marché des
animaux
de compagnie,
République
tchèque,
voie
d'introduction,
espèces
envahissantes,
climat*

Le marché des tortues de compagnie a augmenté ces dernières années et devient une voie importante pour l'introduction d'espèces exotiques en Europe. L'importation de *Trachemys scripta elegans* a été interdite par le règlement européen en raison du territoire d'expansion de cette espèce et de son impact négatif sur les espèces indigènes. Depuis, la demande des éleveurs amateurs persiste, et l'interdiction de l'importation de cette sous-espèce populaire ouvre la possibilité pour l'introduction d'autres tortues potentiellement envahissantes. Nous avons déterminé les espèces de tortue les plus courantes dans le commerce des animaux de compagnie au sein de la République tchèque, qui est le plus important producteur, importateur et exportateur d'animaux aquatiques ornementaux dans l'UE. La détermination du risque d'implantation dans l'UE dans son ensemble a ensuite été évalué individuellement pour les espèces de tortues sur la base de modèles d'implantation connus. *Chelydra serpentina*, *Apalone spinifera*, *Apalone mutica*, et *Sternotherus odoratus* ont été considérées comme les plus problématiques, car ces espèces ont un risque d'implantation sérieux et sont importées dans l'UE en nombre substantiel. De plus, les lieux dans l'UE où la probabilité est la plus forte pour l'établissement des tortues non indigènes, ont été identifiés.

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INTRODUCTION

Alien invasive species are among the major causes of biodiversity loss (Dukes and Mooney, 1999; Strayer *et al*., 2006; Ricciardi, 2007), and conservation agencies around the world devote various degrees of attention to this phenomenon (Hulme, 2006). Time, money and considerable effort are spent each year in eradication, control and mitigation of alien species impacts (Pimentel *et al.*, 2005), mainly for reasons that these invaders may displace native species from their ecological niches through 1) competition for resources, 2) hybridization, 3) introduction of pathogens, or 4) predation (Williamson, 1996; Manchester and Bullock, 2000; Kraus, 2009).

In contrast to plants, the invasiveness of animals, and especially vertebrates, has attracted much less attention in the past (Pyšek *et al*., 2010). Reptiles, in particular, have been widely overlooked in systematic invasion studies (Kraus, 2009; Bomford *et al*., 2009; Henderson *et al*., 2011), and their establishment potential and invasion dynamics remain poorly understood (Ernst *et al*., 2011). Delivering Alien Invasive Species Inventory for Europe – DAISIE (2012) recognizes in Europe 72 alien reptile species. While not all of these reptiles are exotic to Europe, many of them, such as the European pond turtle (*Emys orbicularis*) and slow worm (*Anguis fragilis*), were translocated within the continent into several countries where they are not native (McGuire and Marnell, 2000; Mlíkovský and Stýblo, 2006; Kark *et al*., 2009).

Turtles, which constitute a relatively species-poor order, comprise the group with the globally highest number of introduction events among reptiles (Kraus, 2009). It is not surprising, therefore, that the highest densities of alien reptiles in Europe are found in aquatic habitats (Pyšek *et al*., 2010), and 13 of 17 species of introduced alien turtles are of freshwater origin (DAISIE, 2012).

Turtles of the family Emydidae – with 2,108 recorded introduction events – are the most commonly introduced reptile taxon in the world. Within Emydidae, moreover, 68% of the aforementioned introduction events involve pond sliders (*Trachemys scripta*) (Kraus, 2009). This species is taxonomically sorted into three subspecies (Fritz and Havaš, 2007) from which the red-eared slider (*Trachemys scripta elegans*) is the most common subspecies with the greatest native range, encompassing the Mississippi Valley in the USA and northern parts of Mexico (Ernst *et al*., 1994).

Mainly due to its appearance, *T. s. elegans* is also one of the most popular reptile pets worldwide (Franke and Telecky, 2001). When it reaches adulthood, however, it loses its attractive coloration, and hobby keepers often release their turtles into local waters (Cadi and Joly, 2003). At these locations, the released individuals may indirectly exclude or outcompete native turtle species (Cadi and Joly, 2003; Cadi and Joly 2004; Polo-Cavia *et al*., 2008) and can indeed negatively affect other species in aquatic communities (Mlíkovský and Stýblo, 2006; Teillac-Deschamps and Prevot-Julliard, 2006; Pešát, 2008). Therefore the import of *T. s. elegans* was banned by the EU's Commission Regulation No 338/1997 (EC, 1997). However southern and western states of the European Union (EU) have already established vital populations of *T. s. elegans* including Spain (Martínez-Silvestre *et al*., 1997), France (Cadi *et al*., 2004), and Italy (Sindaco *et al*., 2006). Although it seems reasonable to stop import of the pond slider, this does open up the possibility for introduction of other invasive species, inasmuch as the demand for aquatic turtles by hobby keepers still persists. Since 1997, other species of turtles may have met the market demand while replacing *T. s. elegans* in the EU pet trade, but, due to a lack of information (among other factors), these turtles may pose the same problem as the forbidden *T. s. elegans*.

Identifying the potential danger posed by alien species and then preventing new introductions is currently considered the most effective management approach (Mack *et al*., 2000; Thuiller *et al*., 2005; Keller *et al*., 2008). In accordance with this view, we determined which turtle species are now most common in the pet trade and their trade quantities. Data from the Czech Republic authorities were utilized, since the Czech Republic is the main producer, importer and exporter of aquatic ornamental animals in the EU (Livengood and Chapman, 2007; Miller-Morgan, 2009; Peay, 2009). Establishment risk for the EU as a whole was then

evaluated individually for important turtle species within the pet trade based upon a known establishment model (Bomford, 2008; Bomford *et al.*, 2009).

The present paper aims to highlight the possible problems with imports of other turtle species which should be regulated at EU level as is the case for *T*. *s*. *elegans*. The relationship among zoogeographical or family origin with obtained establishment risk ranks was additionally tested.

METHODS

> *EXAMINING DATA ON TURTLE IMPORTS*

Under Czech Republic laws and regulations, the importation of animals and their products is subject to reporting to the Customs Administration as well as the State Veterinary Administration. We used more precise data from the Veterinary Administration, where importers' requests for import authorization are evaluated and processed. Information about species or genera of live turtles imported into the Czech Republic is available since 2008. While these data represent issued permits, the actual numbers of imported individuals might be smaller because shipments do not always reach the maximum permitted quantity due to supply issues. Nevertheless, the true numbers may not be larger than those quantities stated in the permits (Zhou and Jiang, 2008). On the other hand, it cannot be excluded that other individuals entered EU via the black market but true numbers are obviously unknown. The proportions of the various turtle species imported were approximated based on interviews with six important wholesalers in the Czech Republic that are known to be the main importers of live turtles. The information thus obtained was combined with that from the permits and the imported numbers of each species per year were accordingly estimated.

> *DETERMINATION OF ESTABLISHMENT RISK FOR EU*

We used a model designed by Bomford (2008) and Bomford *et al.*, (2009), which is based on parameters: (i) climatic similarity of source (native distribution of species) and target regions (termed *climate match risk* score), (ii) species' ability to establish populations elsewhere (termed *prop.species* value), (iii) establishment success of the other species from the same family (termed *family random effect*), and constant value characteristic (iv) jurisdiction score, which accounts for expected variability in establishment success rate due to the effect of particular jurisdiction (country, state or province).

Climate match risk scores were computed using the program Climatch v1.0 (Bureau of Rural Sciences, 2008). A Euclidean algorithm and 16 temperature and rainfall variables with sum of scores for classes 6–10 was used (Bomford, 2008).

Due to fact that some introductions events occurred after 2008, we cannot take original *prop.species* values from Bomford (2008). Therefore values of *prop.species* scores were computed anew for this study using the Kraus (2009) database and following instructions given by Bomford (pers. comm.). When values for calculating *prop.species* or *prop.genus* were insufficient (*i.e.* fewer than 3 introduction attempts), we did not compute a *prop.family* value (Henderson *et al*., 2011) but instead used approximation according to phylogenetically related genera (*i.e.* the closest branches on an up-to-date turtle phylogenetic tree (Guillon *et al*., 2012)).

Family random effect was taken from Bomford (2008).

As the target region we utilized all states of the EU, including the autonomous islands of Macaronesia (namely the Azores, Madeira, and Canary Islands) in a manner similar to Arnold (2003), while, due to their geographical remoteness, the overseas departments and regions of France were not included into our study as parts of the EU. The target region contained 1113 climate stations. The jurisdiction data for the entire EU did not exist and no jurisdiction score is available for the EU as a whole. Therefore we used a combined jurisdiction score,

Table I

Estimated annual numbers of the most marketed turtle species imported by pet wholesalers into the Czech Republic during 2008–2012.

Species	2008	2009	2010	2011	2012	sum	origin
Trachemys scripta	28000	59900	44000	38500	41200	**211600**	USA
Graptemys pseudogeographica	15000	27500	23500	23000	26000	**115000**	USA
Sternotherus odoratus	9000	26060	21000	11120	10762	**77942**	USA
Pseudemys concinna	9000	22000	20000	10000	10600	**71600**	USA
Pseudemys peninsularis	9000	20135	20012	11000	10000	**70147**	USA
Sternotherus carinatus	4000	10800	16010	11050	7600	**49460**	USA
Apalone ferox	4000	5035	10000	5006	3500	**27541**	USA
Apalone spinifera	4000	5035	10000	5000	3000	**27035**	USA
Apalone mutica	4000	5000	10000	5000	3000	**27000**	USA
Chelydra serpentina	500	1170	1280	1767	500	**5217**	USA
Mauremys sinensis	1000	250	2400	1000	0	**4650**	Taiwan
Pelodiscus sinensis	1000	0	0	0	0	**1000**	Taiwan
Kinosternon scorpioides	10	50	37	195	550	**842**	USA
Platemys platycephala	60	40	37	60	600	**797**	Surinam
Malaclemys terrapin	500	70	0	0	0	**570**	USA

Note: Listed are only species with sum of more than 500 imported individuals. Data from 2012 are for January–September only. *Trachemys scripta* species include only subspecies *scripta* and *troostii*.

based on published values for previously tested countries or states (Bomford, 2008; Bomford *et al*., 2009). Before we applied our modification, the model was calibrated on *Trachemys scripta scripta* for EU and we got presumable serious risk rank.

> STATISTICS

For testing the dependence of establishment risk for the EU upon zoogeographical and family origin, we used only risk ranks from the model. Risk ranks were evaluated as low = 0, moderate = 1, serious = 2, and extreme = 3. When risk rank categories had ranges, we used the mean value. Due to a great number of categories (6 zoogeographical regions, 9 families) and low number of dependent variables (34 turtle species), we used separate non-parametric Kruskal–Wallis tests. To determine if there is a balanced, market offer of turtles from different zoogeographical regions or families, we computed chi-square tests of homogeneity (observed vs. balanced expected values). Tests were computed using Statistica 10 (Statsoft, 2010). We used $\alpha = 0.05$ to evaluate statistical significance.

> RESULTS

Based on data from the Czech Republic (Table I) we postulate that species of turtles imported into the EU in substantial numbers are *Trachemys scripta* (subspecies *scripta* and *troosti*), *Graptemys pseudogeographica, Sternotherus odoratus*, *Pseudemys concinna* and *Pseudemys peninsularis*. Turtle origins were not evenly distributed among zoogeographical regions ($\chi^2 = 33.42$, *df* = 5, *P* < 0.001), which is true also for turtle families ($\chi^2 = 17.36$, *df* = 8, *P* < 0.05). Most species were from the Nearctic zoogeographical area (53%) and Emydidae family (29%). The results from the model (Table II), revealed no differences among families (*K–W* test, *df* = 8, *H* = 11.88, *P* = 0.16) or zoogeographical regions (*K–W* test, *df* = 5, *H* = 1.12, *P* = 0.95) in ranks for establishment risk.

Table II
Results of computed establishment risk model for individual species of turtles imported to EU. Conversion of establishment risk score to establishment risk ranks follows set up values: low ⩽ 0.16, moderate 0.17–0.39, serious 0.40–0.85, extreme ⩾ 0.86.

Species	Family	Risk score	Risk rank
Pelomedusa subrufa	Pelomedusidae	0.51	serious
Pelusios sinuatus	Pelomedusidae	0.24	moderate
Pelusios subniger	Pelomedusidae	0.11	low
Podocnemis unifilis	Podocnemididae	0.03 – 0.40	low - serious
Hydromedusa tectifera	Chelidae	0.15 – 0.78	low - serious
Chelodina reimanni	Chelidae	0.05 – 0.49	low - serious
Macrochelodina rugosa	Chelidae	0.05 – 0.49	low - serious
Platemys platycephala	Chelidae	0.11 – 0.72	low - serious
Chelus fimbriatus	Chelidae	0.16 – 0.79	low - serious
Chelydra serpentina	Chelydridae	0.83	serious
Carettochelys insculpta	Carrettochelyidae	0.02 – 0.27	low - moderate
Apalone ferox	Trionychidae	0.27	moderate
Apalone mutica	Trionychidae	0.49	serious
Apalone spinifera	Trionychidae	0.75	serious
Pelodiscus sinensis	Trionychidae	0.32	moderate
Kinosternon baurii	Kinosternidae	0.06	low
Kinosternon scorpioides	Kinosternidae	0.06	low
Kinosternon subrubrum	Kinosternidae	0.16	low
Sternotherus odoratus	Kinosternidae	0.64	serious
Sternotherus carinatus	Kinosternidae	0.19	moderate
Clemmys guttata	Emydidae	0.13	low
Chrysemys picta	Emydidae	0.34	moderate
Graptemys geographica	Emydidae	0.28	moderate
Graptemys pseudogeographica	Emydidae	0.06	low
Malaclemys terrapin	Emydidae	0.05	low
Pseudemys concinna	Emydidae	0.12	low
Pseudemys nelsoni	Emydidae	0.06	low
Pseudemys peninsularis	Emydidae	0.05	low
Pseudemys rubriventris	Emydidae	0.06	low
Trachemys scripta	Emydidae	0.36	moderate
Cyclemys dentata	Geoemydidae	0.07	low
Mauremys reevesii	Geoemydidae	0.09	low
Mauremys sinensis	Geoemydidae	0.05	low
Rhinoclemmys pulcherrima	Geoemydidae	0.05	low

Note: We present range of values of establishment risk scores for families Carettochelyidae, Chelidae, Podocnemididae due to the absence of the family random effect (Bomford, 2008).

No introduction of *Carettochelys insculpta* is known, moreover this species belongs to monotypic family, therefore it was not possible to compute prop.species value due to specific environment demands (Doody *et al*., 2003) therefore we decided to set it as 0.

Trachemys scripta species includes only subspecies *scripta* and *troosti*.

Number of imported individuals (more than 500 individuals among 2008–2012) (Table I) combined with establishment risk (serious and extreme risk rank) (Table II), suggests that reproduction will be recorded in the future in the following species: *Sternotherus odoratus*, *Apalone spinifera*, *Apalone mutica* and *Chelydra serpentina*.

DISCUSSION

The pet trade is growing in intensity globally, and its contribution to new introductions of amphibians and reptiles exceeds by almost four times any other recognizable pathway (Kraus, 2009). Hence, pet-trade species of amphibians and reptiles also have the highest absolute numbers among species established worldwide (Kraus, 2009).

Generally, introduced species are successful in establishing new populations or invading within non-native ranges only when a combination of several variables is favourable. These are 1) propagule pressure, also recognized as introduction effort (Lockwood *et al*., 2005; Simberloff, 2009; Wilgen and Richardson, 2012); 2) biotic factors like life history, but also including presence of predators, pathogens and competitors (Bomford, 2003; Strauss *et al*., 2006; Proches *et al*., 2008); and 3) abiotic factors, especially the climatic similarity of the native and non-native ranges (Thuiller *et al*., 2005; Hayes and Barry, 2008; Bomford *et al*., 2009).

In the models by Bomford (2008), and partially Bomford *et al.* (2009) used in this study, biotic and abiotic factors were taken into account. Biotic factors are represented by the variables *prop.species* value and *family random effect*. Abiotic factors are included into the *climate match risk* score, which reflects similarity of native and non-native range in terms of temperature and rainfall variables. We do not incorporate propagule pressure into the models, which can be viewed as a weakness of our approach. Although the propagule pressure is considered to be a major factor in establishment or invasion studies (Lockwood *et al*., 2005; Bomford *et al*., 2009; Simberloff, 2009; Wilgen and Richardson, 2012), precise information about the number of released individuals is rarely available (Kolar and Lodge, 2001; Hayes and Barry, 2008; Bomford *et al*., 2009). In accordance with Copp *et al*. (2010), however, the data on turtle imports presented in Table I can be used as a roughly correlating measure for propagule pressure, although we are cognizant of the approximate value of the presented data. Such correlation between high propagule pressure and imports can be seen in the example of *T. s. elegans*, as more than 52 million individuals of this species were imported from the USA between the years 1989 and 1997 and the majority of these ended up in Europe as pets (Cadi *et al.*, 2004). Due to the mass imports, these turtles were sold for relatively low prices and thus were available to almost anyone. When pets are sold to a large number of people, the proportion of those who do not have proper information about their breeding potential and their release into the wild is likely to be high (Fujisaki *et al*., 2010). High propagule pressure in combination with favourable biotic and abiotic factors can be presumed to explain the successful establishment of *T. s. elegans* in Europe (Ficetola *et al*., 2009).

There is generally a non-random pattern in the origin of introduced vertebrate species, with most of these coming from the Northern Hemisphere (Jeschke and Strayer, 2006; Kraus, 2009). The majority of pet-trade freshwater turtles (50%) came to Europe from the Nearctic zoogeographical region. This bias reflects the historical and modern trade connections between Europe and North America (Kraus, 2009). While until the 19th century species introductions from Europe to North America dominated, the reverse was true in the 20th century (Jeschke and Strayer, 2006). Our results confirm the findings of Kraus (2009) and of Wilgen and Richardson (2012) that most pet-trade species among turtles are members of the Emydidae family. This pattern is probably associated with their attractive coloration (Thornhill, 1993). On the other hand, it could be also an artefact of the Emydidae family's origin, because it demonstrates the greatest diversity in North America (Ernst *et al*., 1994).

While our conclusions about the rankings of establishment risk and their association with family or zoogeographical regions is limited due to the small data set, our results seem relevant for the EU. When looking at the family origins of the most risky species, the most dangerous turtles (*i.e.* likely to establish if released) are from families other than Emydidae (*Chelydra serpentina* – Chelydridae, *Apalone spinifera* – Trionychidae, *Pelomedusa subrufa* – Pelomedusidae, *Sternotherus odoratus* – Kinosternidae). Due to the absence of *family random effect* values in Bomford (2008), we compute ranges of potential establishment risk scores for the families Carettochelyidae, Chelidae and Podocnemididae by inserting lowest and highest theoretical values (taken from Bomford 2008) of the *family random effect* into

the model formula. It is surprising that the model computations rate no other member of the *Emydidae* family as serious except *T. s. elegans* that is already established in the EU. This finding suggests that the establishment potential of this family (Wilgen and Richardson, 2012) may be overestimated due only to the success of *T. s. elegans* (see also the Kraus, 2009 database). While taxonomic levels are sometimes useful predictors of establishment success for introduced species (Bomford *et al*., 2009; Fujisaki *et al*., 2010), our *post hoc* comparison for freshwater turtles in the EU pet trade did not confirm that members of particular families have higher risk ranks then others here shown on the *Emydidae* family.

Establishment risk rank for turtles is not significantly connected with their zoogeographical origin, thus suggesting that particular species' niche breadth plays a more important role in establishment potential. This is consistent with the finding that the most risky species (*Chelydra serpentina, Apalone spinifera, Sternotherus odoratus*, and *Pelomedusa subrufa*) exhibit among the most extensive native ranges. Greater range usually means – and especially so in the temperature zone – that a species must face various biotic and abiotic conditions (Angiletta *et al*., 2004). Since we use the whole territory of the EU as the target region, and as this territory has a large climatic amplitude, it is not surprising that species whose native ranges cover the most distinctive climatic conditions (Kolar and Lodge, 2001) were evaluated as most dangerous.

As in several analogous studies (Thuiller *et al*., 2005; Bomford *et al*., 2009; Fujisaki *et al*., 2010), *climate match risk* score was the strongest predictor of establishment risk. In agreement with Wilgen *et al*. (2009), we show that some species have small areas predicted as suitable (*e.g. Mauremys reevesii* – south Germany, *Hydromedusa tectifera* – Po Valley in Italy, *Chelus fimbriatus* – Galicia in Spain) but low average establishment risk score. On the EU maps of climate match risk, some areas appear more frequently as suitable for pet-trade freshwater turtles (Figure 1). These include the vicinity of Rome and Foggia on the west and east coast of central Italy; the Danube Valley in Slovakia, Hungary, Romania and Bulgaria; lowlands of the rivers Maritsa and Tundzha in Bulgaria; and the lowlands of northern Greece. Other important areas are the Po Valley in Italy; the Sava and Krka valleys in Slovenia; as well as the coasts of the Mediterranean Sea of Northern Italy, France and Spain, including Corsica, and Sardinia (compare with Ficetola *et al*., 2009).

The limitation of presented approach lies in fact, that we used only variables discussed above (prop.species value, family random effect and climate match risk score). Therefore it must be mentioned that establishment-risk scores cannot be viewed as precise estimates of probability for establishment but they rather provide a relative ranking of establishment risk for freshwater turtle species introduced into EU.

Several non-native freshwater turtles in the pet trade have been reported from the wild in EU states, but these findings are rather recent (Burgert *et al*., 2011). Reproduction in the wild has been confirmed heretofore only for *T. s. elegans*, but this does not necessarily mean that other turtles are not able to reproduce. Reproduction could be easily overlooked (Hulme, 2006) or postponed in time due to the relatively long period in life before turtles reach sexual maturity (de Magalhaes and Costa, 2009). Based on our results we tentatively predict that reproduction will be recorded in the future in the following species: *Sternotherus odoratus*, *Apalone spinifera*, *Apalone mutica*, and *Chelydra serpentina*. Allee effects can dramatically influence establishment success (Taylor and Hastings, 2005), and the expectation of reproduction in turtles which were (or will be) released in substantial numbers will be also impacted spatially. Copp *et al*. (2010) demonstrated that urban areas, with their characteristically high population density, are also the most affected by animals introduced from the pet trade. It is noteworthy that after fishes, amphibians and reptiles are relatively invisible to the public when they escape or are released into the wild. These animals have the advantage of more time to establish vital populations before any eradication action comes into force. Therefore, standing waters close to large agglomerations within the suitable climatic regions of the EU should be given greater attention in monitoring. Data from these areas should be evaluated further before any new restrictions will be applied.
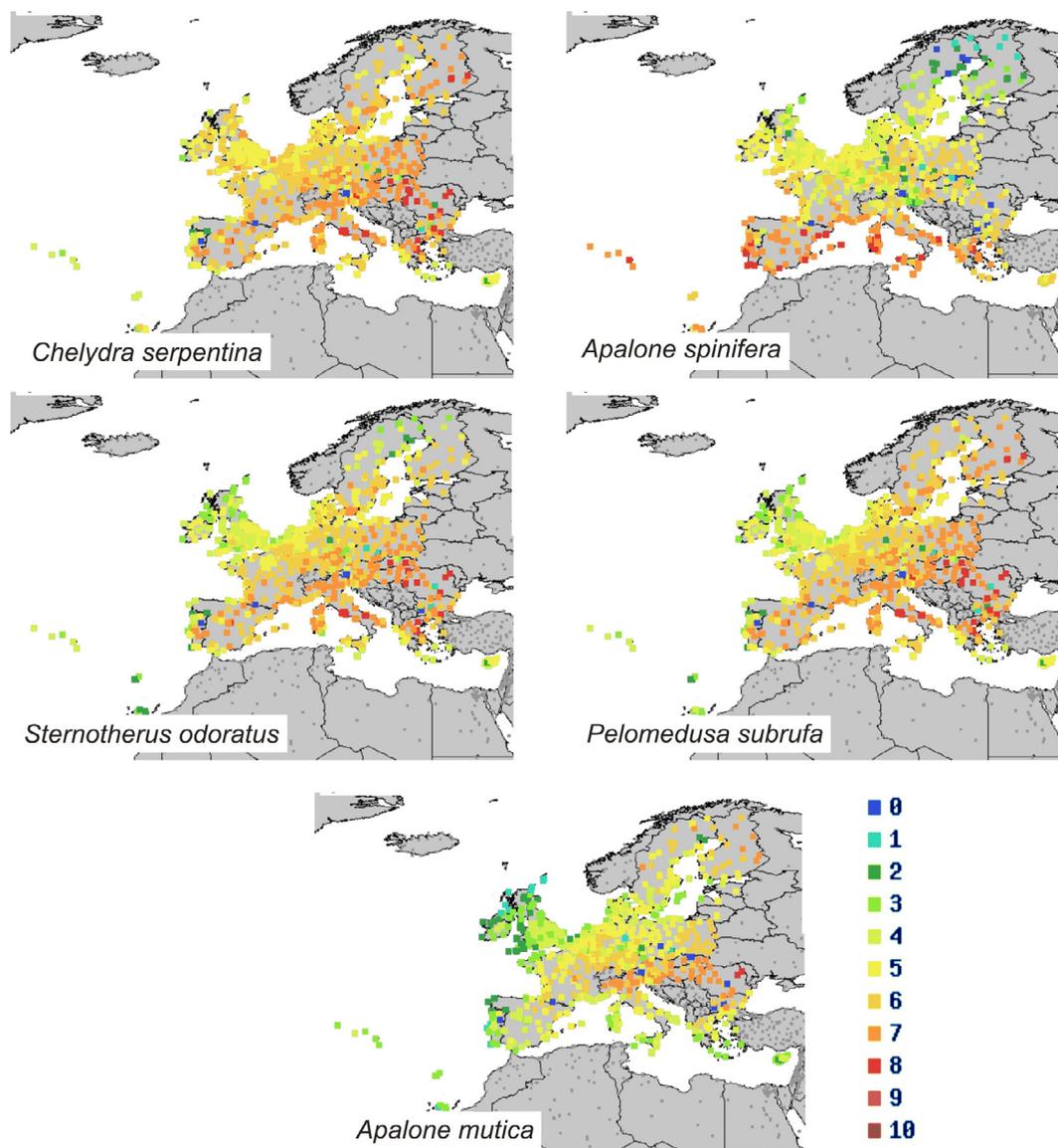
Figure 1
Climate match risk maps showing those places with highest probability of establishment for the five most dangerous species of freshwater turtles (evaluated by model as serious).

ACKNOWLEDGEMENTS

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