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Distribution of released pet turtles in the UK: a citizen science survey

Suzie M. Simpson & Richard A. Griffiths

Durrell Institute of Conservation and Ecology (DICE), School of Natural Sciences, University of Kent, Canterbury, CT2 7NR, UK

Non-native freshwater turtles have established in numerous countries globally, through accidental or deliberate release by pet owners. Long-term monitoring is an important part of management practices considering potential impacts to native fauna and flora. In 2018, a citizen science project (Turtle Tally UK) was initiated to investigate the distribution, numbers and species of released pet turtles in the UK. Data collected between 2019–2023 were analysed comprising 832 reports by 795 participants. In total, 1,387 individual turtles were reported as being seen in the wild over this period. Spatial hotspot analysis showed clustered locations for sightings in London and urban areas of north-west England. From the number of individuals reported, 628 (45%) were verified using photographic evidence submitted by participants. Most verified sightings comprised yellow-bellied sliders (*Trachemys scripta scripta*, n = 235), red-eared sliders (*Trachemys scripta elegans*, n = 98) and 'slider/cooter turtles' (i.e. *Trachemys scripta* ssp. and *Pseudemys* spp., n = 164). Of these verified individuals, 75% were considered lone turtles with the remaining 25% being two or more (max. verified group size = 12, max., unverified group size = 30+). All (except one) were of adult/subadult size including 190 (30%) females, 51 (8%) males and 387 (62%) 'unknown sex'. Due to the majority being single individuals, the impacts on habitats at a landscape scale are likely to be low, but there may be other risks associated with pathogen pollution and animal welfare. Prohibiting sales of IAS species and natural seasonal mortalities due to the temperate climate could be reducing numbers in the wild but is impeded by the replacement of unregulated species in the pet trade. This focal citizen science project provided a larger dataset over a shorter period and helped to raise public awareness of the issue.

Keywords: chelonia, terrapin, invasive species, wildlife trade

INTRODUCTION

Human activities (e.g. pet trade, goods shipments, tourist travel) have been a longstanding introduction pathway for non-native species such as freshwater turtles. The red-eared slider *Trachemys scripta elegans* has been identified as one of the world's most invasive species globally (Lowe et al., 2000; Global Invasive Species Database, 2010). Studies have provided evidence of their invasive potential including adaptability and impacts on native turtle populations (Lowe et al., 2000; Bringsøe, 2006; Ernst & Lovich, 2009; Van Dijk et al., 2011; Martinez-Silvestre et al., 2015; Lambert et al., 2019). However, current research on impacts and potential risks in the UK is limited, especially in the context of absent native turtle populations. Freshwater turtles are documented as having an important ecological role including energy transfer (egg deposition as food for land predators), scavenging value (feeding on detritus), biomass contribution and seed dispersal (Lovich et al., 2018). A study by Dupuis-Desormeaux et al. (2022) found that where native turtle populations were no longer present or greatly diminished in urban degraded environments, the introduced turtle populations act as a partial analog contributing positively to these ecosystems. However, introductions are not condoned, yet the authors found positive contributions may occur where native turtles are not present in more anthropogenic environments.

In the late 1950s and 1960s, turtle farms in southern parts of the USA started breeding turtles in large numbers, including many *T. s. elegans*. This continued into the 1990s with imports into Europe and Asia for the pet trade and Asian food markets (Cadi & Joly, 2004; Bringsøe, 2006; Mali et al., 2014). The number of imported specimens from this time to 2012 were documented as ranging from 26–126 million by various sources (Arvy & Servan, 1998; Telecky, 2001; Reed & Gibbons, 2003; Mali et al., 2014). Unfortunately, due to inconsistency in data collection and seizure quantities being grouped together (i.e. turtles and tortoises), determining precise numbers is challenging (Nijman, 2010; CITES, 2021). Misidentification of species and/or subspecies, reporting biases and inclusion of 'hybrid' categories contributes to numbers being potentially inaccurate regarding trade and movement of animals (Bosch et al., 2016; CITES, 2021; Easter & Carter, 2024). Nevertheless, the figures highlight the high numbers of freshwater turtles that have been traded historically.

Correspondence: Suzie Simpson (turtletallyuk@gmail.com)

In 1997, the European Union trade regulations (EU Protection of Species of Wild Fauna and Flora) banned the importation of *T. s. elegans* into EU countries. This resulted in US traders breeding yellow-bellied sliders *Trachemys scripta scripta*) instead, alongside other similar species to meet demand (Bringsøe, 2006; Van Dijk et al., 2011). Even though demand had reduced during the early 2000s, there were still high numbers of US exports of *Trachemys* ssp. and *Pseudemys* spp. (Mali et al., 2014). In January 2015, the EU Invasive Alien Species (IAS) Regulation (1143/2014) came into force imposing restrictions on all *T. scripta* subspecies prohibiting them from being bred, kept, exchanged or sold (GOV.UK, 2020). Under the Wildlife and Countryside Act 1981, it is illegal to release non-native species in Great Britain (DEFRA, 2007), yet these animals have been found living in lakes and ponds nationally. They are also found throughout Europe and records of natural reproduction have been documented in Mediterranean countries such as France, Greece, Italy, Spain and Turkey (Luiselli et al., 1997; Cadi & Joly, 2003; 2004; Cadi et al., 2004; Urošević, 2014; Kalaentzis et al., 2023). Outside Europe they have been introduced to Australia, Cambodia, Indonesia, Singapore, South Africa, Taiwan and Thailand (Van Dijk et al., 2011; Csurhes & Hankamer, 2016). Many studies have shown the negative impacts of established feral populations on native turtles. For example, European pond turtles *Emys orbicularis* have been outcompeted by *T. s. elegans* for vital resources such as food and basking locations affecting body condition (Arvy & Servan, 1998; Cadi & Joly, 2003; 2004; Pearson et al., 2015; Martins et al., 2017). To address these issues, management strategies have been implemented, in addition to regulations. Between 2011–2013, the European Commission funded 'Project LIFE Trachemys' (LIFE09 NAT/ES/000529) focusing on the eradication of invasive turtles in 17 wetland areas in Valencia and Portugal. The outcome resulted in a reduction in *T. s. elegans* adults and neonates due to trapping, removal and nest destruction. Public awareness aimed to reduce pet releases and increase volunteer and NGO contributions, however, these efforts were still insufficient (European Commission, 2013). Focusing on a combination of actions, with feasible long term preventative measures, were surmised as more effective. The lower success rate of removal once the animals are established highlights the importance of prevention strategies. Although native turtles are not present in the UK, the release of pet turtles is assumed to continue and potentially impact other species of conservation concern without further research and intervention.

Citizen science is an effective way to engage people in conserving ecosystems (both locally and nationally), building empathy and connectivity, promoting responsible actions and monitoring non-native and invasive species (Newing et al., 2011; Lawson et al., 2015; Haklay & Francis, 2018; Parrish et al., 2019; Phillips et al., 2019; Oswalt et al., 2021). Recruitment of volunteers can range in knowledge and experience, from those in specialist groups through to 'untrained scientists' collecting and submitting data (Bonney et al., 2014; Allf et al., 2022). Advances in technology have made this process more accessible gaining greater reach through online platforms (e.g. apps) and social media (Bonney et al., 2014). Kalaentzis et al. (2023) used 240 occurrence records based on personal observations, iNaturalist and social media platforms to map and identify invasive turtles in Greece. This method often produces presence-only data which can affect modelling accuracy and outcomes where more biases are present (Zhang, 2019; Johnston et al., 2023). By collecting both presence and absence data (Alarcos et al., 2010), modelling becomes more accurate, but execution is time consuming, needing further resources and funding often not available.

In the mid to late 1990s, a National Terrapin Survey was undertaken covering the whole of the UK. This early study documented turtle abandonment, with more than 200 sightings submitted, 25% being present in the London area (Langton et al., 2011). Langton et al. (2011) carried out a further survey using records in London, dating back to the 1980s. Over this 30-year period, 300+ sightings were recorded, and 2,000 individuals identified. Broadening the scope and application provides a larger scale assessment of released individuals and further contribute to mitigation strategies. In 2018, discussions were held between the lead author (SS) and various stakeholders including the British Herpetological Society (BHS) and Amphibian and Reptile Groups (ARG UK) on the issue of feral turtles. Reviewing evidence of numbers, distribution, species and impacts, it was concluded that most studies on the topic were primarily carried out outside of the UK. This resulted in the initiation of the citizen science project called 'Turtle Tally UK' with the focus to gather wide-scale data on introduced turtles. As part of the initiative, the importance was placed on data collection, raising public awareness and input from discussions with the pet trade and rehoming organisations. This aided in understanding the underlying issues (socioeconomic factors) and identifying possible solutions in the prevention of releases and escapes. The primary objectives of the survey were to determine: 1) distribution, numbers and demographics of feral turtles; 2) areas with higher densities of turtle releases; 3) links between species listed on EU IAS regulations and species identified from sightings; and 4) any unusual observations.

MATERIALS & METHODS

Ethical approval was gained from the Ethics Committee of the School of Conservation and Anthropology, University of Kent Ethics (Application no. 149, Ethics ID: 20221655230373149). This process approved the questionnaire used as part of the citizen science survey. Questions asked included: participant contact details, sighting location (Grid reference, What3Words and/ or description of location), date and time of sighting, species (image guide from Langton et al., 2011) and the number of individuals seen (see supplementary materials 1). Photographic evidence was requested to verify sightings, and these were submitted via email. A statement was provided at the beginning of the survey informing participants that by completing the questionnaire they were giving consent for their personal details to be kept for the duration of the study period. To comply with GDPR legislation (Regulation (EU) 2016/679 of the European Parliament and of the Council) submissions were given an ID number and details were not shared with third parties.

Initially, the survey was hosted on the Hadlow College website (2019–2020) and opened for submissions in February 2019. Social media was used to share the survey using herpetological fora and tags to gain further reach. Presentations for park ranger teams, conservation organisations and volunteers were provided both online and in person to generate participation. Leaflets were created with the survey link and a short description of the purpose of the project. These were given to delegates at events and distributed in pet shops and at other locations i.e. country parks. In 2021, the website was created (www.turtletally.co.uk) hosting the questionnaire link to the JISC Online Survey platform which continued to be accessible to participants throughout the year. Correspondence was primarily via email if further clarification or communication was needed regarding the sighting, submission or general queries from the public. Each email was checked and responded to throughout peak season (February–October). Health and safety guidelines were provided for citizen scientists including adhering to government guidance during the Covid-19 pandemic, taking care whilst surveying around waterbodies and adult supervision recommended where children took part. It was clearly stated that participants should not handle, remove or touch the turtles as this may pose further risk to themselves and the animals. As such the survey was purely observational.

The term 'sighting' is used in reference to a participant completing a single survey reporting an observation which may include one or more individual turtles in the same location (see supplementary materials 2). Participants varied in level of knowledge from novice to experienced herpetologists. Data collected between 2019–2023 were split into two categories: 'verified' and 'unverified'. Verified sightings were those that were submitted with photographic evidence to enable the lead researcher (SS) to check that (a) a turtle was present and (b) the species identification. Further experienced team members assisted in verification. Photographs provided an opportunity to collate and estimate the number of individuals in locations, the life stage and sex of individuals, where visible. Sexually dimorphic characteristics were used to identify the sex of individuals. These primarily included the front claw length, carapace dimensions and distance proportionately from cloaca to plastron (Ernst, 1990; Whitfield Gibbons & Greene, 1990; Bringsøe, 2006; Ernst & Lovich, 2009). Where these could not be identified with high certainty, the 'unknown' category was assigned. Where species identification could not be confidently selected, the individual was placed in the 'other' category.

Although, records were accessible from other sources and recording platforms (NBN Atlas, ARG Record Pool, GBIF), these were not included in the dataset to ensure there were no duplications where citizen scientists submit to multiple platforms. Annual datasets of spatial point data were collated, and locations provided (What3Words, grid references) were converted to standardise geographic co-ordinates in latitude and longitude for uploading to ArcGIS Pro 3.03.3 for visualisation and analysis. Using the symbology function, Kernel Density Estimation (KDE) provided a graduated colour ramp displaying concentrated areas of reports in a continuous heat map with hot (high density) and cold (low density) visualisation. This tool was applied to the vector data to visualise the clustering of sightings across the UK, although KDE does not show statistically significant results, it is a suitable method for point data concentrations (GOV.UK, 2022).

RESULTS

Submissions of sightings were collated from a 5-year period, between January 2019 to December 2023. In total, 832 reports were received from 795 participants and 1,387 individual turtles reported. Of this amount, 628 (45%) of these were verified using photographic submissions (Table 1; Fig. 1).

Records were submitted between February and November annually during the study period. In 2021 and 2022, the first sightings were on the 27 February, and the last sightings were in the final weeks of October. In

Table 1. Summary of participants and reported observations as part of the verification process. The individuals reported were categorised as to whether they were present or not regarding evidence provided.

Year	Total no. of reports	No. of participants	No. of turtles reported	Verified individuals	Unverified individuals
2019	22 (3%)	22	29	21 (72.4%)	8 (28%)
2020	55 (7%)	52	65	31 (48%)	34 (52%)
2021	197 (24%)	190	408	143 (35%)	265 (65%)
2022	334 (40%)	321	507	246 (49%)	261 (51%)
2023	224 (27%)	210	378	187 (49%)	191 (51%)
Total	**832**	**795**	**1,387**	**628**	**759**

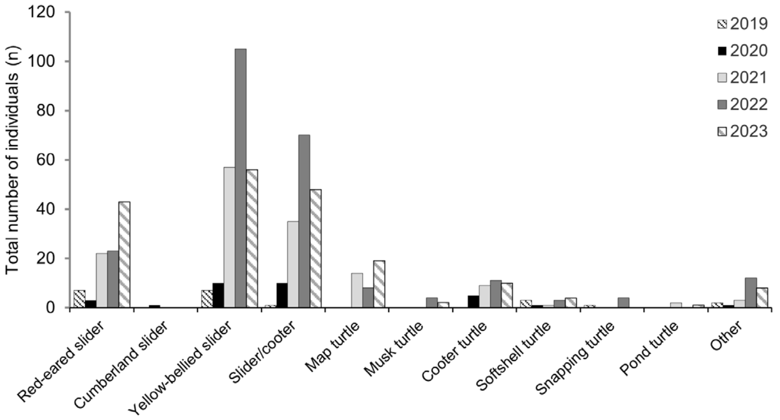

Figure 1. Annual number of species (individuals) reported (2019–2023), categorised by species or subspecies (verified where photographic evidence was provided).

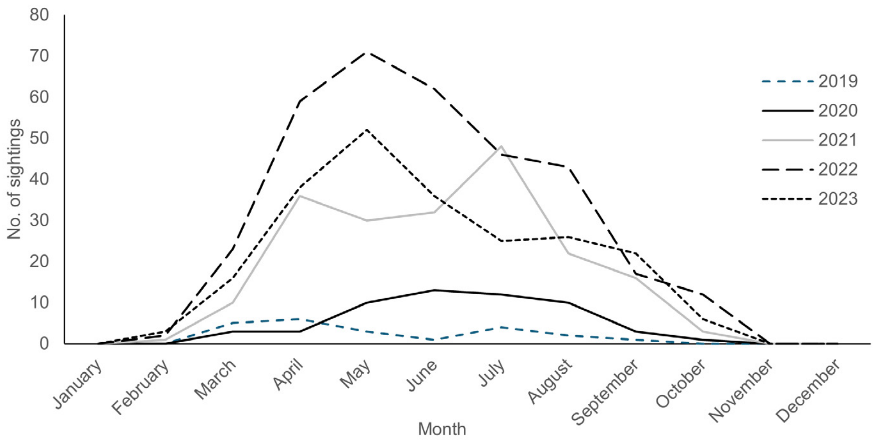

Figure 2. Seasonal distribution of report submissions and turtle sightings during the study period (2019–2023).

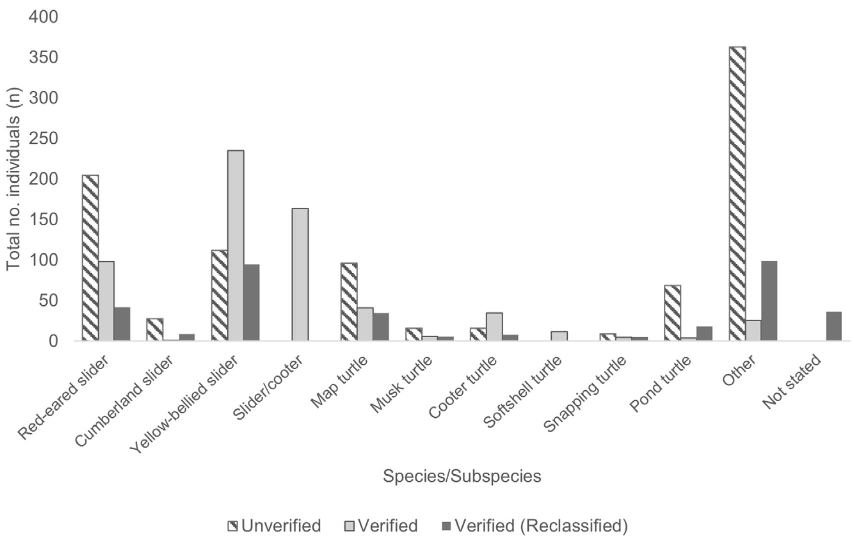

Figure 3. Total number of unverified individuals (individuals not visible in photographic evidence or where evidence was not submitted) compared to total number of verified individuals as to species categories. The turtles considered misidentified by participants were reclassified and the total number of individuals recategorised is represented.

2023, the first sighting was on the 3 February and the last sighting on the 9 November. Each year the peak times for observations were between March–August (Fig. 2).

Most verified sightings were yellow-bellied sliders (235 individuals), with slider/cooters being the second largest (164 individuals) and red-eared sliders being the third largest (98 individuals). Red-eared sliders were reported in higher numbers by participants, but many could not be verified (Fig. 3). Due to incorrect identification, 329 out of 628 verified cases (52%) were reclassified into different

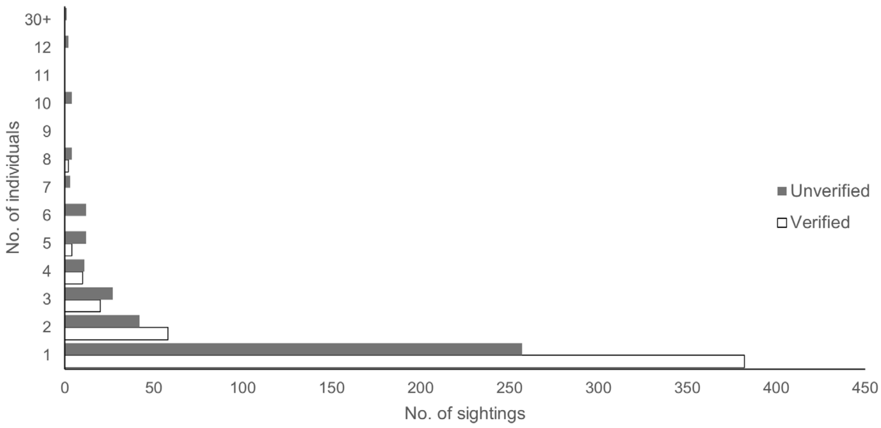

Figure 4. Number of individuals (verified and unverified) observed by participants per sighting (2019–2023), showing a larger proportion of single individuals compared to groups.

Figure 5. (Left) Avian foot and leg bones identified (waterfowl) in common snapping turtle (*Chelydra serpentina*) faecal sample excreted 24 hours following removal from canal inlet.

species categories. Out of 69 turtles submitted as *E. orbicularis*, only two were confirmed. One was found by a member of the public moving across land in Braintree, Essex and another, in Emsworth, Portsmouth. Of the *E. orbicularis* reports, 23 were reclassified as other species including *T. scripta* ssp. or *Pseudemys* spp.. The category ‘not stated’ occurred due to observations being reported directly to the researchers instead of using the survey and also the initial survey years allowing non-completion of this category. This was amended in latter years.

In total, 75% of sightings (verified and unverified) were single lone turtles (median = 1) (Fig. 4). Other turtles may have been present in the area but were not reported or visible in photographs so not included in the dataset. The remaining 25% of sightings were groups of two (12%) or more (13%). In 2021, one record of 30+ turtles was reported but no evidence was submitted to confirm this. Due to the distance, quality and angle of photographic evidence, sex of individuals could only be identified where sexually dimorphic characteristics were clearly visible. If there was uncertainty, the category 'unknown' was used. Out of verified individuals, 190 (30%) were considered female, 51 (8%) male and 387 (62%) unknown. All verified individuals, except one, were considered adult/subadult. One musk turtle was identified as juvenile (not hatchling size), but no further juveniles or hatchlings were evidenced during this period.

One submission, was a large adult female *Chelydra serpentina*, living behind a house in a canal inlet in New Maldon, Essex. This animal had been emerging in spring each year, for six years, and basking in the same shallow vegetated pool. Within 24 hours of removing this individual, a faecal sample was produced, and a bird leg was excreted (Fig. 5). In June 2022, an adult female red-eared slider was found crossing a path, on land, from a fishing lake (Leybourne Lakes, Kent) suspected to be seeking a nest site. (Fig. 6a & b). The turtle was relocated to a rehoming centre, where a health assessment and x-ray was carried out confirming the female was carrying eggs (Fig. 6c). It was difficult to determine whether she was gravid when released/escaped, however due to her external condition (Fig. 6d & e), it was assumed that she was not a recent release. Scarring on the carapace

Figure 6. a) Adult female feral red-eared slider found crossing a dirt track by a lake, heading inland suspected to be seeking nesting locations in a country park, **b)** Nearby fresh dig marks indicating an attempt to nest, **c)** X-ray gravid female post-removal, eggs present, **d)** Carapacial wounds, bone fractures right costal scutes, and **e)** Healed impact wound, left side of the carapace.

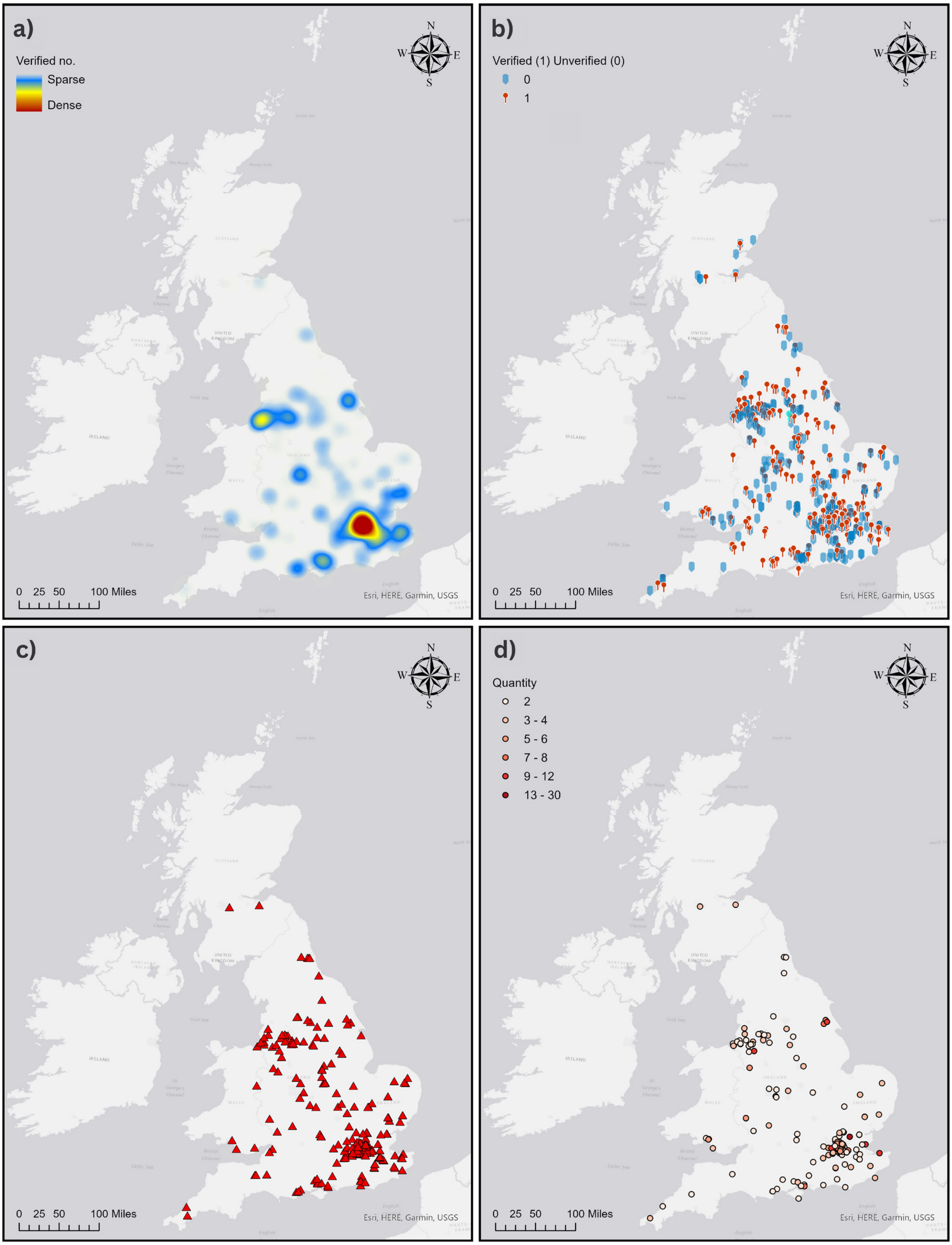

Figure 7. Maps showing density of individuals and groups across the UK submitted to the Turtle Tally UK survey between 2019–2023 – **a)** Hotspot spatial analysis, presence only data, visualising clusters of verified individuals in areas showing greater or lesser densities, **b)** all individual sightings (verified and unverified), **c)** Reclassified individuals showing reports of species submissions which were reclassified as part of the verification process, and **d)** Locations identified where groups of two or more turtles (verified and unverified) were observed and reported in one sighting.

inferred that severe injuries had occurred and healing had followed over a period of months.

In total, 831 reference points were used in the mapping of turtle presence with submissions received from England, Scotland and Wales. Many records were submitted without spatial data, and some were indiscernible or erroneous grid references. Of the mapped vector data, 505 (61%) were verified and 326 (39%) were unverified sightings (no photographic evidence). Spatial hotpot analysis showed clustered sightings in two locations within England (Fig. 7a). These were primarily in the Greater London area and the Manchester/Liverpool localities. But further presence was identified throughout the Midlands and southern regions. Verified and unverified reports were mapped to show spread across England, Scotland and Wales (Fig. 7b). Reclassified verified species (total 354 turtles) were also mapped showing a similar spread to the overall mapped data points (Fig. 7c). The numbers of turtles reported in groups across the UK were scattered with the larger groups identified (verified and unverified) in more densely populated urbanised areas (Fig. 7d).

DISCUSSION

Over the 5-year study, 795 participants took part reporting 1,387 feral turtles (verified and unverified), sighted on land and in water, across three countries within the UK (England, Wales and Scotland). Although initial years yielded low submission numbers, with increasing collaborative support by external stakeholders the project visibility increased. This produced greater numbers of submissions in subsequent years. The greatest number of total annual sightings was in 2022 with 334 reports submitted (40% of data gathered). During this period, 75% of the 628 verified turtles were identified as lone individuals. Consequently, their impact on the surrounding environment is considered lower compared to larger groupings that may exist. However, lone turtles may still be potential sources of pathogen pollution (Silbernagel et al., 2013; Lawson et al., 2015; Sodagari et al., 2020; Bonacina et al., 2021; Moroni et al., 2025; Muslin et al., 2025;). Of the verified sightings, all were considered adults/subadults based on species size and shell dimensions in relation to objects, markings and pigmentation. The presence of young turtles could not be confirmed, as there were no clear signs that juveniles are present in current populations.

Accuracy is often an issue regarding citizen science reporting and identification (Zhang, 2019). Many actions were taken to minimise this such as providing identification keys (Langton et al., 2011) and photographic submission for verification purposes. However, an extract of the dataset (see supplementary materials) shows an ~11-mile stretch of waterway with verified and unverified sightings present. This increases the likelihood of unverified sightings being true. Although sightings of the same individual moving along the waterway reported by different observers could be misrepresented. Identifying specific individuals becomes difficult without being in closer proximity, so was not an aspect evaluated. Further factors hindering species identification included hidden markings due to distance, photograph quality, positioning and melanistic traits e.g. darkened pigmentation (Fig. 8). Melanism is a characteristic seen in slider species and documented as a change often identified in older males (McCoy, 1968; Ernst, 1990; Hays & McBee, 2009). This loss or change in markings creates further difficulties for accurate identification (Fig. 9). In total, 52% of verified turtles needed to be reclassified to other species categories. For example, out of 18 submissions of *E. orbicularis*, only two were correctly identified. The most reclassified category, from the survey was 'other'. Participants may have chosen this option due to lacking confidence in assigning a specific species. The 'not stated' category was created due to participants not submitting a species identification in the initial survey years (2019–2020). Additionally, some reports were sent outside of the survey, and a

Figure 8. Melanistic *Trachemys scripta elegans* considered an older male, due to cloaca distance from the plastron , shorter front claws. Darkened skin colour, pupil and scute pigmentation.

Figure 9. Turtles basking on a fallen tree in the water, at Leybourne Lakes Country Park, Kent. Positioning may reduce visibility of markings and characteristics showing limitations in identification.

species was not assigned. These were classified where photographs were submitted and overall, *T. s. scripta* and *T. s. elegans* were largely misidentified. This may be due to similarities in visual characteristics including markings, shape and size. The 'red ear' is a common identifier, but this is not present in melanistic individuals and fades to varying degrees. Similarly, the distinct yellow 's' postorbital marking either side of the head of yellow-bellied sliders fades in some individuals (Fig. 9) (Ernst, 1990). Reliance upon participant identification alone in a citizen science project can increase the chance of erroneous identification. Although, mapping locations of the reclassified individuals does not show any clear indication that regional differences affect accuracy. Those considered 'more experienced' were also identified as misidentifying individuals, therefore an area for further training (Lovich et al., 1990). There are future opportunities for development of educational tools to aid identification skills. Due to submissions increasing over the study period, more time and effort was needed to carry out the verification and reclassification process. This element of the study is time consuming but sets the project aside from mainstream recording platforms. Although, without removal and genetic analysis, accuracy of species identification is limited (Vamberger et al., 2020).

Other species identified, were map turtles (41 individuals), including Ouachita map turtles *Graptemys ouachitensis* and False map turtles *Graptemys pseudogeographica*. All map turtle species (genus *Graptemys*) are listed on the Convention on International Trade in Endangered Species (CITES) as Appendix II or III allowing regulated trade, US exports and permits (Vogt, 2018; CITES, 2022; CITES Secretariat, 2022). Common musk turtles *Sternotherus odoratus* and razor musk turtles *Sternotherus carinatus* were also reported. These species are smaller in size, compared to others mentioned. Native wild individuals are recorded as averaging 13.7–15.0 cm max straight carapace length (SCL) and are well camouflaged in their environment. Bottom dwelling in nature, they are less likely to be observed by citizen scientists, in water amongst vegetation (Ernst & Lovich, 2009). This makes it difficult to gauge numbers of released individuals, distribution and demographics due to being small and cryptic in nature. As popular pets, they are often sold in multiples due to their size. There are potentially larger numbers present in waterbodies yet a lower detection rate by citizen scientists results in an underrepresented dataset. This remains an area for further investigation and there are few studies representing presence outside of their native range (Foglini, 2021). Species bias can occur because of this and further techniques such as eDNA may aid in identifying presence and distribution (Feng & Lougheed, 2023).

More concerning and unusual species reported were nine common snapping turtles *Chelydra serpentina*, and eleven Chinese softshell turtles *Pelodiscus sinensis*. *Chelydra serpentina* (omnivorous) and *P. sinensis* (primarily carnivorous) are larger in size than pond sliders and more effective ambush predators (Ernst & Lovich, 2009), therefore, we believe these species may pose a higher risk to native wildlife. *Chelydra serpentina* will float under the water surface or sit in the shallows to bask therefore may not be reported as often, resulting in underestimated presence. However, both of these species were reported as lone individuals within the survey. In contrast, one-off unusual observations reported in the media may give the impression that rare sightings are more common than perceived. Although such bias by the media may raise awareness on the topic, it can also ignite concerns in the public through inaccurate representation. For example, after the survey period ended, a juvenile alligator snapping turtle *Macrochelys temminckii* was found in a Cumbrian tarn (2024) and gained mainstream news coverage, yet none were reported during the 5-year study period.

Following winter dormancy, submissions of turtles emerging occurred from late February–early November showing activity earlier in the year compared to previous observations (Inns, 2009). This is also considered early emergence compared to their native range and the temperate climate is presumably the reason for this. Most sightings were during the middle of the day which reflects natural basking and feeding activity. Peak season for sightings occurred between April–July showing seasonal presence linked to spring and summer periods. This coincided with reports of individuals moving on land assumed to be seeking nesting locations, mates, returning/leaving overwintering sites (Ernst & Lovich, 2009) or escaped from pet owner residences. The State of UK Climate 2023 (Kendon et al., 2024) reported that the UK has become 'warmer, wetter and sunnier' and 'extreme temperatures have been affected much more than average temperatures'. In early spring, sudden drops in temperature following initial warmer periods, could be the reason for small numbers of mortalities reported to the project at this time. With turtles emerging from winter dormancy early, they are more likely to succumb to mortality due to their depleted body condition over winter. Suboptimal environmental parameters can result in increased disease risk and higher mortality rates. More tropical species, such as *Pelodiscus nelsoni*, need warmer environments and are potentially more at-risk post-release due to the climate. Variation across the UK may affect survival of turtles, therefore numbers present. In 2024, data collated by Cathrine (2024) included 42 records of turtles (between 1993–2022) located in both rural and urban areas, primarily pond sliders. These were not identified to subspecies level, but our findings show a similar distribution of reports in Scotland. Numbers of sightings and distribution outside of England could have been affected by the limited reach of the project causing a geographic data bias. Due to a lack of sightings from Ireland, further discussions with stakeholders could support research in this area. Clustered sightings, shown through the hotspot analysis, in urban areas suggest that increased population density (increased probability of turtle pet ownership), higher footfall, less vegetation and increased rates of detectability may be driving the number of sightings reported. Rato et al. (2025) also identified human population density being a strong predictor for invasive turtles being reported in the wild.

Citizen science provides a large, widespread resource contributing to conservation. There has been an exponential growth in engagement in citizen science over the last two decades (Bonney et al., 2014; Hayhow et al., 2019; Parish et al., 2019; Allf et al., 2022). It is estimated that 19,000 volunteers contribute data through monitoring schemes equating to a cost of £20 million. With a further 70,000 individuals submitting sightings through unstructured schemes, contributing to conservation (Newing et al., 2011; Marshall et al., 2012; Lawson et al., 2015), this tool provides valuable data in monitoring on a wider scale whilst reducing costs.

All verified species were identified as being available within the pet trade, except for *T. s. elegans*, *T. s. scripta* and *Trachemys scripta troostii* being listed on the EU IAS Regulations. Similar citizen science studies in Europe have also identified *T. scripta* ssp., *Pseudemys* spp., *Mauremys sinensis*, *P. sinensis* and *C. serpentina* as being present, mirroring our findings (Kalaentzis et al., 2023). In total, 235 individuals were identified as yellow-bellied sliders *T. s. scripta* and 98 identified as red-eared sliders *T. s. elegans*. Banned in 1997 and 2016, these subspecies are found in large numbers assumed due to longevity, adaptability and hardiness. It is predicted that these numbers will diminish over time. This brings into question how effective regulations are. Some EU IAS listed species have been recorded as sold illegally following the bans (Bosch et al., 2016; Rato et al., 2025). Careful consideration should be made when implementing turtle import restrictions and regulations to reduce risks of 'replacement species'. However, the trade is dynamic, and an ongoing issue of replacement species filling the void created by bans is evident (Carpenter et al., 2004; Tapley et al., 2011). Pienaar & Sturgeon (2024) found that exotic pet owners showed preferences for species that are not large adult sizes and do not have long life expectancies. Replacement species such as *Pseudemys* do grow to similar, if not, larger sizes than *T. scripta* ssp., which pet owners may also find difficult to accommodate appropriately, thereby perpetuating this cycle (Ambrose et al., 2024).

A further consideration is the sustainability of eradication strategies regarding time, funding and resources. A multi-faceted approach is recommended with an enhanced focus on preventative measures: 1) tax (or levy) on imports of freshwater turtles, raising value and reducing numbers sold (Pienaar & Sturgeon, 2024); 2) turtle size sale restrictions (Rato et al., 2025); 3) increased education of prospective pet owners at point of sale (POS) including adult size potential, lifespan and securing of accommodation (Pienaar & Sturgeon, 2024); 4) strengthening rehoming and adoption infrastructure to offset released turtles (Baek et al., 2023). Any additional funds generated could be redirected back into conservation and education programmes to aid in managing the issue (TFWTWG, 2003).

The data collected in this study can be used to help inform future management strategies and conservation programmes (Zhang, 2019; Oswalt et al., 2021). At present, the UK climate is considered 'suboptimal' not meeting required environmental parameters for full term incubation of fertile eggs, therefore feral populations are not suspected to be naturally increasing. No hatchlings or juveniles were reported via the survey or verified over the 5-year period resulting in a lack of evidence for breeding populations in the UK. Nevertheless, with future predicted climatic changes and varying microclimates, it is important to support ongoing monitoring programmes to identify when and if this does occur. If environmental parameters become more suitable and clutch hatching success increases, it is predicted to result in male hatchlings due to temperature-dependent sex determination and therefore, a skewed population output of males (Gilbert, 2000). Further research into impacts due to presence, both positive and negative, and socioeconomic factors linked to distribution is needed to inform future mitigation methods.

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Author contributions

Suzie Simpson conceived and wrote the manuscript. Richard Griffiths supervised the project, reviewed and edited the manuscript and provided feedback.

Data accessibility

Data used in this study can be acquired via correspondence with the author. Survey questions and detailed verification processes are provided in the supplementary materials.

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