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Alien Freshwater Turtles in Greece: Citizen Science Reveals the Hydra-Headed Issue of the Pet Turtle Trade

Konstantinos Kalaentzis [1,2,*], Christos Kazilas [2], Ilias Strachinis [3], Elias Tzoras [4] and Petros Lymberakis [5,*]

[1] Hydrobiological Station of Rhodes, Hellenic Centre for Marine Research, 85100 Rhodes, Greece
[2] Naturalis Biodiversity Center, P.O. Box 9517, 2300 RA Leiden, The Netherlands; ckazilas@gmail.com
[3] Department of Genetics, Development and Molecular Biology, School of Biology, Faculty of Natural Sciences, Aristotle University of Thessaloniki, 54636 Thessaloniki, Greece; strachin@bio.auth.gr
[4] Independent Researcher, 26442 Patras, Greece; eliastzoras@outlook.com
[5] Natural History Museum of Crete, University of Crete, 71409 Heraklion, Greece
* Correspondence: k.kalaentzis@hcmr.gr (K.K.); lyberis@nhmc.uoc.gr (P.L.)

Abstract: Citizen science is emerging as a powerful tool for the early detection of biological invasions. The exotic pet trade has been deemed as the most significant cause of establishment for reptiles, and among them, turtles have the highest number of introduction events. In Europe, at least 13 species of alien freshwater turtles have been recorded in the wild. In Greece, only two species of alien turtles have been reported, namely the American pond slider *Trachemys scripta* and the Florida cooter *Pseudemys floridana*. In this study, we provide an updated checklist of the alien freshwater turtles recorded in Greece, using citizen science, personal observations, and literature. Our results provide the first records for the country of five species, namely the Florida red-bellied cooter *Pseudemys nelsoni*, the Eastern river cooter *Pseudemys concinna*, the Chinese stripe-necked turtle *Mauremys sinensis*, the Chinese soft-shelled turtle *Pelodiscus sinensis*, and the Common snapping turtle *Chelydra serpentina* and new localities for *T. scripta*. Similar to the myth of the Lernaean Hydra (i.e., for every head chopped off, more would regrow), the pet turtle trade has been proven to have multiple heads.

Keywords: biological invasions; pet trade; non-native species; invasive alien species; aquatic invasions; terrapins

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1. Introduction

The constant rise of international commerce has led to an escalation of biological invasions worldwide with no clear signs of stabilizing in the near future [1–3]. The introduction of biota beyond their native geographic range and potential spread affects not only native biodiversity and ecosystem services (i.e., through competitive replacement [4] or hybridization with native taxa [5–7], pathogen transmission [8,9], and food-web modification [10]) but also human health [11,12] and economy [13,14]. Management of invasive alien species (IAS) corresponds to prevention, eradication, and control, the success of which mostly relies on the early detection of incipient populations [15]. The necessity of early detection and the attempt to rapidly eradicate IAS is also highlighted in EU Regulation 1143/2014.

Citizen science, i.e., public participation in research, is emerging as a powerful tool for biological invasion surveillance, which might revolutionize our ability to handle IAS in the early stages of the invasion. In Greece, data provided by citizen scientists have aided research endeavors in intercepting alien species at the onset of their invasion or mapping their spread [16–18]. Even though the validity and taxonomic accuracy of photographic data provided by citizen scientists can sometimes be of question [19–21], the distinctive morphological features of alien species can be used to distinguish them from their native

counterparts [22,23]. Citizen science has facilitated herpetological research on numerous occasions worldwide [24,25], although in Greece only a few recent studies have supplemented their dataset with citizen-science data [26–28].

For reptiles and amphibians, the exotic pet trade is the most significant cause of the introduction of alien taxa worldwide [29]. Undoubtedly, the highest densities of alien reptiles in Europe have been recorded from aquatic habitats [30]. Freshwater turtles are very popular in the pet trade and are usually abandoned or released in the wild, where they may become established [31,32]. Even though turtles are considered a relatively species-poor order, they have the highest number of introduction events among reptiles [29]. At least 61 species of chelonians have been recorded in the worldwide pet trade [33]; in Europe, at least 17 alien turtles have been reported from the wild, of which 13 were of freshwater origin [34].

In Greece, two alien species of freshwater turtles have been recorded so far; the American pond slider (APS) *Trachemys scripta* (Thunberg, 1792) and the Florida cooter (FC) *Pseudemys floridana* (Le Conte, 1830), both of which have been found in co-occurrence with the native species, i.e., the Western Caspian turtle *Mauremys rivulata* Valenciennes, 1833 and the European pond turtle *Emys orbicularis* (Linnaeus, 1758) [35,36].

The APS is a voracious species, currently introduced all around Europe. It poses a significant threat to native freshwater turtles with whom it competes for food sources, basking and nesting sites [37,38]. The Red-eared slider *Trachemys scripta elegans* (Wied, 1838) was the most traded subspecies of freshwater turtle since the 1950s and until its ban in the EU in 1997 (EU Regulation 338/1997; EU Regulation 349/2003), which has only shifted the pet trade interest to the other APS subspecies, but also to other turtle species [39,40]. It is considered one of the most harmful IAS according to the Global Invasive Species Database (GISD) in the world [41] and in 2016, it was listed among the IAS of EU concern (EU Regulation 2016/1141). Breeding populations have so far been reported from Spain [42], Italy [43], France [44], Portugal [45], and possibly Greece [46,47], Serbia [48], and Slovenia [49]. Attempts to eradicate individuals and nests of the APS in the wild have been made by Portugal in the Iberian project LIFE + *Trachemys*. In Greece, individuals of the APS have been recorded from the Greek mainland, but also in numerous islands, i.e., Crete, Corfu, Ikaria, Kos, Cephalonia, Lesvos, Thasos, and Zakynthos [35,36,50–54].

The FC is an opportunistic omnivorous turtle native to North America. It is one of the "substitute" pet species of freshwater turtles following the import ban of *T. scripta* by the EU [55] and has been characterized as a potentially invasive species [31]. It is known to lay six clutches per year, which is the maximum among the most frequently traded freshwater turtles [31]. In Europe, it has been recorded from Spain [56] and quite recently from Greece [36].

In this paper, we update the checklist of the alien freshwater turtles in Greece, including first records of the Florida red-bellied cooter *Pseudemys nelsoni* Carr, 1938, the Eastern river cooter *Pseudemys concinna* (Le Conte, 1830), the Chinese stripe-necked turtle *Mauremys sinensis* (Gray, 1834), the Chinese soft-shelled turtle *Pelodiscus sinensis* (Wiegmann, 1835), and the Common snapping turtle *Chelydra serpentina* (Linnaeus, 1758), using citizen-science data, personal observations, and literature data.

2. Materials and Methods

The collection of records of alien freshwater turtles in Greece was mostly based on citizen-science observations, originating from both the citizen-science platform of iNaturalist [57] and social-media groups administrated by the authors (i.e., "Reptiles and Amphibians of Greece & Cyprus" and "Alien Species in Greece & Cyprus"), which were supplemented by personal observations and literature data. The data acquisition process ended in December 2022. Species identification from the acquired photographic material (Figure 1) was based on the checklist by Rhodin et al. [58], while for the identification of the *Pseudemys* species, the diagnostic characters mentioned by Seidel & Ernst [59] were

used. Consultation with specialists confirmed the identification of Trionychidae observations (Daniel Escoriza, pers. comm.). Citizen-science observations of poor quality where the angle of the photographs made it impossible to observe diagnostic features and records without accurate coordinates were excluded from the dataset.

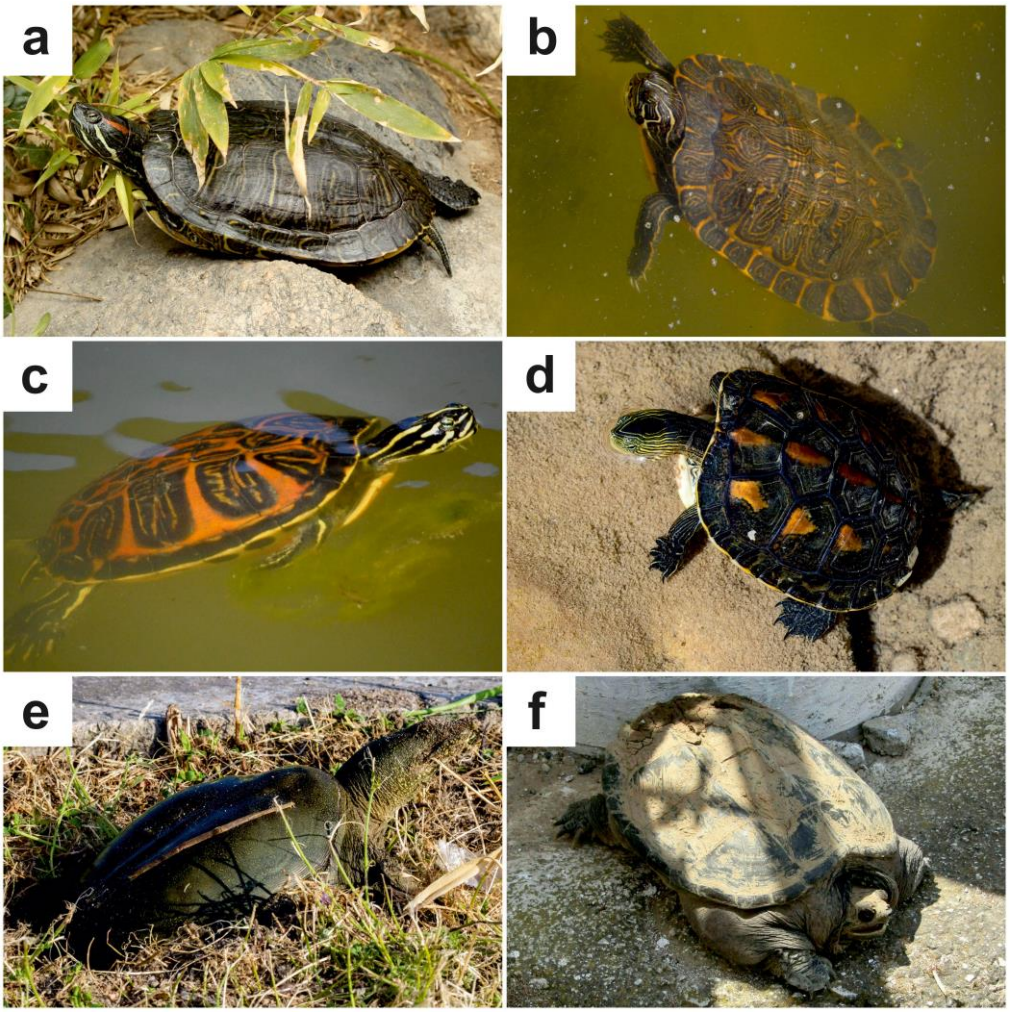

Figure 1. Individuals of alien freshwater turtles recorded in Greece. (**a**) American pond slider, *Trachemys scripta* observed in Pedion Areos Park in Thessaloniki (2009); (**b**) Eastern river cooter, *Pseudemys concinna* in Antonis Tritsis Park in Athens (2022); (**c**) Florida red-bellied cooter, *P. nelsoni* in Antonis Tritsis Park (2022); (**d**) Chinese stripe-necked turtle, *Mauremys sinensis* in Valanaris Stream, Penteli (2021); (**e**) Chinese soft-shelled turtle, *Pelodiscus sinensis* in Water Garden Park in Thessaloniki (2019); (**f**) Common snapping turtle *Chelydra serpentina* in Loutro Wetland near Athens (2019). Photos by Ilias Strachinis (**a**,**e**), Giorgos Darras (**b**,**c**), Vasilis Stergios (**d**) and Chris Vlachos (**f**).

Base maps for each species including occurrence records per source (i.e., citizen science, personal observations, and literature) were generated using QGIS version 3.28.1. Each record was assigned to a specific body of water, while records from localities interconnected in the same water basin were merged. Each body of water was characterized as natural (i.e., natural lakes, streams, marshes, wetlands, salt flats, estuaries, lagoons, and seasonal ponds) or anthropogenic (i.e., artificial lakes, dam reservoirs, and parks), while the co-occurrence with any of the two native freshwater turtles was assessed based on literature, citizen-science data, and personal observations.

3. Results & Discussion

A total of 240 occurrence records from 76 water bodies (Supplementary Material Table S1) were acquired, corresponding to observations from 2002 to the end of 2022. The final dataset included 160 citizen-science records (i.e., 126 records from iNaturalist and 34 from social-media groups), 29 records from personal observations, and 51 literature records. Species-wise, the vast majority of records corresponded to *T. scripta* (223 records; Figure 2), while the rest of the species were represented by significantly fewer observations; five records for each *M. sinensis* and *P. nelsoni*, four for *P. sinensis*, and one for each of the other species (Figure 3).

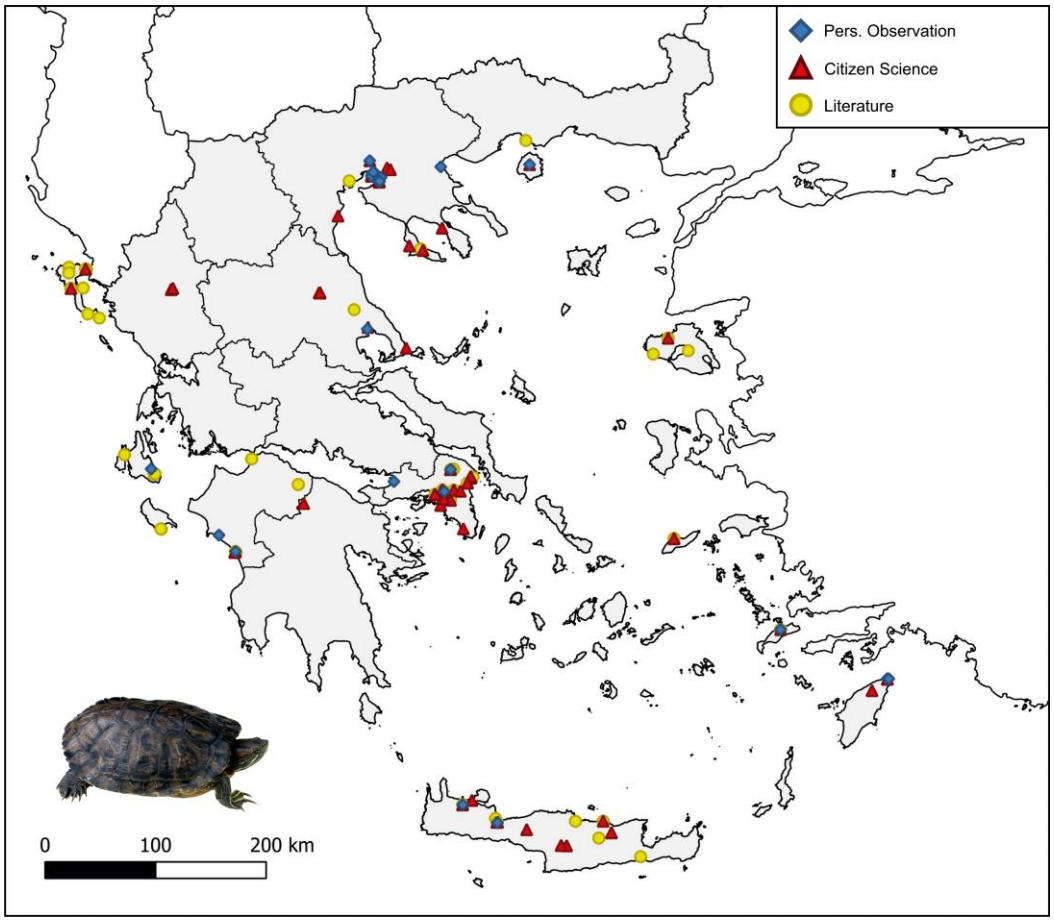

Figure 2. Occurrence map for the American pond slider, *Trachemys scripta* in Greece based on our dataset. Literature records are shown as yellow circles, citizen-science records as red triangles, and personal observations as blue rhombi.

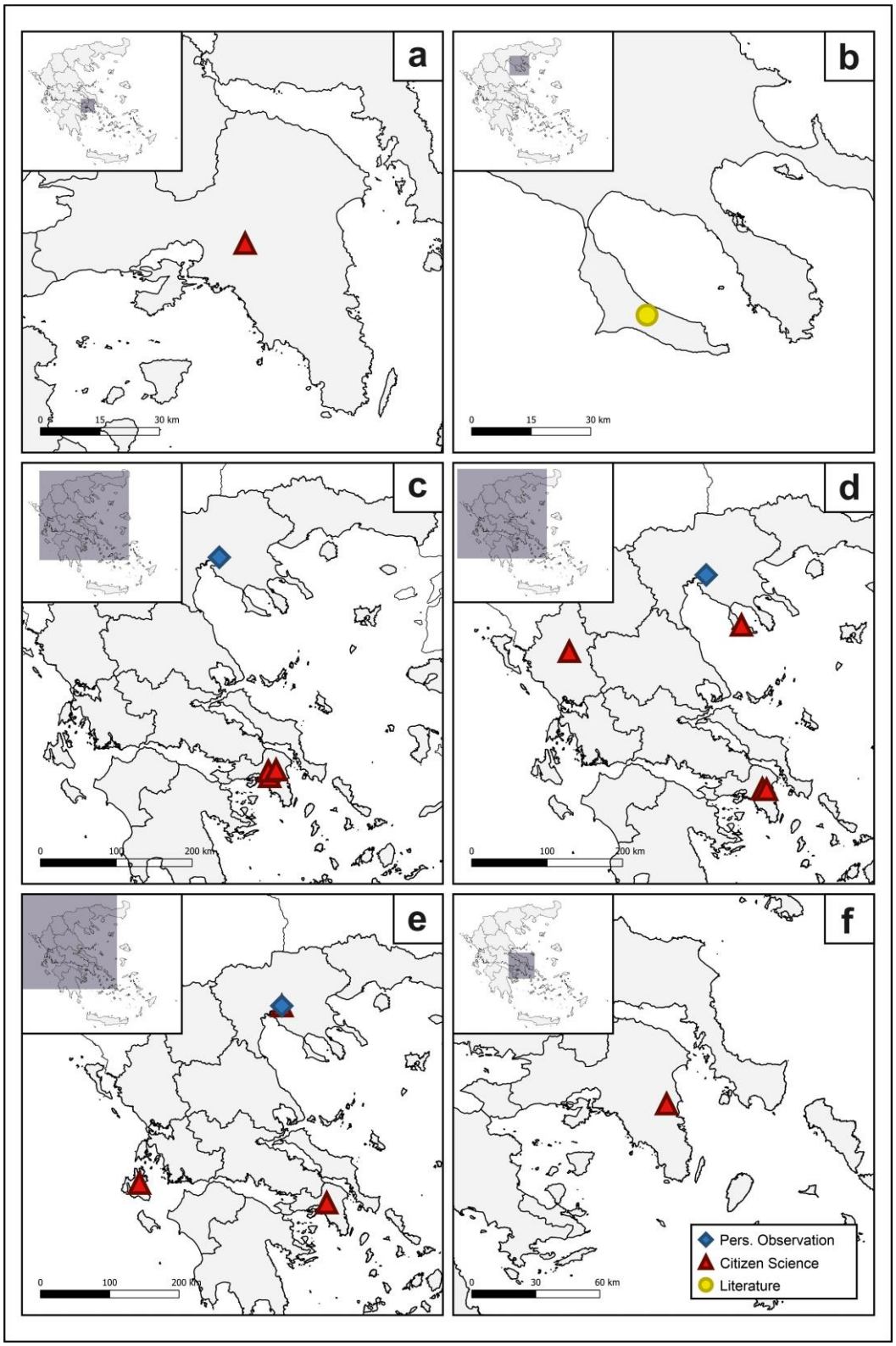

Figure 3. Occurrence maps for six alien freshwater turtles recorded in Greece based on our dataset. (**a**) Eastern river cooter, *Pseudemys concinna*; (**b**) Florida cooter, *Pseudemys floridana*; (**c**) Florida red-bellied cooter, *Pseudemys nelsoni*; (**d**) Chinese stripe-necked turtle, *Mauremys sinensis*; (**e**) Chinese soft-shelled turtle, *Pelodiscus sinensis*; and (**f**) Common snapping turtle, *Chelydra serpentina*. Literature records are shown as yellow circles, citizen-science records as red triangles and personal observations as blue rhombi.

Excluding the latter three species which were represented by only one record in our study, the vast majority of our dataset originated from citizen-science data. Regarding the type of invaded bodies of water, only *T. scripta* had a positive ratio of natural over anthropogenic environments, which can be explained by the longer period this species has dominated the pet trade (since the 1950s [39]). The substitute species replaced APS in the European pet trade only quite recently, meaning that their natural-to-anthropogenic ratio might follow a trend similar to their predecessor.

Finally, inspecting the co-occurrence with native species of freshwater turtles in the invaded bodies of water showed that in 70% of them, one or more alien species co-existed with at least one of the native ones (Figure 4; Table S1).

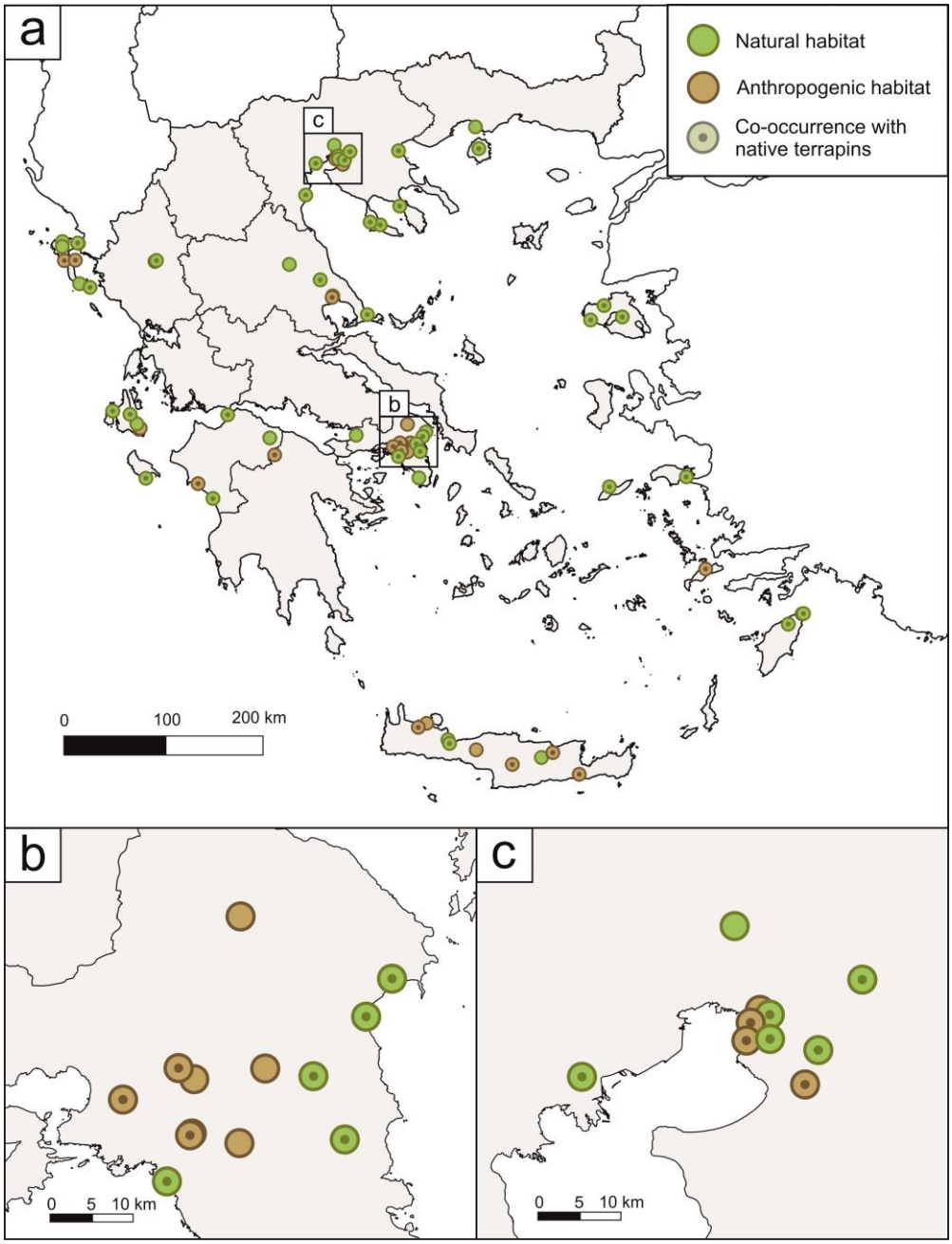

Figure 4. Water bodies, where at least one alien freshwater turtle was recorded, illustrated as natural (green) or anthropogenic (brown). Co-occurrence with at least one of the two native terrapins is shown as a dotted circle. (**a**) Water bodies in Greece. (**b**) Water bodies in and around the urban center of Athens. (**c**) Water bodies in and around the urban center of Thessaloniki.

3.1. American Pond Slider-Trachemys Scripta

The American pond slider (Figure 1a) is still the most common alien freshwater turtle in Greece with numerous occurrence records from the mainland and islands, with the vast majority of the citizen-science observations being after the total ban (i.e., import, trade, breeding, transport) imposed by the EU in 2016. The distribution of the species is updated, including several new localities for mainland Greece, namely in Attica, Corinth, Chalkidiki, Ioannina, Magnesia, Larisa, Pieria, and Thessaloniki, but also for Crete and Rhodes, and a new record of the species for the island of Thasos (Figure 2).

Based on our results, *T. scripta* was recorded in 74 bodies of water, 62% of which were natural. In 51 bodies of water (69%) it co-existed with either *M. rivulata*, *E. orbicularis,* or both (Table S1). Large numbers were observed in anthropogenic environments in the urban centers of Athens (e.g., National Garden, Antonis Tritsis Park, Diomidous Botanical Garden) and Thessaloniki (e.g., Water Garden Park, Thermi Dam Reservoir), but also in natural habitats (e.g., Agia Lake, Savoura Pond, Anavyssos Salt Flats, Mesakti-Myrsonas Lagoon). Undisputed proof of reproductive populations (i.e., evident umbilical scar on hatchlings) was not provided by our dataset. However, very small individuals which may qualify as hatchlings and hint reproduction of APS in the wild have been observed by the authors and citizen scientists up to four years post-ban in Kaiafas Lake (Ileia, Peloponnese), Linopotis Artificial Lake (Kos, South Aegean), Thermi Dam Reservoir (Thessaloniki, Central Macedonia) and Pirsinella Park (Ioannina, Epirus).

The co-occurrence of the APS with native species of freshwater turtles can be rather problematic for the populations of the latter since the APS is known to be a rather competitive species in terms of food sources, basking, and nesting sites [37,38]. The APS shows high adaptability to new environments due to its earlier maturity, greater fecundity, tolerance to a wider range of temperatures, ability to move longer distances, and higher tolerance to human pressures than native turtles [39,60,61]. This, together with the extremely fragile freshwater ecosystems due to climate change and human impact [62], raise significant concern for the conservation of the native species of freshwater turtles. The competitive dominance of the APS, based on the loss of body mass and high mortality of *E. orbicularis* when in co-occurrence, has been demonstrated in past studies [63]. Though, the study of the population trend of *M. rivulata* and *E. orbicularis* in co-occurrence with the APS under a 12-year monitoring scheme on the island of Lesvos by Christopoulos & Zevgolis [51] showed contradictory results, i.e., stable population with minor annual fluctuations.

Evidently, the import ban imposed by the EU did not have a considerable impact on the populations of *T. scripta*, since the majority of the citizen-science records in our dataset (i.e., 91.8%) postdate the ban. Even though this can be explained by the long lifespan of the APS (commonly 30 years, max. 42 years in the wild [64]), the presence of several individuals qualifying as hatchlings, even four years after the ban, is alarming and provides a substantial indication for either the natural reproduction of the APS in the wild or the illegal continuation of its breeding in the pet trade.

3.2. Eastern river Cooter-Pseudemys Concinna

The Eastern river cooter (ERC; Figure 1b), native to North America, is recorded for the first time in Greece with only one record from Antonis Tritsis Park (Figure 3a), an anthropogenic environment in Athens, where at least three more alien species of freshwater turtle and one native have been released (Table S1). The presence of this species is not surprising and was anticipated since the ERC is one of the most actively imported substitute species following the APS import ban [34] and has already been recorded in several European countries including Germany, Portugal, Spain, Italy, Austria, and Hungary [57,65,66].

The co-occurrence of this species with *M. rivulata* (Table S1) in an anthropogenic locality such as the Antonis Tritsis Park is not significantly alarming considering that the

park belongs to an isolated urban area. However, a subsequent transfer of *M. rivulata* individuals from the park to a natural body of water could potentially result in the transmission of pathogens to native species since the ERC, as other species in the pet turtle trade, are known to be vectors of pathogenic viruses and parasites [67]. Thus far, no reptile pathogens or parasites of alien origin have been documented in Greece; however, introduced pathogens affecting amphibians have been detected in both native and alien amphibian species since 2003 (i.e., *Batrachochytrium dendrobatidis*) [68,69]. Reproduction in the wild has not been documented in this study, though it would not be surprising if it is already taking place, since it has been documented from the Iberian and Korean Peninsulas with similar climatic conditions to Greece [66,70,71]. For the time being the ERC is considered as a potentially invasive species in Greece, meaning that proof of natural reproduction or adverse impacts on native species is yet to be provided.

3.3. Florida Cooter-Pseudemys floridana

Aside from the initial record of the Florida cooter (FC; *P. floridana*) from Mavrobara Lake in Chalkidiki [36], no further records have been collected in this study. Based on our dataset, the presence of this North American species in Greece seems to be limited so far in this lake (Figure 3b). The co-occurrence of FC with both alien and native species (i.e., *M. rivulata*) has already been documented [36]. The FC is yet another potentially invasive species in European habitats [31]. Due to its high climatic suitability with the coastal areas of Europe and its high reproductive ability (i.e., six clutches per year), the species' presence in the European pet trade may require an immediate legal and regulatory response. The FC should also be considered as potentially invasive for the country.

3.4. Florida Red-Bellied Cooter-Pseudemys Nelsoni

The Florida red-bellied cooter (FRBC; Figure 1c) is recorded for the first time in Greece from four different localities; three in Attica and one in Thessaloniki (Figure 3c). Native to North America, the FRC has already been recorded in Italy and Spain with a particularly broad distributional range in the latter [56,65], while its presence in other European countries can be hinted by numerous records in citizen-science platforms [57]. In contrast to the other freshwater turtle species, which are mainly carnivorous, the FRC is a strictly herbivorous species [72]. In our study, all records refer to anthropogenic environments in the two largest urban centers of Greece, three of which co-occur with at least one native species of freshwater turtle (Table S1). Even though these records are not directly damaging for the natural-occurring populations of the native species of turtles, they could indirectly affect them by transmission of pathogens found in the FRC, if native terrapins present in these sites were relocated to natural habitats [73,74]. Since no reproduction of the species has been documented in the country, the FRC is currently considered an alien species.

3.5. Chinese Stripe-Necked Turtle-Mauremys Sinensis

The Chinese stripe-necked turtle (CSNT; Figure 1d) is recorded for the first time in Greece from five different localities in Attica (two localities), Chalkidiki, Ioannina and Thessaloniki (Figure 3d). Native to SE Asia, it is one of the most commonly traded species in the pet turtle trade and has one of the highest frequencies of populations in human dominated areas [31,34]. In Europe, it has already been recorded from Italy, Spain, Portugal, and Slovakia, where it was found to naturally overwinter [75–77]. Reproduction in the wild has been reported from the Iberian Peninsula [76].

Based on our dataset, the CSNT seems to be the most widespread and perhaps the most alarming of the substitute species, due to its potential negative effects on the native populations of *M. rivulata*. Two of the localities where the species was found, refer to natural bodies of water of high importance; the Valanaris Stream in Attica (Mt. Penteli) and the Mavrobara Lake in Chalkidiki. In both environments, it co-occurs with the native *E.*

orbicularis and *M. rivulata*, respectively (Table S1). In the latter, where co-occurrence with *M. rivulata* is documented (and in the anthropogenic Water Garden Park, Thessaloniki; Table S1), the risk is more imminent, since hybridization events between species in the genus *Mauremys*, and even within the family Geoemydidae, have been documented both in captive conditions and in the wild [78,79]. In Europe, the CSNT has already been documented to hybridize with the Iberian pond turtle *Mauremys leprosa* (Schweigger, 1812) in captive conditions [79]. Even though hybridization between *M. rivulata* and *M. sinensis* has not been studied yet, the risk of genetic introgression is far too great to sit idly by. It can be considered a potentially invasive species for Greece.

3.6. Chinese Soft-Shelled Turtle-Pelodiscus Sinensis

The Chinese soft-shelled turtle (CSST; Figure 1e) is recorded for the first time in Greece from three different localities; two in the urban centers of Athens and Thessaloniki, and one on the island of Cephalonia (Figure 3e). The first two localities refer to anthropogenic environments, in which it co-occurs with several other alien species of turtles, but also with both of the native species (Table S1). The latter, i.e., Karavomylos Pond in Cephalonia, is a natural water body, where both native terrapins have been recorded (P. Drakopoulos pers. comm.).

Native to East Asia, the CSST has established populations in numerous countries worldwide, due to its extended use as a food source in various Asian countries and as a pet [31,34,80]. In the latter, CSSTs rapidly become hard to handle due to their large size and aggressive behavior; therefore, they are often released into the wild by inexperienced keepers [81]. In Europe, free-roaming individuals of CSST have been reported from various Balkan countries, the Iberian Peninsula, Central Europe, and the Baltic region [56,81–84]. According to a risk assessment study [31], the CSST and the African helmeted turtle *Pelomedusa subrufa* (Bonnaterre, 1789) have the broadest suitability to climatic conditions outside their native range. It is among the most marketed turtle species in the pet trade with a moderate risk of establishment in the EU [34]. In Germany, it is already considered potentially invasive [81], while the climatic conditions in Greece are even more favorable for the establishment and successful reproduction in the wild [31]. Regarding its diet, it is generally a molluscivorous species [85], although it has been observed to approach marsh frogs *Pelophylax ridibundus* (Pallas, 1771) in Germany [81]. Until the reproduction of the CSST in the Greek wild is confirmed, it is considered a potentially invasive species.

3.7. Common Snapping Turtle-Chelydra Serpentina

In 2019, one individual of the Common snapping turtle (CST; Figure 1f) was observed in the Loutro Wetland near Athens (Figure 3f). The finding quickly drew the attention of local media, until it was collected and relocated to the ANIMA Wildlife Care Association (M. Ganoti pers. comm.). In the Loutro Wetland, where it was found, *E. orbicularis* are known to occur (Table S1). Even though this particular individual was removed (i.e., no proof of establishment), the risk of successful reproduction in Greece is highly probable. Therefore, it is treated as a potentially invasive species for the country.

A North-American species, the CST has established populations in numerous Asian, European, and South American countries through the international pet and food trade [86]. It is an opportunistic, omnivorous species, which can be extremely harmful to the native biodiversity due to its diverse diet (i.e., crustaceans, macrophytes, mollusks, annelids, fish, amphibians, reptiles, mammals, and birds [87,88]). In Europe, import, trade, and possession of this species have been banned in Germany and Italy, due to its powerful bite and invasion potential [31]. The CST has a wide thermal tolerance (as illustrated by its extensive native range) and can survive in any aquatic environment [88]. According to risk-assessment studies [31,34], it is among the most problematic species of alien freshwater turtles worldwide due to its extreme establishment risk and significant presence in the pet trade.

4. Conclusions

This study provides an updated checklist of alien freshwater turtles in Greece with compiled occurrence maps for each species. Our results serve as an early warning against potentially invasive alien species, which have flooded the pet trade to substitute the recently banned *T. scripta* and are recorded for the first time in the country, with the aid of numerous citizen scientists. It highlights the major risk of the international pet turtle trade, which bears striking resemblance to the myth of the Lernaean Hydra (i.e., a serpentine monster killed by Heracles, which would regrow multiple heads for each head chopped off); the import ban of the most popular pet species led to the presence of multiple "substitute species" in the wild. The potential impacts of these new species on the native terrapins include competition for food sources, basking and nesting sites, the transmission of pathogens, hybridization, and genetic pollution. Still, they also pose a threat to native biodiversity since they can be ferocious predators with wide dietary preferences.

Apart from *T. scripta* which is already considered invasive and quite common in both natural and anthropogenic water bodies, several of the species mentioned here have the potential to successfully reproduce and establish populations in the country. Given that they are still at the early stages of their invasion, we deem that an effective legislative and regulatory scheme for monitoring and capturing the released individuals, but also for preventing the import or release in the wild in the first place, should be immediately applied. Even though EU Regulation 1143/2014 already dictates management measures for IAS (i.e., through population control, containment, or eradication in compliance with the ethical standards) by the EU member states, its application, at least in Greece, remains limited.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d15050691/s1, Table S1: List of water bodies where at least one alien freshwater turtle was observed, including their classification as natural or anthropogenic and the observed species. Alien species are highlighted with red, while native terrapins with green.

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Data Availability Statement: The data that support the findings of this study are available from the corresponding author, (K.K.), upon reasonable request.

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