Non-native land snails in Oklahoma: results from urban surveys and citizen science

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Abstract: Urban habitats within Oklahoma contain diverse assemblages of land snails, including several poorly documented non-native species. Using published accounts, museum collections, and iNaturalist, we list 25 species that include 16 exotic species, 7 extralimital species, and 2 species that are native to a portion of the state but have expanding ranges. The European-native milk snail, *Otala lactea*, is a new Oklahoma record, which was likely introduced in a rural site on trucks carrying the snails from Texas, whereas many non-native snails are dispersed through the plant trade. Verified iNaturalist records were assessed for four non-native species that can be easily identified from photographs (*Cornu aspersum*, *Otala lactea*, *Bradybaena similaris*, *Polygyra similaris*) and these records expanded the known ranges of all of four species, demonstrating the utility of iNaturalist records in updating distributions of land snails, especially urban snails. To be useful, iNaturalist photographs of snails need to be in sharp focus and show distinguishing features (which generally requires more than one image) and a scale. Many iNaturalist snail records were not identifiable or were misidentified. Identification issues can be improved by better photographs, greater input by taxonomists, adding the distinguishing features in comments, and the availability of non-technical regional identification guides.

Introduction

Oklahoma has a diverse land snail fauna and was cited for the state's extensive snail collection efforts (Hubricht 1985) because of numerous, mostly historical surveys. However, these historical surveys, like most land snail surveys, primarily targeted natural areas. More recent land snail surveys in Oklahoma have included urban areas (Bergey 2019; Bergey and Boonmachai 2023; Bergey and Figueroa 2016; Bergey et al. 2014; Bergey and Whipkey 2020) and these urban-based surveys have resulted in numerous new state records of land snails.

Non-native snails are often found in urban areas (Herbert 2010; Horsák et al. 2009; Perez et al. 2021), where they occur in yards (Arruda 2018; Bergey and Figueroa 2016; Bergey and Whipkey 2020; Perez et al. 2021), parks (Hodges and McKinney 2018), in greenhouses and plant nurseries (Bergey et al. 2014; Cowie et al. 2008; Gutiérrez Gregoric et al. 2020; Horsák et al. 2004; Richling and von Proschwitz 2021; Yeung et al. 2019), and even on green roofs (McKinney et al. 2019). Recent snail records from urban areas include multiple non-native species – either originating within the United States but occurring outside their native range (extralimital) or originating from other countries (exotic). Many non-native snails are small and are unlikely to become pests or even nuisance species (Hausdorf 2023) and even large species may not pose se-

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rious problems, although there are certainly exceptions.

The widespread occurrence of non-native snails in urban areas results largely from human-assisted dispersal of land snails and habitat modifications that benefit snail establishment in urban areas. Although snails disperse slowly by themselves, human-assisted movement allows rapid dispersal, sometimes over long distances. Mechanisms of human-assisted dispersal can be intentional, as when snails are moved as pets, food, or biocontrol agents, or unintentional, as when snails are moved on potted plants, on produce, in firewood, or attached to or within shipped goods (Cowie and Robinson 2003). A wide diversity of snails can be dispersed, as evidenced by the 369 species of freshwater and terrestrial snails found on commodities entering the United States over a 5-yr period by US Department of Agriculture inspectors (Robinson 1999). Within the United States, the plant trade is commonly implicated in the dispersal of land snails (Bergey et al. 2014; Cowie et al. 2008; Yeung et al. 2019). Snails found in yards may have arrived in association with potted plants, where snails commonly occur on undersides of the pot, in drain holes, and on the soil surface, where they may be hidden by leaf litter. Finding the species in plant nurseries bolsters the possibility that movement occurred through the plant trade. Nurseries may source plants from multiple other places, many of which are in distant states (Bergey et al. 2014). Other possibilities for introduction include the movement of firewood or landscape materials, snails in plant material such as vegetables or flowers, the release of pet snails, and snails being carried on vehicles (Cowie and Robinson 2003).

Habitat modifications that can aid in the establishment of non-native snails include watering and the provision of thermal microhabitats. Snails are prone to desiccation and watering provides a water source that not only supplements rain but regular watering prevents local drought conditions and can promote snail populations (Bergey and Whipkey 2020). Non-native species that do not tolerate freezing or the hot summers often burrow and may benefit from proximity to buildings, especially poorly insulated ones (Bergey 2019).

In this project, we (1) provided a list of known non-native land snails in Oklahoma and (2) provided detailed accounts of the known distributions of four non-native land snail species in Oklahoma. Two of the four species – the brown garden snail *Cornu aspersum* and the milk snail *Otala lactea* are of particular interest because of their large size, and hence visibility. These two species are easily identified from photographs and survey records can be augmented with photographic records from iNaturalist. The two other species, the southern flatcoil *Polygyra cereolus* and the Asian tramp snail *Bradybaena similaris,* also have distinctive shell morphology. Identification of these latter two species is possible from photographs, but is more challenging than for the two larger species as photographs may not show the necessary distinguishing characteristics.

Methods

Land snail records were obtained from three sources: previously published surveys by the authors, museum records from the Herbarium and Zoological Collection at the University of Science and Arts of Oklahoma, and iNaturalist (iNaturalist 2023; www.inaturalist.org). iNaturalist is an online network in which people post images of organisms for identification. Images and the accompanying data, particularly collection date and location, can be searched to find distribution records. A second online source, GBIF (Global Biodiversity Information Facility; www.gbif.org) was consulted but did not add additional records. GBIF is an online international tool based on amassed databases, including the iNaturalist database. Urban surveys that included records of the four target species were a survey of Oklahoma plant nurseries and three surveys of land snails in residential yards.

iNaturalist records for the four target species were searched in December 2023 using the following searches (by genus; but only one species in each genus is known in Oklahoma):

Cornu:https://www.inaturalist.org/observations?-place_id=12&subview=table&taxon_id=87634

Otala: https://www.inaturalist.org/observations?place_id=12&subview=table&taxon_id=202861

Bradybaena:https://www.inaturalist.org/observations?place_id=12&subview=table&taxon_id=172111

Polygyra:https://www.inaturalist.org/observations?place_id=12&subview=table&taxon_id=91217

All photographs resulting from these queries were copied into PowerPoint and examined for distinguishing features for the corresponding species, without regard to the locality of the record (photographs were numbered and the database information for each photograph was kept in a separate file). Photographs were given one of three scores: (1) correct – the photograph included enough features of the shell to positively identify the target species, (2) not sure – the photographs were inadequate to identify the target species because identifying features were not visible (e.g., features were obscured by the orientation of the shell, the aperture (especially) was not visible because of the snail's body, or the photograph was too blurry to see the identifying features), and (3) incorrect – shells lacked the appropriate identifying features and were sometimes identifiable to a different taxon. In addition, two records were discounted because they were evidently not locally sourced – one was photographed in a (commercial?) snail collection box and the other was described as a purchased pet.

Maps of collection sites were made with BatchGeo (www.batchgeo.com), an online program that maps locations based on address or coordinates. Sites are listed as towns rather than counties because, with one exception, all sites were urban (including plant nurseries, yards, and parks). In cases of multiple iNaturalist records from the same location on different dates, only one record was considered an occurrence.

Results and Discussion: species' accounts

The currently known list of non-native snails in Oklahoma comprises both exotic and extralimital species (Table 1). Although some taxa have long been known from the state (e.g., the slugs *Limacus flavus* and *Ambigolimax valentianus*), many are more recent records resulting from urban surveys. *Otala lactea* is recorded here as a new state record. Two species (*Anguispira alternata* and *Ventridens demissus*) are considered extralimital because, although their native range includes eastern Oklahoma (Hubricht 1985), these species are now much more widely distributed within the state. *Deroceras laeve* is reported as a native species, but recent genetic work has shown that the species is a non-native that originated in Europe (David Robinson, personal communication). Unlike nearly all of the other non-native species listed in Table 1, *D. laeve* has expanded its range beyond urban areas.

Table 1. List of non-native land snails in Oklahoma. 'exotic' species are native outside the United States and 'extralimital' species are native USA species but are not native in Oklahoma (parentheses indicate extralimital species that are native to the eastern one-third of Oklahoma but now occur elsewhere in the state). Documentation of records are indicated ('USAO' = University of Science and Arts Museum; 'plant nurseries': Bergey et al. (2014); 'Norman yards' survey: Bergey & Figueroa (2016); *'Cornu survey'*: Bergey (2019); yards in 'nine towns' in Oklahoma survey: Bergey & Whipkey (2020); 'OKC Zoo' survey: Bergey & Boonmachai (2023). iNaturalist records were only checked for the four target species and records were present for all four species (not listed in the Table).

Family/Species	Native?	USAO Museum	plant nurseries	Norman yards	*Cornu* survey	nine towns	OKC Zoo
Achatinidae							
Allopeas gracile (Hutton, 1834)	exotic	x	x	x		x	x
Rumina decollata (Linnaeus, 1758)	exotic	x				x	
Subulina octona (Bruguière, 1789)	exotic		x				
Agriolimacidae							
Deroceras laeve (Müller, 1774)	exotic	x	x	x		x	x
Deroceras reticulatum (Müller, 1774)	exotic		x			x	
Arionidae							
Arion fasciatus (Nilsson, 1823)	exotic		x			x	
Arion rufus (Linnaeus, 1758)	exotic		x				
Camaenidae							
Bradybaena similaris (Férussac, 1822)	exotic		x	x		x	x
Helicidae							
Cornu asperum (Müller, 1774)	exotic	x	x	x	x	x	
Otala lactea (Müller, 1774)	exotic						
Discidae							
Anguispira alternata (Say, 1817)	(extralimital)	x	x	x		x	x
Gastrodontidae							
Ventridens demissus (Binney, 1843)	(extralimital)	x	x			x	x
Limacidae							
Ambigolimax valentianus (Férussac, 1821)	exotic	x	x	x		x	x
Limacus flavus (Linnaeus, 1758)	exotic	x	x	x		x	
Limax maximus Linnaeus, 1758	exotic					x	
Milacidae							
Milax gagates (Draparnaud, 1801)	exotic		x	x		x	
Oxychilidae							
Oxychilus cellarius (Müller, 1774)	exotic		x				
Polygyridae							
Patera appressa (Say, 1821)	extralimital		x	x		x	
Polygyra cereolus (Megerle von Muhlfeld, 1816)	extralimital		x	x		x	x
Triodopsis hopetonensis (Shuttleworth, 1852)	extralimital	x	x	x		x	x
Xolotrema fosteri (Baker, 1932)	extralimital	x				x	x
Valloniidae							
Vallonia excentrica Sterki, 1893	extralimital					x	
Vallonia pulchella (Müller, 1774)	extralimital					x	x
Veronicellidae							
Angustipes ameghini (Gambetta, 1923)	exotic		x				
Vertiginidae							
Vertigo teskeyae Hubricht 1961	extralimital					x	

***Cornu aspersum* (brown garden snail; family Helicidae; Fig. 1A and Fig. 2A)**

This is a large snail, with a globose shell of 25-40 mm diameter (Herbert 2010). The shell is brown and usually patterned with broken darker brown spiral bands (Fig. 1A). Adults have a white recurved aperture lip. *C. aspersum* is native to the Mediterranean area of southern Europe and northern Africa. The species is raised for food in Europe, as it is a commonly eaten escargot species, known as escargot petit gris (= small gray). *Cornu aspersum* now occurs in many countries and continents (summarized in Herbert 2010). The species first introduction in the USA was thought to be in California the 1850's, when it was imported as an edible species by a Frenchman (Stearns 1900), an origin shared with South Africa (e.g., Herbert 2010).

Cornu aspersum is known from multiple states in the United States, including three states bordering Oklahoma: New Mexico, Colorado, and Texas (NatureServe 2024). In California, the species can reach high densities and can be a pest in citrus and a nuisance in yards but elsewhere it causes little problem.

The first known record of *C. aspersum* in Oklahoma was in a yard in Nichols Hills (Oklahoma County) in June 1994 (USAO #9452)(Fig. 2B). The second record was also in the greater Oklahoma City area, in Edmond (Oklahoma County) in Dec 2011 (USAO #12927). Land snail surveys in urban areas and in plant nurseries documented several more recent locations. In a survey of 28 plant nurseries, a single live specimen was found in a plant nursery in Davis, Oklahoma (Bergey et al. 2014). Subsequent yard surveys found C. aspersum in yards in Norman (Bergey 2019; Bergey and Figueroa 2016) and Altus (Bergey and Whipkey 2020). One of the sites in Norman was an extensive population of 281 counted live snails that ranged over 19 yards (Bergey 2019). iNaturalist had 10 records, of which 3 were correct identifications: two in Oklahoma City and one in Norman.

***Otala lactea* (milk snail; family Helicidae; Fig. 1B and Fig. 2B)**

Otala lactea is a large snail (shell diameter of 20 to 40 mm) originating from the Mediterranean region (Pfleger and Chatfield 1988). The shell is thicker and somewhat flatter than the shell of *C. aspersum*. The dark brown, shiny colored area that completely surrounds the aperture is characteristic. Other than the aperture color, shell coloration is variable, ranging from cream colored to a variable number of brown bands to brown, with the color interspersed with lighter marking (Herbert 2010) (Fig. 1B).

The species has been introduced in some South American countries, Bermuda, and possibly Mexico (summarized by Hayes et al. 2023). Within the United States, *O. lactea* occurs in two states that border Oklahoma (Texas and Missouri), most of the Gulf Coast states, California, Kentucky, Virginia, Ohio, Pennsylvania New York, and Maryland (NatureServe).

The first known record of *O. lactea* in Oklahoma was a set of photographs sent by Cody Rhodes from Pontotoc County in 2021 (Fig. 2B). The site was disturbed rangeland that had previously been a rock mining site. That same year, we received shells and found living snails at the Master Gardener demonstration garden in Norman. Although the gardeners have tried to eradicate this population using snail bait, snails were still present in 2023. One of the gardeners transplanted some plants from the Garden to her yard and subsequently found live snails in her yard in Norman. Both the Pontotoc and Norman populations are small and are considered established.

***Bradybaena similaris* (Asian tramp snail; family Camaenidae; Fig. 1C and Fig. 2C)**

The shell of this medium-sized species is pyramidal with rounded body whorl. The shell is light in color with a single well defined brown band, which can sometimes be indistinct (Fig. 1C). Similar to *C. aspersum*, and as it's common name implies, this species has spread widely across the globe from its origin in Asia (Herbert 2010).

In the United States, the known distribution of *Bradybaena similaris* includes all the Gulf Coast states (Texas, Louisiana, Mississippi, Alabama, and Florida), as well as Georgia, South Carolina, North Carolina (although this state's INaturalist records are unconfirmed), and two 2022 reports in Wisconsin (both in Milwaukee) (Gladstone et al. 2020; iNaturalist; NatureServe).

As far as we are aware, the first records of *B. similaris* in Oklahoma were in eight plant nurseries in six towns (Davis, Edmond, Enid, Inola, Oklahoma City, and Owasso) (Bergey et al. 2014), with a recent finding in the University of Oklahoma greenhouses (where it was apparently introduced since the earlier survey). Our urban surveys found the species in Ardmore and Woodward yards (Bergey and Whipkey 2020) and the Oklahoma City Zoo (Bergey and Boonmachai 2023) (Fig. 2C).

iNaturalist had 75 records of *B. similaris* in Oklahoma. Ten records were misidentified, most commonly these were polygyrids, and 21 records could not be positively identified (to the authors' satisfaction). Of the confirmed *B. similaris* records, 36 were repeated observations,

with 29 records from one street and 7 from another – all during 2023; these were considered as one location for each street. An additional record lacked site location beyond the state and was not further considered. This left 9 records (including the two multiple-record sites) and comprised further sites in Norman and Oklahoma City, and added new locations in Broken Bow, Tulsa, and Moore.

***Polygyra cereolus* (southern flatcoil; family Polygyridae; Fig. 1D and Fig. 2D)**

Polygyra cereolus is the smallest of the four included species (Fig. 1E). The shell is characterized by being flattened, with close spirals, transverse ridges on dorsal shell surfaces, a shouldered body whorl, and a large umbilicus. Adults have a thick white recurved lip on the aperture, which has a single tooth - features that are not present in juveniles. Shells do not have an obvious color pattern, although some specimens, especially juveniles, appear mottled because of coloration of the body (Fig. 1D).

Unlike the other three target species, *P. cereolus* is native to the United States. Hubricht (1985) mapped the then-known distribution as all of Florida and along coastal areas from South Carolina to Texas, with few records inland within these states, noting the species apparent affinity to slightly salty conditions. More recently, this species has greatly extended its range, although NatureServe indicates these same states. By 2008, the species was also found in North Carolina, Kentucky, and Hawaii (Perez and Cordeiro 2008) and the species has become invasive, as *P. cereolus* is now known from southern Europe and northern Africa (Hausdorf 2023), the Caribbean (Charles and Arnaud 2020), and the Middle East (Neubert 1998), and has been intercepted re-entering the United States from Europe (Robinson 1999).

Our surveys found 62 unique site records (a few records were duplicated sites). *Polygyra cereolus* was found in all 28 of the surveyed plant nurseries (Bergey et al. 2014), in 23 of 61 surveyed yards in Norman (Bergey and Figueroa 2016), and in yards in Altus, Elk City, Woodward, and Miami (Bergey and Whipkey 2020), as well as the Oklahoma City Zoo (Bergey and Boonmachai 2023).

iNaturalist listed 72 records of *P. cereolus* in Oklahoma. Thirty records were misidentified as *P. cereolus*, with identifiable taxa including *Ventridens* sp., *Triodopsis hopetonensis*, *Linisia texasiana*, *Anguispira* sp., and *Euchemotrema*/*Stenotrema* sp. We were unable to confidently confirm the identifications of 23 records. Of the remaining 19 records, 3 lacked specific location information and 1 was a repeat record, leaving 15 usable records. These 15 records were all recent (2019-2023), duplicated some city records (e.g., Norman, Oklahoma City), and added five new cities to the known distribution within the state – namely, Bartlesville, Tulsa, Owasso, Stillwater, and Edmond (Fig. 2D).

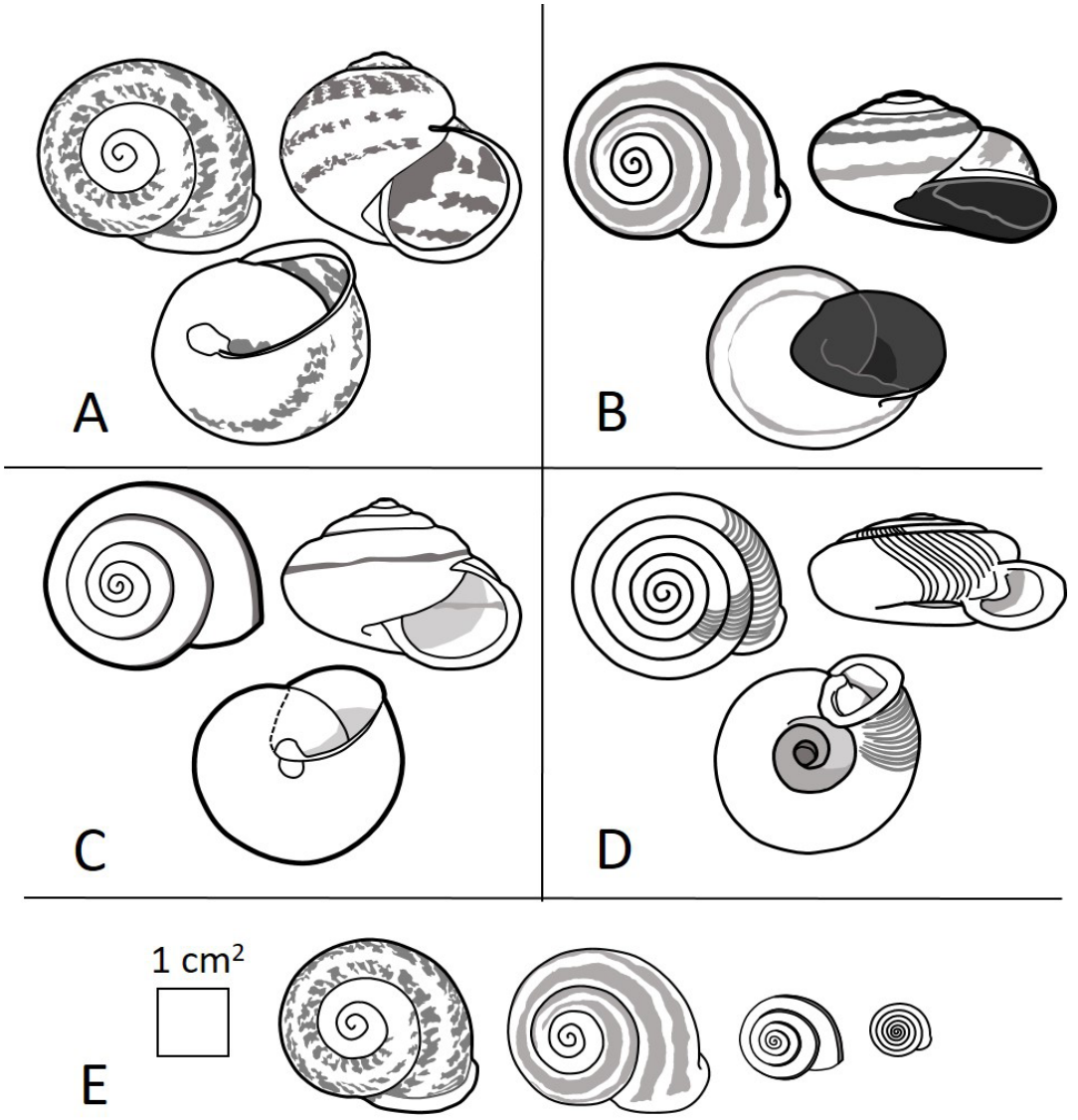

Figure 1. Illustrations (dorsal, lateral and ventral views) of four land snail species. A = *Cornu aspersum*, B = *Otala lactea*, C = *Bradybaena similaris*, D = *Polygyra cereolus*. Shell sizes are shown in E. Drawings were made from shells collected in Oklahoma.

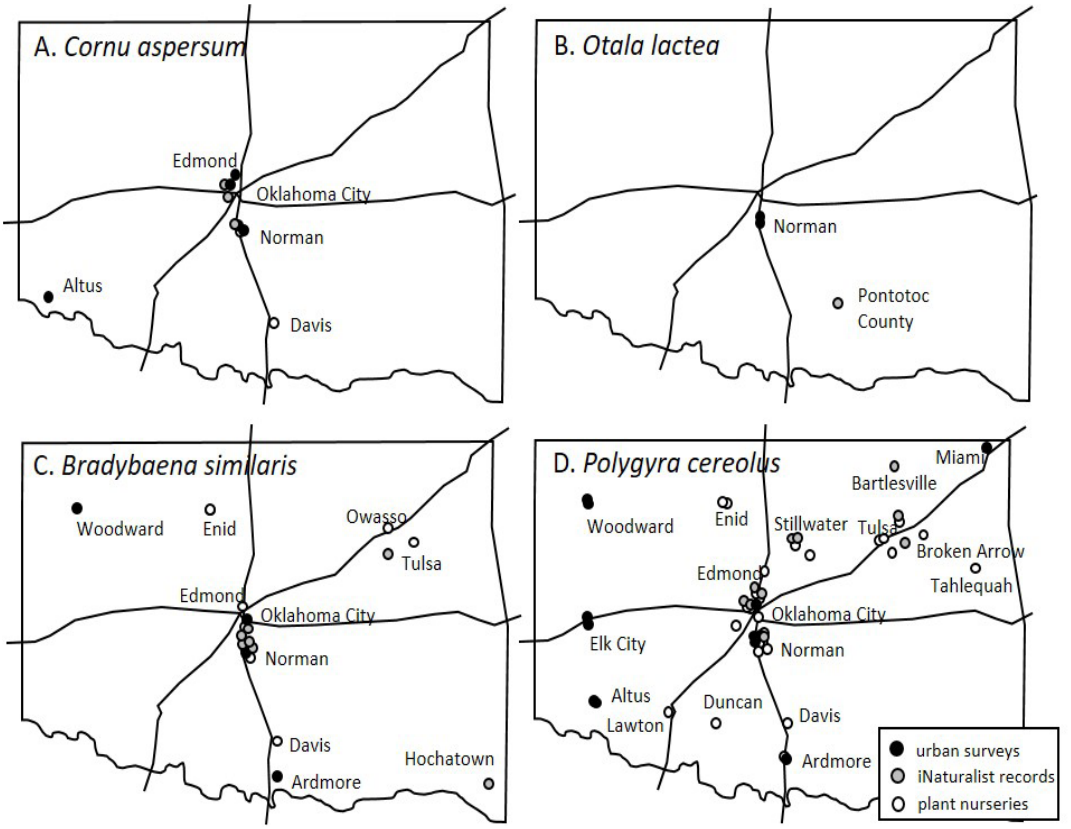

Figure 2. Distribution maps of four land snail species in Oklahoma. The panhandle of Oklahoma is not mapped; there are no records for these species from this part of the state. A = *Cornu aspersum*, B = *Otala lactea*, C = *Bradybaena similaris*, D = *Polygyra cereolus*. The shading in the circles indicates the origin of the records (urban surveys, iNaturalist records, or plant nursery surveys).

Discussion

Surveys in urban areas have been very productive in documenting the presence and distribution of non-native species and species with expanding ranges within the state. These surveys highlight the role that humans play in the distribution and establishment of land snails – both native and non-native species. This is especially evident in the distribution of *Polygyra cereolus* in Oklahoma. Although there were no records of this species in Oklahoma before 2014, *P. cereolus* was found in all 28 surveyed greenhouses (Bergey et al. 2014), indicating that the species is frequently dispersed by the commercial plant trade and its widespread presence in yards and other urban areas (Table 1) is consistent with establishment from transported plants. We know of no records for this species in natural areas away from urban areas and human habitations in the state. Like *P. cereolus*, the *Otala lactea* records in Norman are consistent with introduction through the plant trade (including by landscaping materials) – by its presence in a municipal demonstration garden and then being moved during plant transplanting to a gardener's yard (Georjana Mauldin, personal communication). However, in contrast to *P. cereolus*, the *O. lactea* record in Pontotoc County is the only record in this study that is in a non-urban area. The site is on a large cattle ranch, specifically in an area that had a history of rock mining and it is thought that the snails were transported on trucks from Texas (Cody Rhodes, personal communication), where the species is widely established (Elliott and Pierce 1992). Like some other Mediterranean snails, *O. lactea* climbs above ground to escape

hot, dry conditions (Moreno-Rueda et al. 2009). Such climbing behavior and its role in dispersal was documented when *O. lactea* snails were found attached in the wheel wells and undercarriage of a car imported to Hawaii from southern California (Hayes et al. 2023), where the species is established (La Pierre et al. 2010).

Citizen science contributions through iNaturalist provide a mechanism to greatly expand our knowledge about the distribution of land snails (Rosa et al. 2022), as demonstrated in our study by the new iNaturalist distribution records for each of the four target species. iNaturalist is especially useful in areas of the country with the limited personnel and funding for snail surveys by experts, as occurs in Oklahoma and many other states. iNaturalist can also be used as a platform for more defined citizen science surveys, such as in specific areas or for certain taxa. SLIME is a successful program in southern California (Vendetti et al. 2018) (www.inaturalist.org/projects/slime), in which snail records are verified by experts and may result in specimen collection.

Land snails provide some challenges for the iNaturalist community – especially in users taking photographs useable for snail identification (Rosa et al. 2022), and the availability and willingness of snail experts to make and confirm identifications. The small size of most species of snails makes them difficult to photograph. As a result, there is a bias toward larger species (Barbato et al. 2021), such as *C. aspersum* and *O. lactea* in our study. In order to visualize distinguishing shell characteristics, records should include at least three photographs, with the top view, the side view clearly showing aperture features such as teeth, and the bottom view – along with some sort of scale, such as a coin. The photos should have good focus, which is challenging for small shells when using cell phone cameras (Barbato et al. 2017). An additional photograph of the live snail would be a good addition and provides a record of the presence of living snails (Rosa et al. 2022) but is much less important for identification than shell features (note: most aperture characteristics are not visible when the snail is extended out of its shell). Even with perfect photographs, not all species can be determined, as some require additional features such as microscopic texture on the shell, internal shell ridges or dissection of the reproductive systems (nearly all land snails are hermaphrodites).

As with many invertebrate groups, land snails are a diverse group with few taxonomists. As a result, many identifications in iNaturalist are best guesses – some are correct, but others are either unidentifiable to species or are identified incorrectly. Other identifications are based on iNaturalist artificial intelligence, which also introduces errors (Barbato et al. 2017). Unfortunately, incorrect identifications may be corroborated and one such misidentification among the target species was elevated to 'Research grade' and appeared as a record in GBIF. It would help greatly if identifiers would include the characteristics used to make their determinations; this would not only help substantiate identifications but would be useful to others learning to identify snails.

Urban areas, especially yards, are well represented in iNaturalist snail records (Barbato et al. 2017; Rosa et al. 2022; this study) – likely because of the attention paid in yards during yard care and the convenience of searching near home. This makes iNaturalist an excellent tool for the documentation of urban snails, including non-native species, without the requirement for physical surveys and the necessity for getting permission to survey each site. Indeed, iNaturalist can be an important data source for documenting the spread of non-native species of snails (Rosa et al. 2022).

Land snail identification in Oklahoma is hampered by not having a good snail identification resource, as is available for some states have (e.g., New Mexico: Metcalf and Smartt 1997). However, when guides are available, they are often quite technical, require microscopic examination, and may not include many of the non-native species found in urban areas. Instead of comprehensive guides, there are multiple published lists of Oklahoma snails (e.g., Branson 1961; Branson 1962) and the extensive snail collection data from the OSAO Herbarium and Zoological Collection, which is in the process of being added

to OBIS (Oklahoma Biodiversity Database System) database hosted at the University of Oklahoma (https://obis.ou.edu/taxa/search/main). The key by Burch (1962) is helpful but does not include all possible species, including many of the non-native species. A pictorial flow chart key to some of the common snails (exclusive of slugs) in urban areas of Oklahoma is found in the associated OSF database (Bergey et al. 2024). This key is especially useful for people using iNaturalist, but like other resources, does not includes all species that may be encountered.

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Data availability

USAO Museum, urban survey and iNaturalist records for *Cornu aspersum*, *Otala lactea*, *Bradybaena similaris*, and *Polygyra cereolus* are found in an Open Science Framework database (Bergey et al. 2024) at www.osf.io/4pvxs.

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