

Research Article

Striking diversity and distribution of non-native chelonians in Germany

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Abstract

The introduction of non-native species has created significant global biodiversity challenges, both directly and indirectly, affecting native ecosystems and biodiversity. Since the 1930s, with a peak in the 1980s and early 1990s, human activities have facilitated the global spread of the North American pond slider (*Trachemys scripta*), which seems to be widespread in Germany, occupying numerous waterbodies. However, knowledge on other non-native chelonian species in Germany remains sparse. This study aims to assess the current diversity and distribution of non-native freshwater chelonians in Germany. Using a dataset of 1770 records of non-native terrapins in Germany, derived from the published sources and publicly available citizen-science data, we examine the distributions and their relationship to anthropogenic factors. Herein, we confirm the presence of 14 free-ranging non-native terrapin species in Germany, namely *Chelydra serpentina*, *Chrysemys dorsalis*, *Chrysemys picta*, *Graptemys ouachitensis*, *Graptemys pseudogeographica*, *Mauremys leprosa*, *Mauremys reevesii*, *Mauremys sinensis*, *Pelodiscus sinensis*, *Pseudemys concinna*, *Pseudemys nelsoni*, *Pseudemys peninsularis*, *Sternotherus odoratus* and *Trachemys scripta* and provide a comprehensive overview of their currently known distribution patterns. We also report occurrences of *Emys orbicularis*, which is native to Germany, but, with the exception of the Brandenburg populations, nearly all populations are allochthonous. Our study reveals that species diversity and abundance are highest in and in close proximity to urban areas, confirming a strong correlation between terrapin distribution and anthropogenic presence.

Key words: Citizen Science, Europe, iNaturalist, invasion biology, invasive species, Testudines, turtles



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Introduction

The increasing number of invasive species has created several global challenges (Pyšek et al. 2020). Non-native species may potentially cause severe direct and indirect damages to native ecosystems and biodiversity. Directly, they can prey on native species, outcompete them, displace them from parts of their ecological niches, cause hybridisation and, thereby, potentially drive species to extinction (Mooney and Cleland 2001; Cadi and Joly 2003, 2004; Polo-Cavia et al. 2010; Polo-Cavia et al. 2011; Parham et al. 2013; Pearson et al. 2015; Cuthbert 2019; Vodrážková et al. 2020). Indirectly, they can introduce novel parasites and pathogens, facilitate

their spreading and can act as additional reservoirs (Mooney and Cleland 2001; Iglesias et al. 2015; Demkowska-Kutrzepa et al. 2018; Panlasigui et al. 2018).

Despite the presence of a unifying framework for biological invasions (Blackburn et al. 2011), terms like “alien”, “casual/introduced”, “naturalised/established” and “invasive” are often not used correctly in both scientific and non-scientific literature. We label all terrapin species “alien” or “non-native” (i.e. neozoa) due to human activities enabling them to surpass biogeographical barriers (after the year 1492). Following Blackburn et al. (2011), a species is classified as “invasive” once they establish one or more self-reproducing and dispersing population(s).

To emphasise the serious impacts of invasions, the IUCN Invasive Species Specialist Group (ISSG) created a list of the “100 World’s Worst Invasive Alien Species” (Lowe et al. 2000). Although it might seem contradictory at first, some of the groups mentioned as highly invasive also include some of the world’s most endangered species. For instance, chelonians (Reptilia, Testudines) belong to the most threatened vertebrates globally. Out of the 369 tortoise, turtle and terrapin species worldwide (Uetz et al. 2026), currently 277 are assessed by the global Red List and 62.8% are considered threatened (174 species) or extinct (8 species = 2.9%) (IUCN 2026). At the same time, the pond slider *Trachemys scripta* (Thunberg, 1792) is recognised as one of the most harmful invasive reptile species globally (Lowe et al. 2000; Reshetnikov et al. 2023). *Trachemys scripta*, along with the Brahminy blind snake (*Indotyphlops braminus*) and the common house gecko (*Hemidactylus frenatus*), also ranks amongst the top three most widely distributed invasive reptile species worldwide (Capinha et al. 2017). Additionally, three more freshwater chelonians have a significant chance of becoming invasive: *Graptemys pseudogeographica*, *Chrysemys picta* and *Sternotherus odoratus* (Bugter et al. 2011).

In Europe, there have been reports of at least 17 non-native chelonians species in the wild, with 13 of these originating from freshwater environments (Kopecký et al. 2013). While in France, offering a broader variation of climates, a total of 22 species of testudines (excluding subspecies) have been recorded at least once to date (Maran and Frétey 2023), in Germany, the presence of so far only 10 different species of non-native terrapins have been recorded (Schradin 2020; Tietz 2020; Koppetsch 2021). Additionally, the vast majority of populations of the only native species, *Emys orbicularis*, are allochthonous (Fritz and Günther 1996; Vamberger and Fritz 2018). A recent study genetically confirmed, for the first time, the successful reproduction of three non-native chelonian species in Germany. For two of these species, *Pseudemys concinna* and *Graptemys pseudogeographica*, this represents the first documented instance in a temperate continental region outside their native range (Tietz et al. 2023).

Due to the surprisingly high diversity and new evidence of natural reproduction in three species, there is an urgent need for studies to investigate the extent of established populations and assess the existing and potential impacts of non-native terrapin species across various ecosystems along a climatic gradient (Reshetnikov et al. 2023; Tietz et al. 2023). These data are crucial for revising and harmonising current risk assessments of non-native chelonians. Existing risk assessments have yielded disparate conclusions, reflecting inconsistencies in evaluating the potential impacts of non-native species (Bugter et al. 2011; Masin et al. 2014). This variation underscores the necessity for a more unified and comprehensive approach to risk assessment, which could benefit from integrating new findings to address the discrepancies and enhance predictive accuracy.

This study, for the first time, provides a current overview of the diversity and distribution of non-native terrapins in Germany. The impact of non-native terrapins on their new ecosystems is still mainly unclear (Tietz et al. 2023). Therefore, distribution data are the baseline to enable further research on this topic. Herein, the following three questions are addressed: What is the diversity of non-native terrapin species? What are their distributions in Germany? To what degree are human factors, such as urbanisation, associated with the distribution of non-native terrapin species?

We hypothesise that the influence of human activities is the major (if not only) factor responsible for the introduction of new terrapin species to new locations (Koo et al. 2017). More specifically, we tested whether increased levels of urbanisation are positively correlated with higher number of individuals and greater species richness.

Finally, we discuss the specific stage at which these species are currently positioned within the introduction process, following the framework by Blackburn et al. (2011). Understanding this process is crucial, to effectively allocate sparse conservation management resources.

Materials and methods

Occurrences of non-native terrapins

To assess the current distribution of Testudines species in Germany, five different datasets were used. The majority of data (~ 72%) on alien terrapins in Germany came from citizen-science observations from the iNaturalist platform. Only data points with a “Research Grade” status were included in the analyses. iNaturalist observations attain “Research Grade” status when they are accompanied by a photograph, a date, geographical coordinates and when there is community consensus on the species identification (iNaturalist n.d.). Our downloaded dataset from iNaturalist contained a total of 1268 data points. The respective observation dates span from 12 August 2001 to 30 June 2024. Out of 1268 points, 200 are classified as “obscured”, which means that the exact latitude and longitude are replaced with random coordinates within a square area of approximately 22 km × 22 km in size (at mid-latitudes) (iNaturalist 2024). In addition, a dataset from the Federal Environment Agency Baden-Württemberg was included, which comprised 107 data points from 03.04.2000–11.09.2018 (LUBW 2019). During the literature research process, three additional datasets were identified which are also relevant to this paper: 209 records by Tietz (2020), 179 records by Schradin (2020) and seven records by Koppetsch (2021).

Observations for which the species could not be determined were excluded. Sightings that were not recorded in the wild, but in private households, gardens or zoos were removed from the dataset as well. Recordings from parks, botanical gardens and public green spaces, on the other hand, remained included in the dataset. This resulted in a total dataset of 1770 occurrence records, which is available from ZENODO (Schloddarick et al. 2026).

Since data from iNaturalist primarily consist of citizen-science contributions, mostly collected, uploaded and reviewed by the user community, a random sample cross-check verification was conducted to identify and estimate potential taxonomic identification errors. For this, every 20th observation was checked, totalling to 69 data points (detected error rate was 0%). Species taxonomy follows the list provided by Turtle Taxonomy Working Group (TTWG 2025). Therefore, *Chrysemys dorsalis* and *Chrysemys picta* are considered two distinct species. Subspecies were

not differentiated. Taxonomic identification follows Maran and Frétey (2023); especially shape of carapax, colouration of bridge between carapax and plastron and colouration of the sides of heads are useful identification characters.

Urbanisation

Urbanisation was derived from the CORINE Land Cover 5 ha (European Union 2020) dataset which offers a vector-based description of the landscape and includes both land-cover and land-use aspects across Europe. Initiated in the 1990s, this pan-European data collection process uses satellite-derived geographical information (Umweltbundesamt 2015). The first campaign, referencing the year 1990 (European Union 2020), defined 44 land-use classes, 37 of which are relevant for Germany (Stallmann 2014). We grouped the 37 classes into five categories: urban areas (CLC code 111-142), agricultural areas (CLC code 211-243), natural areas (CLC code 311-335), wetlands (CLC code 411-423) and waterbodies (CLC code 511-523) (Suppl. material 1: table S1).

Data processing

Occurrence maps for each species of Testudines were generated using QGIS version 3.34.2 (QGIS Development Team 2024). Each data point in the dataset represents an observation of one or more individuals. Similar to Niemeier et al. (2020), the proportion of urban areas, natural areas, agricultural areas, waterbodies and wetlands within a 1 km buffer zone surrounding the sightings were evaluated in this study. Additionally, a diversity raster map in QGIS was created, using a raster cell size of 20 km within the UTM 32N projection for Europe.

Statistical analysis

Statistical analyses were performed with R version 4.3.0 (2023-04-21 UCRT) (R Core Team 2023), using a significance level of 0.05 and applying Bonferroni correction, the rule applying that the null hypothesis (no difference between groups) is rejected, if the p-value is less than or equal to $\alpha/2$ (i.e. 0.025).

Results

Distribution patterns

The combined dataset consisted of 1770 observations, encompassing 15 freshwater terrapin species recorded in Germany (Fig. 1). Of these, 14 are considered non-native: *Chelydra serpentina* (Linnaeus, 1758), *Chrysemys dorsalis*, *Chrysemys picta* (Schneider, 1783), *Graptemys ouachitensis* Cagle, 1953, *Graptemys pseudogeographica* (Gray, 1831), *Mauremys leprosa* (Schweigger, 1812), *Mauremys reevesii* (Gray, 1831), *Mauremys sinensis* (Gray, 1834), *Pelodiscus sinensis* (Wiegmann, 1835), *Pseudemys concinna* (Le Conte, 1830), *Pseudemys nelsoni* Carr, 1938, *Pseudemys peninsularis* Carr, 1938, *Sternotherus odoratus* (Latreille, 1802) and *Trachemys scripta* (Thunberg, 1792). The sole native species, but mostly consisting of allochthonous populations is *Emys orbicularis* (Linnaeus, 1758).

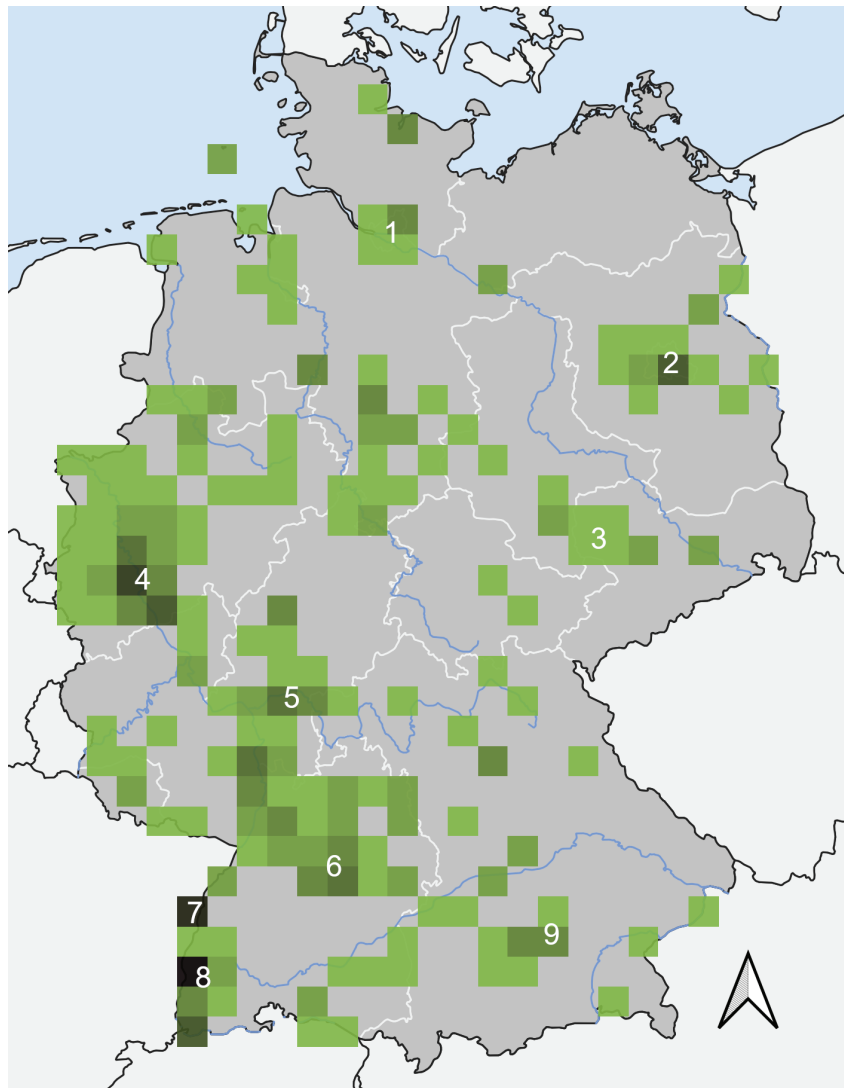


Figure 1. Diversity of non-native terrapins in Germany, highlighting areas of occurrence and diversity across different species. Major urban areas are indicated by numbers: 1 = Hamburg, 2 = Berlin, 3 = Leipzig, 4 = Ruhr metropolitan region, 5 = Frankfurt a.M., 6 = Stuttgart, 7 = Offenburg, 8 = Freiburg i. Brsg., 9 = München. The map displays the federal states as well as major rivers for orientation purposes (from Natural Earth). Map was created with QGIS (QGIS Development Team 2024). The findings are displayed within 20 km × 20 km grid squares, with colour coding representing species diversity, from light green (1 species) to dark green (9 species).

In the dataset, *Trachemys scripta* is dominant, accounting for the majority of records with 1237 observations (~ 70%). The remaining species are represented by fewer records: *Pseudemys concinna* (166 records, ~ 9.4%), *Graptemys pseudogeographica* (106 records, ~ 6%), *Chrysemys picta* (31 records, ~ 1.8%), *Pseudemys nelsoni* (31 records, ~ 1.8%), *Graptemys ouachitensis* (19 records, ~ 1%), *Mauremys reevesii* (12 records, ~ 0.7%), *Pseudemys peninsularis* (four records, ~ 0.2%), *Chelydra serpentina* (three records, ~ 0.2%), *Mauremys sinensis* (three records, ~ 0.2%), *Pelodiscus sinensis* (three records, ~ 0.2%), *Chrysemys dorsalis* (two records, ~ 0.1%), *Sternotherus odoratus* (two records, ~ 0.1%) and *Mauremys leprosa* (one record, ~ 0.05%). Being the only native species amongst the records, *Emys orbicularis* accounts for a total of 150 observation records.

Mapping the diversity (Fig. 1), it is noticeable that the highest species diversity can be found in and around densely populated areas. The focal points of terrapin

sightings are primarily clustered around highly urbanised regions, predominantly in western Germany. Notable clusters include areas around Hamburg, the Ruhr area, Frankfurt am Main, Offenburg, Freiburg im Breisgau, Stuttgart and Munich. In contrast, eastern Germany exhibits only a single cluster around Berlin, with isolated sightings around Leipzig (Figs 1–3).

Urbanisation

The mean proportion of urbanised areas within a 1 km radius buffer around each sighting was approximately 60%. A highly significant difference ($p < 0.0001$, $Z = -4.924$) in the degree of urbanisation in the surrounding areas is observed between *Chrysemys picta* and *Graptemys pseudogeographica*. This indicates that the mean urbanisation level at the locations where *Chrysemys picta* (40.5%; $n = 31$) was found is significantly lower than that for *Graptemys pseudogeographica* (73.3%, $n = 104$) (Suppl. material 1: table S3).

A highly significant difference ($p < 0.001$, $Z = -4.499$) is detected between *Chrysemys picta* and *Pseudemys concinna*, with *Chrysemys picta* ($n = 31$) being present in lower mean urbanisation levels (40.5%) than *Pseudemys concinna* ($n = 162$; 69.4%).

Similarly, a significant difference ($p < 0.001$, $Z = 4.132$) is observed between *Graptemys pseudogeographica* and *Trachemys scripta*, *Graptemys pseudogeographica* (73.3%; $n = 104$) showing higher mean urbanisation levels than *Trachemys scripta* (59.2%; $n = 1203$). Additionally, a notable difference ($p = 0.0242$; $Z = 3.502986$) is found between *Pseudemys concinna* and *Trachemys scripta*, with *Pseudemys concinna* (70.3%; $n = 162$) displaying higher mean urbanisation levels than *Trachemys scripta* (58.6%; $n = 1203$).

All observations indicate that turtle sightings are consistently associated with an average urbanisation level of 60% and a greater number of species were found in urban centres (Fig. 1). This suggests that increasing levels of urbanisation may be linked to a higher number of individuals and greater species richness in these waterbodies.

Discussion

For the first time, a comprehensive overview of the diversity and distribution of non-native terrapins across Germany is provided. This study offers important insights into spatial patterns and contributes valuable baseline data to understanding their potential ecological impact.

Based on the findings of a detailed study in south-western Germany (Tietz 2020), we hypothesised that at least nine species (*Chrysemys dorsalis*, *Graptemys pseudogeographica*, *Mauremys leprosa*, *Mauremys reevesii*, *Pseudemys concinna*, *Pseudemys nelsoni*, *Sternotherus odoratus*, *Trachemys scripta*) could be widely distributed across Germany. However, the present study only partially confirms the hypothesis, as *Chrysemys dorsalis* and *Sternotherus odoratus* have, so far, been observed only in two regions (north Rhine-Westphalia and Baden-Württemberg) and *Mauremys leprosa* has been recorded exclusively in the Freiburg area (Tietz 2020), indicating that more detailed local studies might reveal additional species. Species such as *Chelydra serpentina*, *Graptemys ouachitensis* and *Pseudemys peninsularis* were detected across Germany, expanding their known non-native distribution range.

The distribution of various terrapin species is notably aligned with urban centres (Fig. 1), underscoring the influence of environmental and human factors. Human activities, such as the intentional release of terrapins, are expected to play a

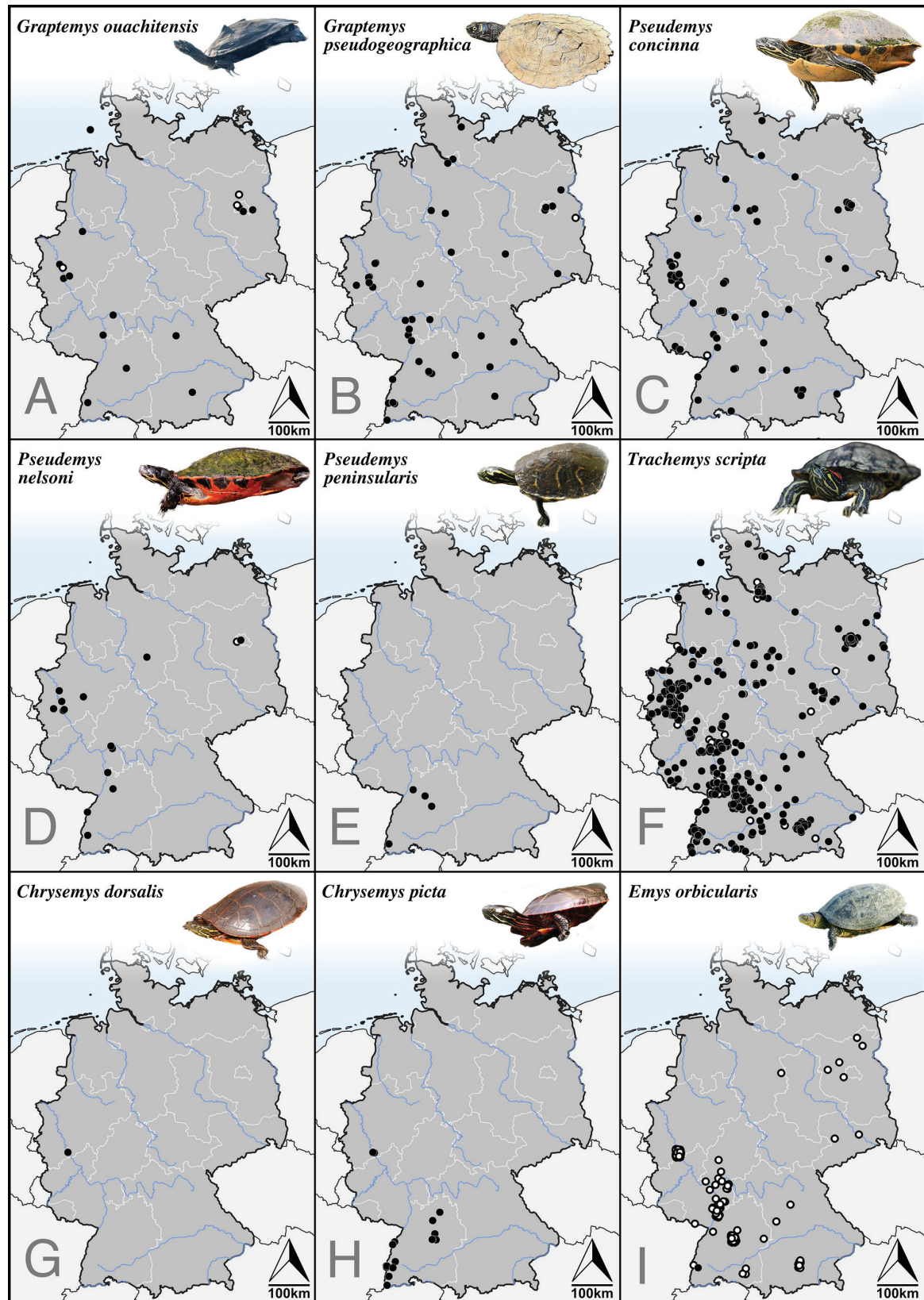


Figure 2. Distribution map of nine non-native terrapin species in Germany, sorted by taxonomy. Full circles represent precise locations, empty circles are obscured observations. Species are (no. of records in brackets). **A.** *Graptemys ouachitensis* (n = 19); **B.** *Graptemys pseudogeographica* (n = 106); **C.** *Pseudemys concinna* (n = 166); **D.** *Pseudemys nelsoni* (n = 31); **E.** *Pseudemys peninsularis* (n = 4); **F.** *Trachemys scripta* (n = 1237); **G.** *Chrysemys dorsalis* (n = 2); **H.** *Chrysemys picta* (n = 31); **I.** *Emys orbicularis* (n = 150). The map displays the federal states as well as major rivers for orientation purposes (from Natural Earth). Sources of terrapin photos are given in the Suppl. material 1.

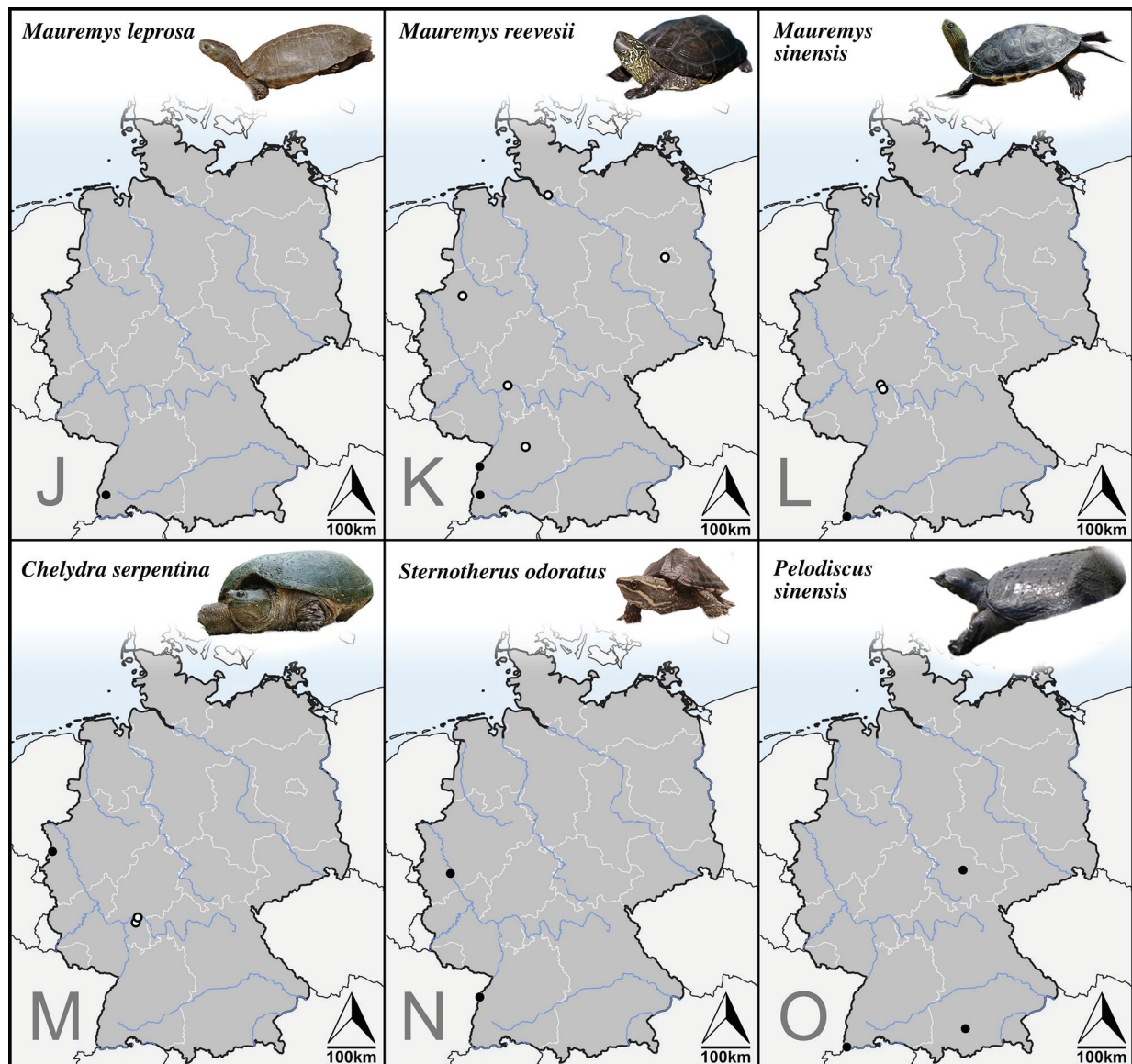


Figure 3. Distribution map of the remaining six non-native terrapins in Germany. Full circles represent precise locations, empty circles are obscured observations. Species are (number or records in brackets). **J.** *Mauremys leprosa* (n = 1); **K.** *Mauremys reevesii* (n = 12); **L.** *Mauremys sinensis* (n = 3); **M.** *Chelydra serpentina* (n = 3); **N.** *Sternotherus odoratus* (n = 2); **O.** *Pelodiscus sinensis* (n = 3). The map displays the federal states (white lines) as well as major rivers (blue lines) for orientation purposes (from Natural Earth). Source of terrapin photos is given in the Suppl. material 1.

crucial role in their introduction (Koo et al. 2017). Overall, urban areas accounted for 14.5% of Germany's land in 2022 (Bundesumweltministerium 2020), whereas the mean proportion of urbanised areas within a 1 km radius buffer around each sighting was approximately 60%, supporting the correlation between sightings and proximity to human structures. Similar correlations have been shown for ornamental freshwater fish, which are more likely to be released in waterbodies close to roads and footpaths (Copp et al. 2005) and for non-native grass snakes (*Natrix natrix*) in Germany, which are mostly found in urban locations with high public accessibility, such as parks and artificial green spaces (Griesbaum and Pacher 2024; Kordges 2025). This suggests that urban environments with easy access are particularly prone to introductions of non-native species, including terrapins.

This raises the question why certain species, such as *Trachemys scripta*, *Pseudemys concinna* and *Graptemys pseudogeographica*, are more widespread in Germany than

others. One explanation is their high popularity as pets over the past 70 years (Telecky 2001). *Trachemys scripta*, *Pseudemys concinna* and *Graptemys pseudogeographica* are relatively common pets due to comparatively simple husbandry requirements, appealing appearance and affordability. Specifically, *Trachemys scripta elegans* has been traded internationally at least since the 1950s and is likely the most widely traded reptile, with over 52 million individuals exported from the US between 1989 and 1997 (Telecky 2001). In 1997, the European Union halted the import of *T. scripta elegans* (Regulation 338/1997; Regulation 349/2003) due to the high invasion risk, which led to a significant increase in the trade of the two other subspecies (*T. scripta scripta*, *T. scripta troostii*) and hybrids (Scalera 2007). Sale of all subspecies was banned in 2016 (Regulation 1143/2014). Other non-native terrapin species in Germany show low observation numbers, appearing sporadically and locally without consistent distribution patterns and data are too limited to draw firm conclusions about dispersal or establishment trends.

Emys orbicularis is the only native terrapin species in Germany. Currently, it is recorded from nearly the entire country, but most records refer to introduced or escaped pets rather than native populations (Fritz and Günther 1996; Vamberger and Fritz 2018). Historical populations of *E. orbicularis* are assumed to be extinct, with a few exceptions in Brandenburg (Schneeweiß and Fritz 2000; Velo-Antón et al. 2011) which remain in critical conservation status (Fritz and Chiari 2013). Only one genetic lineage, endemic to north-eastern Germany and neighbouring Poland, represents native pond turtles in Germany. All other populations show strong genetic influence of non-native lineages from southern and south-eastern Europe (Fritz et al. 2004; Velo-Antón et al. 2011). This situation is particularly significant because, despite the endangered status of the remaining native *E. orbicularis* populations, allochthonous occurrences may threaten conservation efforts in native habitats. *Emys orbicularis* could, therefore, be classified both as native (autochthonous populations) and non-native (allochthonous populations). This problem still appears understudied. Recent European examples of similar situations include marsh frogs (*Pelophylax ridibundus*) (Denoel and Dufresnes 2025) and grass snakes (*Natrix natrix*), where several German populations now contain alien individuals, putatively *N. n. moreotica* from the Balkans, with hybridisation seemingly already happening (Grosse 1995, 2009, 2011; Griesbaum and Pacher 2024; Kordges 2025).

Possible impacts of non-native terrapins on native ecosystems and species

Impacts of non-native terrapins can be broadly categorised into direct and indirect effects. Direct effects include potential predation on other species of flora and fauna due to the broad omnivorous feeding behaviour of many terrapins (Bonin et al. 2007; Ernst and Lovich 2009), although no data are currently available on the specific dietary habits of these non-native chelonians in Central Europe.

Indirect effects are also significant and have gained increasing research attention. Non-native terrapins may introduce novel diseases and parasites, acting as reservoirs that could affect native species (Gong et al. 2014; Iglesias et al. 2015; Héritier et al. 2017). *Trachemys scripta* is known to carry various *Salmonella* strains and other pathogens (Shen et al. 2011; Gong et al. 2014; Moroni et al. 2025) and is vulnerable to Ranaviruses (Moore et al. 2014). Parasite transmission, such as helminths, from invasive to native chelonians has been documented

in Europe (Héritier et al. 2017; Demkowska-Kutrzepa et al. 2018). Despite these findings, there is a substantial lack of data on the indirect effects of other invasive chelonian species in Europe, aside from *T. scripta*.

The fact that non-native terrapins are more frequently recorded in urban habitats suggests that they are either less often introduced in natural habitats or less likely to be recorded there. Their impact on threatened species could, therefore, be relatively small, assuming that threatened species occur predominantly in natural rather than urban areas. However, natural areas often have higher connectivity between habitats, so even fewer non-native terrapins could have more severe effects in such landscapes. This underscores the need for more nuanced, habitat-specific studies and for proactive preventative measures.

Management

Of the 14 non-native terrapin species in Germany, 11 survive in the wild, but no successful reproduction has yet been documented for *Chelydra serpentina*, *Chrysemys dorsalis*, *Chrysemys picta*, *Graptemys ouachitensis*, *Mauremys leprosa*, *Mauremys reevesii*, *Mauremys sinensis*, *Pelodiscus sinensis*, *Pseudemys nelsoni*, *Pseudemys peninsularis* and *Sternotherus odoratus*. These species are currently at the boundary between the “survival” and “reproduction” barriers, as described by Blackburn et al. (2011) (see Fig. 4; cf. Robertson et al. 2020). Four species (including *E. orbicularis*) are between “reproduction” and “dispersal”. Thus, following Blackburn et al. (2011), none of the recorded species should currently be considered invasive in Germany. However, with advancing climate change, more species are expected to overcome reproduction barriers and establish reproducing or spreading populations, raising concerns about future impacts on native ecosystems (e.g. Ficetola et al. 2009; Kaya et al. 2026).

Effective management of non-native species must address monitoring, prevention of introduction and spread and control of existing populations. One important measure is extensive public outreach to educate about the harmful consequences of releasing pets, highlighting risks both to the released animals and to the ecosystems they enter (Teillac-Deschamps et al. 2009; Masin et al. 2014). Additional research on the ecology of non-native terrapins outside their natural range (Rodrigues et al. 2016) and their potential impacts in Europe is essential. Existing risk assessments (Bugter et al. 2011; Masin et al. 2014) should be reviewed and updated to reflect current knowledge.

Establishing a mandatory “certificate of competence” for exotic pet ownership could ensure that potential owners understand care requirements and the consequences of illegal releases. In Germany, such a system already exists on a voluntary basis for aquarium and terrarium keepers and could be expanded into a broader legal framework. Educational initiatives may be complemented by measures such as mandatory PIT (passive integrated transponder) tags for chelonians to facilitate tracking and prosecution of illegal releases (Tietz et al. 2023). Implementing a “conservation fee” on chelonian sales would increase the price for potential owners and encourage more thoughtful purchasing decisions, while providing funds for research and rescue centres (Tietz et al. 2023). There is also a pressing need for more legal options for re-homing unwanted animals. Many facilities, such as animal shelters, are not equipped for terrapins and have reached their limited capacity and the only specialised facility in Germany, the Reptile Rescue Center in Munich (Auffangstation für Reptilien, München e. V.), faces chronic funding and space constraints.

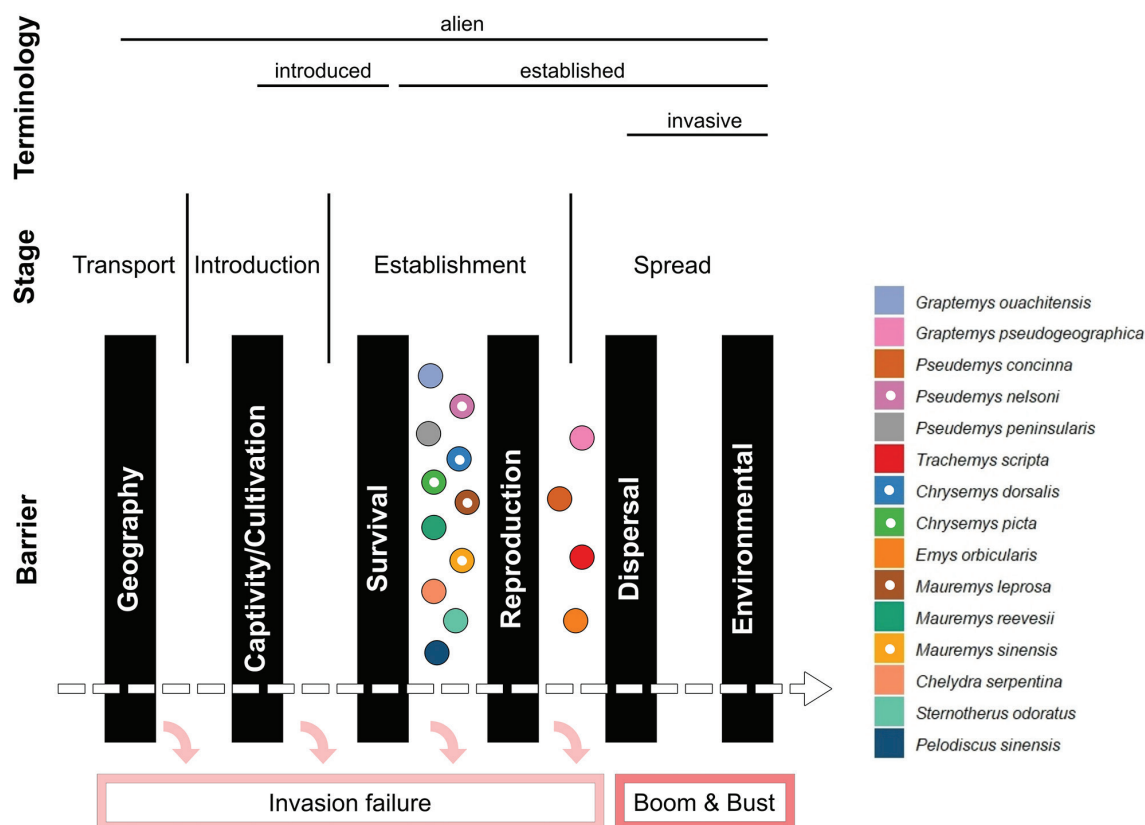


Figure 4. The unified framework for biological invasions by Blackburn et al. (2011) divides the invasion process into distinct stages, with barriers that must be overcome for a species to progress to the next stage. Species are referred to by different terms depending on their stage in the invasion process, with different management interventions applied at each stage. Various aspects of the framework emphasise individuals, populations, processes or species. The recorded terrapin species in Germany are colour coded with their respective evidence-based position.

While prevention is a key aspect of management (Rodrigues et al. 2016), it is equally important to address non-native animals already released into the wild. Although *Trachemys scripta* originates from the Mississippi region of the USA, it has established wild populations on all continents, except Antarctica (Kikillus et al. 2010; Pérez-Santigosa et al. 2011; Sancho et al. 2013). These non-native populations often reproduce successfully and may become significant ecological concerns. Managing already-released animals therefore remains crucial, as even non-reproducing populations require monitoring to mitigate potential impacts and identifying suitable habitats for targeted intervention can help prevent further spread.

Various strategies exist for managing invasive species, including gradual removal by professional trappers and volunteers (Bugter et al. 2011), but the efficacy of this approach is often difficult to evaluate. Evidence suggests that gradual removal may be less effective than more immediate and comprehensive methods. Successful eradication usually involves prompt and thorough removal, often using more aggressive techniques such as “destructive” trapping (Genovesi 2005; Clout and Williams 2009), which has proven effective in other countries and is frequently necessary for successful management (Lambert et al. 2019). However, the need for such interventions depends on context. In urban environments, extensive removal may not be required because habitats are completely artificial, contain no threatened species and terrapins may play a relevant ecological role (Dupios-Desormeaux et al. 2022). In natural areas, adjacent to habitats with threatened species, especially where autochthonous populations of native species, such as *Emys orbicularis*, are present, prompt action is critical.

The case of *T. scripta* demonstrates that species-specific trade bans alone are insufficient to manage non-native terrapins. Many individuals are already in circulation, highlighting the need for alternative solutions, such as establishing legal surrender points, to prevent unnecessary releases into the wild.

We also emphasise the importance of ongoing surveillance of non-native terrapin species in European ecosystems. Similar to regular biodiversity monitoring, this can be substantially supported by Citizen Science (CS) data (Roy-Dufresne et al. 2019; Pawson et al. 2020; Dimson et al. 2023). Several biological invasions were first detected by citizen scientists (e.g. Vendetti et al. 2018; Eritja et al. 2019). However, CS data are prone to biases resulting from observer differences, reporting preferences and false positive errors (Johnston et al. 2023). Observers may choose locations based on convenience, such as near homes or roads (Dennis and Thomas 2000; Millar et al. 2019), leading to stronger spatial bias than in systematically designed surveys. In addition, observers differ in skills, experience, behaviour and equipment, which affects detection and identification rates (Moyer-Horner et al. 2012) and changes in observation techniques can introduce temporal bias. Nevertheless, errors and biases in CS data are often comparable to those in other large-scale databases (Kosmala et al. 2016).

After randomly double-checking 5% of all iNaturalist observations in this study without finding a single identification error, we are confident that “research grade” observations are useful. However, the lack of comprehensive presence–absence data and detailed local surveys results in no nationwide coverage, so non-native terrapins may be overlooked in less frequently monitored habitats. To close this gap, we encourage all people working in herpetology, local ecology and conservation to include non-native terrapins in their monitoring schemes, also to collect data on abundance and actual numbers. Furthermore, we invite everyone to contribute to the growing iNaturalist project “Turtles of Germany” (<https://www.inaturalist.org/projects/turtles-of-germany>) to complement this central database covering all regions. Callaghan et al. (2022) provide strong arguments for contributing to large CS datasets, also as expert identifiers, particularly with regard to potentially invasive species. The more experts contribute to the “Turtles of Germany” project, not only by uploading observations, but also by confirming or correcting identifications, the more valuable the dataset will become for understanding the occurrence and expansion of non-native chelonians in Germany and Europe.

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Supplementary material 1

Image sources and additional figures and tables

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Data type: docx

Explanation note: Image sources of Figs 2, 3. **fig. S1**. Number of recordings on the citizen science platform iNaturalist. **fig. S2**. Boxplots showing percentage of urban area for non-native terrapin in a 1 km circular buffer. **table S1**. CLC land use classes grouped into five categories such as urban areas (CLC code 111–142), agricultural areas (CLC code 211–243), natural areas (CLC code 311–335), wetlands (CLC code 411–423) and waterbodies (CLC code 511–523) (European Union 2020). **table S2**. Mean with standard deviation for the variables: urban area [%], agricultural area [%], natural area [%], wetland area [%], water area [%] per non-native terrapin species in Germany. **table S3**. Z-values and p-values of the significance for urban area [%] across different non-native terrapin species in Germany.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Artificial Intelligence (AI) use

Regarding the use of AI in the preparation of this manuscript, the authors declare the following:

For linguistic adjustments (including grammar, spelling, and text improvement), and paraphrasing of quotes, the OpenAI software ChatGPT was utilized to some extent (OpenAI 2024).

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Author contributions

HS and JP conceptualised the study; HS and FG collated data and verified it; HS analysed the data; HS, FG and JP visualised the data; all authors wrote the first draft of the manuscript.

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Data availability

All of the data that support the findings of this study are available in the main text, Supplementary Information, and the dataset from ZENODO (<https://doi.org/10.5281/zenodo.18339214>).