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Land Snails at the Zoo: A Biodiverse Community with Conservation and Educational Potential

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Abstract: The combination of animals and plants in zoological gardens provides the opportunity for conservation within the grounds. An example is pollination gardens that support free-moving butterflies and bees. Pollination gardens and other areas with plants also support a wide range of other non-captive animals, including soil-associated invertebrates. This study targeted land snails, a species-rich group that links the brown decomposition food web and the plant-based web that is preyed upon by fireflies and birds, among others. A survey of 24 sites within the Oklahoma City Zoo and Botanical Garden revealed a diverse snail fauna of 23 species. The majority were native species but included 10 non-native species that are common regional urban species, likely introduced through the plant trade. No distributional pattern of snails was evident, probably because of the similar management scheme throughout the zoo. Snails and other observed soil-associated invertebrates (e.g., isopods, millipedes, and earthworms) support non-captive birds and other animals. Lightly managed areas with leaf litter and downed wood are especially conducive to snails and other soil-associated invertebrates and are nesting sites for bees. These communities can form conservation demonstration areas that can be the basis of educational programs, including outreach programs.

Keywords: conservation; Gastropoda; in situ conservation; urban snails; zoo conservation

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1. Introduction

Zoos exhibit a variety of animals, with a strong emphasis on mammals—which aligns with the interests of many of zoo visitors [1]. However, invertebrates have always been associated with zoos, both in exhibits and as wild (or non-captive) animals. Invertebrate exhibits commonly include butterfly houses or marine invertebrates housed in aquaria or touch tanks [2–4]. Beyond exhibits, some zoos promote invertebrate conservation through field surveys and breeding or head starting programs. For example, the Minnesota Zoo breeds sizable numbers of two species of rare prairie butterflies for release and head starts freshwater mussels [5]. Zoos also host a diverse array of non-captive invertebrates [6]. An obvious example is visitors to pollination gardens that specifically target butterflies and bees [7].

Plants, whether planted or growing fortuitously, provide many functions within zoos [8]. Plantings produce green spaces that highlight the diversity of native and non-native plants; provide a vegetated backdrop along paths and around enclosures; vegetate enclosures for decoration; or provide food, shelter, and enrichment for captive animals.

Planted areas, especially if not highly manicured, can support high invertebrate biodiversity. For example, flowering plants can support pollinators beyond designed pollination gardens [9,10]. Other insects also visit flowers—flies, beetles, wasps, ants, and predators, such as crab spiders. Although less obvious, soil-associated invertebrates, including land snails, earthworms, spiders, isopods, and millipedes, are also found in planted areas.

This research targets land snails at the Oklahoma City Zoo and Botanical Garden in the state of Oklahoma (USA) (hereafter the 'OKC Zoo'). Land snails are an ecologically significant group that feeds largely on decaying matter, converting this into snail biomass that is readily eaten by a variety of predators, such as snail-specialist beetles [11], including firefly larvae [12], small mammals [13], other snails [14], and many types of birds. In calcium-poor areas, snail shells can be important calcium sources (e.g., to help meet the high calcium demands of egg-laying birds [15]).

Snails travel slowly on their own [16,17], and areas such as roads and extensive mown lawns can be movement barriers [18,19]. In contrast, land snails are easily, though often unintentionally, transported through human activities; for example, land snails enter the United States on commodities such as flowers, plants, and tiles [20], among other modalities [21]. Within the United States, evidence indicates that the plant trade is a primary means of snail transport [22,23]. Common in plant nurseries [22–24], snails can be introduced into yards [25], green roofs [26], and other planted areas. As a consequence, urban areas contain a combination of native, human-associated, and non-native snails [27–30].

Zoos offer a unique study area for land snails because of the many assessable areas, extensive plantings, numerous potential barriers to self-directed snail movement, and cohesive management. Our goal was to survey land snails at multiple sites in the OKC Zoo in order to (1) document snail biodiversity of both native and non-native species and (2) describe distributional patterns of land snails across the OKC Zoo. We hypothesized that snail composition would differ among regions within the zoo because of stochastic introductions combined with impediments to dispersal in the form of paved areas, lawns, and animal enclosures and because of differences in 'use' (e.g., children's zoo, central concession area, and unimproved areas). We also hypothesized that snail compositions would vary among habitat types, such as isolated planted areas, leaf litter under trees, and relatively open areas with few shelters for snails—with different compositions and reduced species richness in areas with few shelters.

2. Methods

2.1. Survey Methods

The Oklahoma City Zoo and Botanical Garden first opened in 1902 and comprises 53 ha (130 acres). The OKC Zoo is located in the northeast part of Oklahoma City and is surrounded by a reservoir, a museum, a golf course, a small city park, and roads.

We surveyed snails in vegetated areas in 23 sites near pathways, around buildings, in isolated planted areas, and in fringe areas (near the lake and along perimeter fences) within the visitor-accessible areas of the OKC Zoo (Figures 1 and 2A–D). The 24th site was the OKC greenhouses, which are not publically assessable. A large area in the central part of the OKC Zoo was under renovation and not accessible, but the ongoing ground disturbance greatly reduced the chance of finding snail populations (Figure 2E). In addition, the aquarium building area, including the pollination garden, was assessable but not maintained in preparation for renovation. The shoreline of the reservoir was largely inaccessible. Sampled habitats included a bamboo grove with thick litter; slopes with trees, exposed bedrock, and some leaf litter or sometimes undergrowth; a wooded area along the lakeshore; and large planted beds. Full details (latitude and longitude, sampling date, search time, and a short habitat description) are in an online database at osf.io/g89cp, accessed on 16 November 2023.

Sampling consisted of visual searches by both authors with occasional assistance from OKC Zoo personnel or zoo visitors (generally children). Although live snails are generally cryptic, snails can be inventoried by the shells left after death; hence, both live snails and shells were inventoried. We searched under leaf litter and ground cover, under and between landscape stones, and along the edges of sidewalks and walls. Most of the stones were the local sandstone, the most common ground cover was periwinkle (*Vinca minor*), and leaf litter was dominated by little-decayed oak leaves. Downed wood and debris piles were largely absent. The survey times averaged 38.8 (SE = 3.9) min, ranging from 15 min for a small isolated area between two sidewalks to 100 min for the two greenhouses (including outside the pots of plants). Snails were identified based on their shell morphological characteristics. The majority of live snails were counted and released at their original location, while empty shells were retained. Both the shells and some live micro land snails were collected and subsequently identified in the laboratory using a microscope at a magnification of 10× or higher.

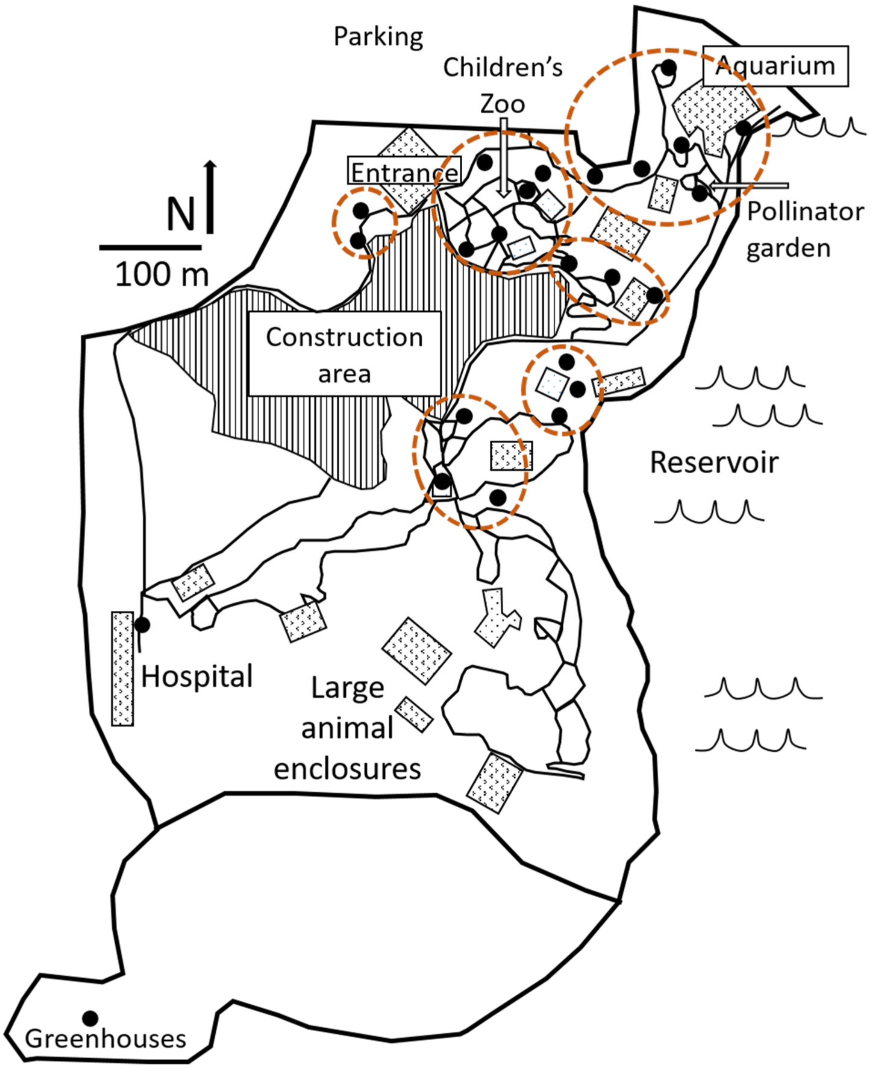

Figure 1. Map of the Oklahoma City Zoo and Botanic Gardens. Major walkways in the public area are shown. Black dots are the approximate location of the 24 land snail survey sites (sites are larger than the dots). Brown dashed circles show sites in different regions of the zoo.

2.2. Data Analysis

Snail taxa were classified as native if they were known to occur in or near Central Oklahoma in Hubricht [31] and non-native if they were beyond the known distribution but native to the United States (extralimital) or were not native to the US (e.g., native to Europe). This classification for the slug *Deroceras laeve* was problematic. Although once considered native to Oklahoma [32], the species is well-traveled and invasive [33,34], constituting 8.1% of non-marine gastropods intercepted by the US Department of Agriculture—the most of any snail [20]. Genetically indistinguishable from the same species in Europe, *D. laeve* is generally considered non-native in North America (D. Robinson, personal comm.).

Succinid snails cannot be identified from their shells, so they were not classified as native or non-native.

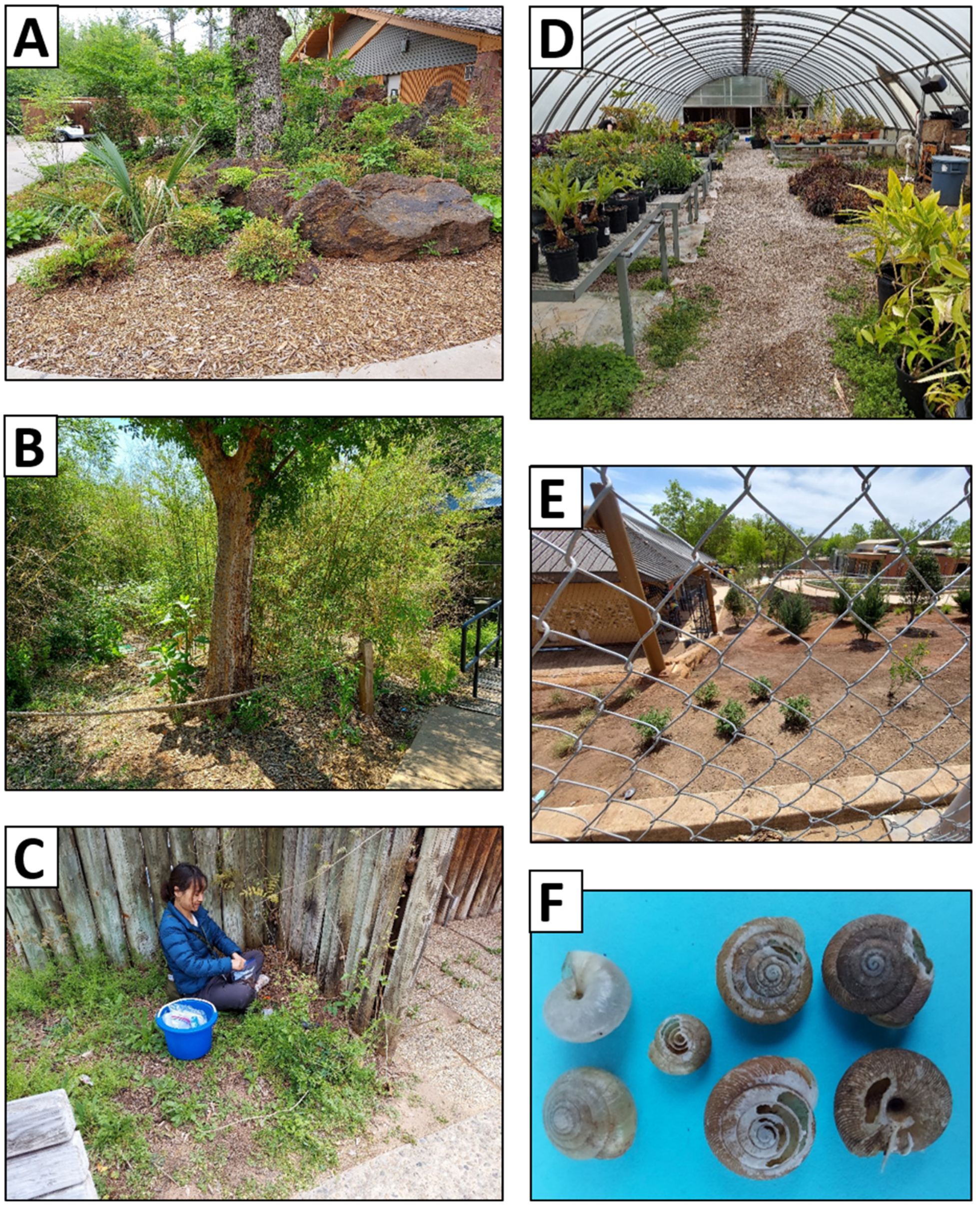

Figure 2. Examples of sites at the OKC Zoo. (**A**) = isolated planting with large trees, shrubs, and emergent boulders (site 17); (**B**) = edge of bamboo grove with leaf litter (site 21), (**C**) = back side of Canopy Café, where microsnail shells accumulated near the wooden fence in an open site (site 9); (**D**) = a greenhouse (site 24); (**E**) = construction area showing disturbance of soil surface and new plantings; and (**F**) = *Ventridens demissus* on the left with rasped shells (most are *Triodopsis hopetonensis*).

A species accumulation plot was used to assess the adequacy of the survey in describing the biodiversity of land snails by plotting the cumulative number of species versus the cumulative number of sites. Using 999 permutations, S (obs) illustrates the actual data, whereas Chao1 provides the trend toward the likely number of species present. Data were analyzed using Primer 6 Version 6.1.12 (Primer-E).

Non-metric multidimensional scaling (NMDS) was used to graphically compare the similarity in land snail composition among the 24 survey sites. Snail species and abundance data for each site were transformed to presence–absence data, Curtis–Bray was used as the similarity index, and 25 restarts were used. In the resulting two-dimensional graph, small circles represented the snail composition of each site, and the relative closeness of the circles indicated the similarity in the snail compositions among the sites. A cluster analysis on the same presence–absence dataset was used to group sites in the NMDS plot based on the similarity of their snail faunas. These analyses used Primer 6 (Primer-E).

Analysis of Similarities (ANOSIM) was used to test whether land snail composition, based on presence data, differed among regions and habitats across the OKC Zoo and used Primer 6. Sites were divided into six regional groups based on proximity (excluding two outlier sites that were distant from other sites; Figure 1) and included groupings such as narrow plantings along paths in the Children's Zoo, wooded and primarily unimproved areas near the aquarium building, and next to a café and along paths near the large animal enclosures. In a second ANOSIM analysis, sites were divided into four broad habitat types: leaf litter below trees or below bamboo stands; isolated or demarcated planted beds; shrubs or narrow strips of woody vegetation; and 'open' areas, usually bare soil or areas without shade (including the pollination garden). Examples of habitat types are shown in Figure 2A–C. ANOSIM is a non-parametric analysis and was based on the same Curtis–Bray similarity matrix as the NMDS analysis. The option of 999 permutations was selected.

In addition to species composition, species richness and abundance were separately analyzed for regional and habitat differences using (2-way) General Linear Models without interaction terms because not all combinations of region and habitat type were present. These analyses used SigmaPlot for Windows Version 14.5.

The geographical distribution of species richness was graphically presented using latitude–longitude site coordinates (location data are available online at osf.io/g89cp, accessed on 16 November 2023) as the axes and bubble plots of each site, with bubble size relative to species richness. This graph was made using SigmaPlot 14.5 (Systat Software).

3. Results

A total of 2319 snails were identified, including 396 live snails that were released. The 23 taxa comprised 12 native species, 10 non-native species, and the unclassified succinid (Table 1). The non-native species included two slug species (*Deroceras laeve* and *Ambigolimax valentianus*) found only at the greenhouses site and nearly all the larger taxa; only *Opeas pyrgula* and *Vallonia pulchella* were non-native microsnails. In contrast, the native taxa were nearly all microsnails, with the exception of the largest species collected, the polygyrid *Mesodon thryoides*.

The number of collected species (=richness) varied among sites, ranging from 2 to 12 taxa and averaged 7.7 (SE = 0.6) species per site. The species accumulation curves indicated that the survey was adequate for describing the full species diversity, with both the curves of S_{obs} and Chao1 leveling out and Chao1 estimating 23.5 species (SD = 1.3) (Figure 3).

A single species, the non-native *Ventridens demissus*, was found at all 24 sites, and this species accounted for 42% of all surveyed snails (Table 1). Other common non-native species were *Opeas pyrgula* (21 sites) and *Triodopsis hopetonensis* (20 sites). The most common native species was *Gastrocopta contracta* (20 sites), and three other native species were found at 15 to 17 sites (Table 1).

Most sites had a similar snail composition (Figure 4), with 17 sites forming a cluster that was consistent with the 60% similarity level based on species presence/absence. Three single-site outliers (sites 2, 6, and 10) were the sites with only two species—*V. demissus* and a second species that differed among the three sites. The other distant outlier was the greenhouse site (24), the only site with the two slug species. Sites 17 and 20 were the only sites with *Xylotrema fosteri* and also shared several relatively large species (e.g., *Anguispira alternata*, *M. thryoides*, and *T. hopetonensis*). These sites were two large isolated planted areas with trees, shrubs, and emergent large boulders (site 17; Figure 2A) and the slope between the aquarium building and the shoreline, where several of the large (live) snails were on a stranded, partly decomposed log on the gravel road near the shoreline (site 20). Snail composition was not statistically different among the six surveyed regions within the zoo (ANOSIM: Global R = −0.093, p = 0.826), nor did snail composition differ among the four habitat types (Global R = −0.02, p = 0.517).

Table 1. List of snail taxa found during the 2023 survey at the Oklahoma City Zoo and Botanical Gardens. Twenty-four sites were sampled, and numbers of sites and the total number of snails (shells plus live snails) are given for each species. For non-native species, 'Ex' = extralimital and 'I' = originating from outside the USA.

Family	Species	Native?	No. of Sites	No. of Snails
Achatinidae	*Opeas pyrgula* Schmacker & Boettger, 1891	no (In)	21	280
Agriolimacidae	*Deroceras laeve* (Müller, 1774)	(no)(In?)	1	26
Camaenidae	*Bradybaena similaris* (Férussac, 1822)	no (In)	3	29
Discidae	*Anguispira alternata* (Say, 1817)	no (Ex)	5	51
Gastrocoptidae	*Gastrocopta armifera* (Say, 1821)	yes	2	4
Gastrocoptidae	*Gastrocopta contracta* (Say, 1822)	yes	20	163
Gastrocoptidae	*Gastrocopta pellucida* (Pfeiffer, 1841)	yes	1	1
Gastrocoptidae	*Gastrocopta procera* (Gould, 1840)	yes	4	7
Gastrocoptidae	*Gastrocopta tappaniana* (Adams, 1841)	yes	1	2
Gastrodontidae	*Glyphyalinia indentata* (Say, 1822)	yes	6	13
Gastrodontidae	*Ventridens demissus* (Binney, 1843)	no (Ex)	24	970
Gastrodontidae	*Zonitoides arboreus* (Say, 1817)	yes	17	173
Helicodiscidae	*Helicodiscus parallelus* (Say, 1821)	yes	3	10
Limacidae	*Ambigolimax valentianus* (Férussac, 1821)	no (In)	1	7
Polygyridae	*Mesodon thyroides* (Say, 1819)	yes	5	9
Polygyridae	*Polygyra cereolus* (Megerle von Muhlfeld, 1816)	no (Ex)	4	35
Polygyridae	*Triodopsis hopetonensis* (Shuttleworth, 1852)	no (Ex)	20	273
Polygyridae	*Xolotrema fosteri* (Baker, 1932)	no (Ex)	2	5
Pristilomatidae	*Hawaiia minuscula* (Binney, 1841)	yes	16	135
Pupillidae	*Pupoides nitidulus* (Pfeiffer, 1839)	yes	8	19
Stropilopsidae	*Strobilops texasianus* (Pilsbry & Ferriss, 1906)	yes	15	93
Succineidae	unidentified	?	2	7
Valloniidae	*Vallonia pulchella* (Müller, 1774)	no (Ex)	3	7

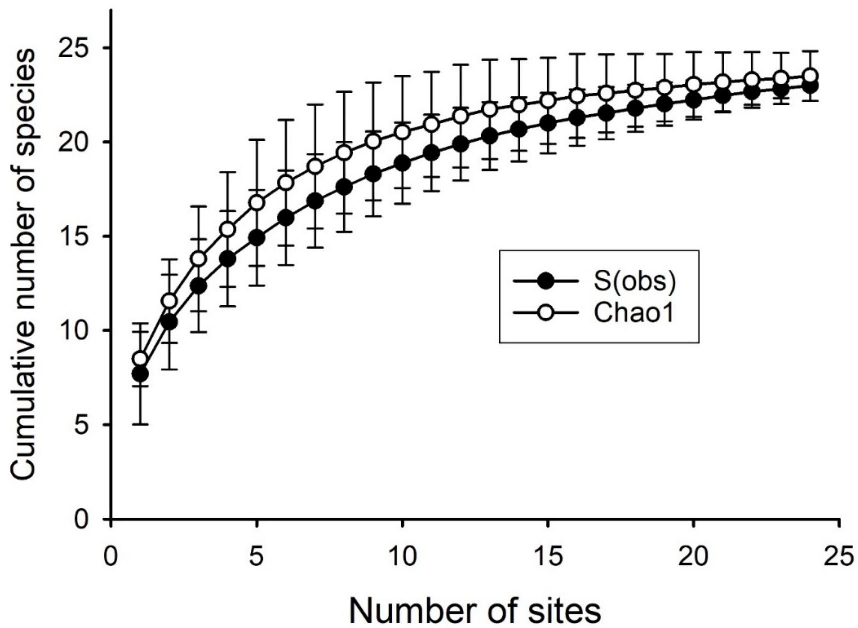

Figure 3. Species accumulation curves based on the actual data (S(obs)) and the estimated number of species (Chao1). Error bars show standard deviation.

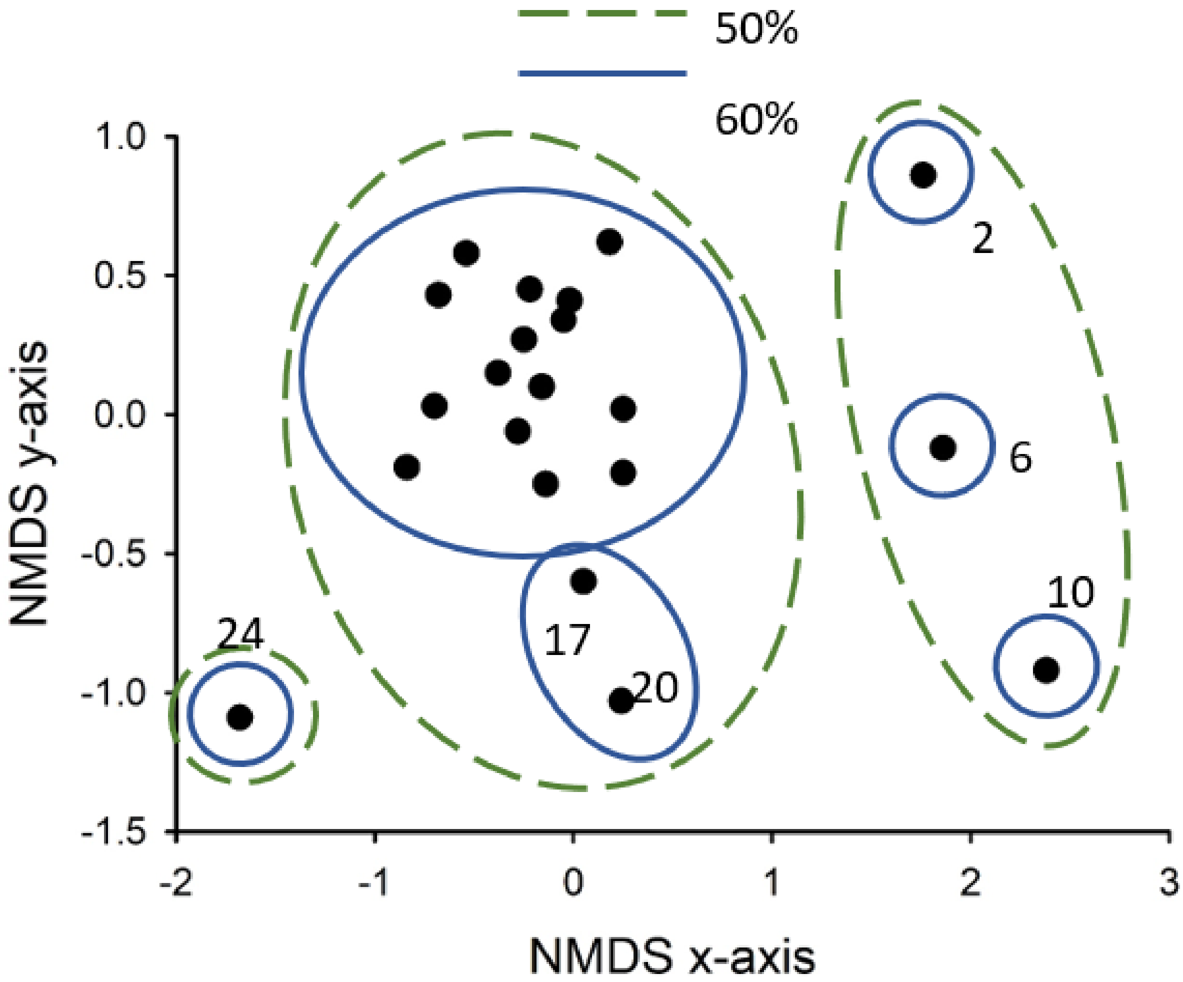

Figure 4. Non-metric multidimensional scaling plot of the land snail composition from 24 survey sites at the zoo. Dots represent the snail composition of each site and closer dots indicate more similar snail compositions. The NMDS stress value is 0.12, which indicates a good depiction. Cluster analysis results are overlain on the NMDS plot and show the 50% (dashed green line) and 60% (solid blue line) similarity levels. Site numbers are given for sites outside the large cluster.

The distribution of snail taxonomic richness across the OKC Zoo did not show an obvious geographical pattern (Figure 5). There was no difference in snail richness when statistically analyzed with respect to either region within the zoo (GLM: $F_{6,14} = 1.131$, $p = 0.394$) or habitat type ($F_{3,14} = 0.136$, $p = 0.937$). Similarly, there was no difference in snail abundance (the number of inventoried live snails and shells) among regions within the zoo (GLM: $F_{6,14} = 1.078$, $p = 0.421$) or among habitat types ($F_{3,14} = 0.334$, $p = 0.801$).

Sites with only two species were either small, isolated areas (narrow edging bamboo next to a sidewalk, a raised area with periwinkle over thick oak leaves) or an area with little habitat (a grassy slope with embedded sandstone rocks). Areas with high richness included a set of three isolated beds that differed in plantings (site 8), a set of nearby plant beds separated by sidewalks in the Children's Zoo (site 11), a habitat-poor area next to a low-laying building (the Canopy Cafe) where micro snail shells accumulated (Figure 2C), and an ecotone between a thick bamboo stand and an area with trees (site 21; Figure 2B). Some high-richness sites were on slopes where shells were often more apparent after being either exposed or moved and deposited by runoff from rain. In general, areas within sites with mulch had few or no snails, with the exceptions of older decomposing mulch and some areas of thinner mulch under plants.

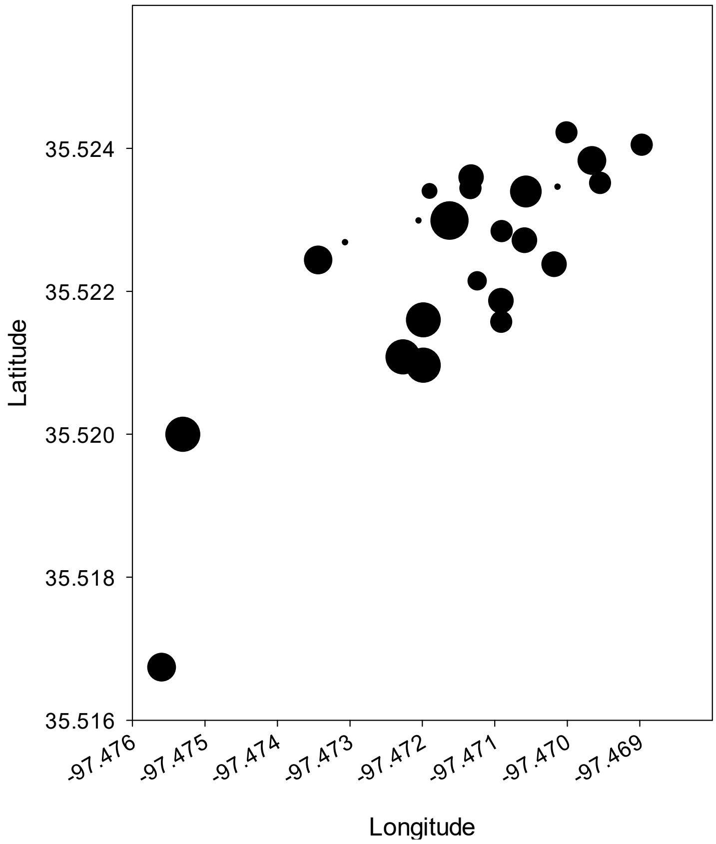

Figure 5. Map of sites (similar to Figure 1), with the size of dots indicating the relative species richness of land snails in each sampling site (e.g., larger dots have greater species richness). Dot locations correspond to sites on the map (Figure 1).

4. Discussion

Land snail diversity at the OKC Zoo was high (with 23 species) and was generally characterized by a combination of small native species and larger, primarily non-native species. The non-native species included both extralimital species, such as *Polygyra cereolus* from Florida, and species originating from other countries, such as *Bradybaena similaris*, originally from Asia. Nearly all the non-native snails at the OKC Zoo have been found in Oklahoma plant nurseries [22], indicating that the plant trade may be the main source of the non-native species. For example, new plantings in the construction area within the Zoo (Figures 1 and 2E) may introduce snails that occur in the pots with the purchased plants. However, snails may also be moved around in other ways, including on vehicles, in produce, and in landscape materials [21]. Other zoos likely also have diverse snail populations. For example, an extensive survey of free-living organisms in the Basel Zoo found 3110 species, of which 37 species were snails, including both aquatic and terrestrial taxa [6].

The average of 7.7 species per sampled site is slightly lower than the 8.9 average number of snail species per yard in Central Oklahoma [25], but the area surveyed per site at the OKC Zoo was much smaller than the yards. Nearly all OKC Zoo sites had both native and non-native species, with only a single site having two non-native species and no native species. This mix of native and non-native species is typical of regional urban yards [25,30,35], whereas parks and natural areas with fewer plantings may have relatively fewer non-native species of snails [27].

There is very little information on non-captive land snails associated with zoos in the United States; indeed, the only reference we found was a statement that *Ventridens demissus* was a common snail in the Atlanta Zoo, where it was also the only species found on the Zoo's green roofs [26]. This species was found at all sites in our survey and is common in both regional plant nurseries [22] and yards [25,35]. An interesting observation associated with this species is the rasping of empty shells, presumably as a source of calcium. The results of this behavior were observed at the OKC Zoo, where conspecific empty shells and shells of *T. hopetonensis* were sometimes rasped (Figure 2F). This ability to obtain calcium may partially explain the success of *V. demissus* in introduced sites where calcium may be a limiting resource for snails.

Slugs, both of which are non-native species, were only found in the greenhouses. Their lack of a noticeable shell means a lack of evidence after death, making finding live slugs a requirement for noting their presence. Slugs can be quite cryptic, especially during dry weather, such as the spring weather experienced during the survey. It is likely that slugs occur elsewhere in the OKC Zoo and may be visible after rains. One or both of the slug species are commonly found in plant nurseries [23,24,36]. *Deroceras laeve* occurred in 19 of 28 surveyed plant nurseries in Oklahoma, and *A. valentianus* was found in 14 of these nurseries [22].

Although non-native snails are frequently found in urban areas [30,37], the ecological consequences of these snails have been little studied [38], as most studies are faunal surveys (e.g., this study) or distributional studies of selected species [34,38–40]. Often, such snails do not expand beyond human-impacted areas, with exceptions including the slug genus *Deroceras* [34], which was found in the zoo greenhouses and is widely distributed in Oklahoma [32]. Under some conditions, non-native snails can be agricultural or garden pests [41,42]. In Oklahoma, the combination of cold winter weather and hot, dry summers may suppress the high population densities of non-natives. Non-native snails generally have no known impacts on native species [38], with the notable exception of introduced predatory snails—especially the rosy wolf snail, which is a main contributor to the loss of several tree snail species on Pacific islands [43].

We anticipated regional differences in snail community composition across the OKC Zoo but found no evidence of differences despite the multitude of movement barriers [18,19], including pathways and roads, enclosures with trampling and lawn-like vegetation, and buildings. We suspect that the movement of plants, soil, and landscape materials within the zoo contributes to this lack of distributional patterns. For example, during our survey, zoo gardeners were beginning to transplant plants from the area around the soon-to-be renovated aquarium building to other locations around the zoo. Most non-native snail species are synanthropes (associated with humans) [34] with wide distributions that indicate tolerance to environmental conditions, which may explain the lack of difference in snail composition among habitats (and different environmental conditions) in the OKC Zoo.

We did find variations in snail composition among individual sites. The three sites with only two species each were not contiguous, nor were the sites with primarily larger snails. Although we anticipated that sites near the lakeshore might be more speciose because the sites might be wetter, access to the shoreline was limited, so we were unable to test this possibility. One near-lake site had built-up berms, and most snails were shells exposed by runoff on the slopes (site 22), and the other site (20) was primarily lawn with shells exposed by in gopher mounds or under a washed-up log on the gravel roadway near the water; both sites had seven snail species. A third site (site 16) was primarily a low-laying, relatively wet runoff area next to the Devon pavilion, with clumped grass, where most of the six species of snails were in the uphill planted area with emergent boulders. At this site, like many others, the snails were concentrated next to boulders and under plants rather than under the thick wood mulch, which typically has few snails [25].

5. Conclusions and Recommendations

We found a diverse land snail fauna of 23 species, including native and non-native taxa. Non-native land snails are common in regional urban habitats, and the non-native species found at the OKC Zoo are typical of the region. Although we expected to find distributional patterns and differences among habitats in the snail communities, the lack of such patterns indicates a high level of human-assisted movement of snails within the zoo. Snails may be introduced or moved in association with the movement of plants, soil, and landscape materials.

Although we surveyed snails, we observed other invertebrates—isopods (pillbugs) were especially common, and we frequently saw millipedes and earthworms, spiders, beetles, and other taxa. Together, these invertebrates help support other wildlife in the OKC Zoo, such as birds. The diversity of these invertebrates at the OKC Zoo is unknown, and additional surveys are recommended. Mechanisms to accomplish such surveys are through a longer-term concerted effort, as was undertaken at the Basel Zoo [6], or through a single day or short-term BioBlitz [44,45]. Setting up an iNaturalist OKC Zoo Biodiversity project and encouraging the public to submit photographs and details of non-captive animals, and possibly plants, would increase biodiversity knowledge and could be a fruitful form of outreach [46].

Ground maintenance at the OKC Zoo and other zoos is a trade-off between keeping the grounds tidy (especially near and on the walkways), having planted beds, and providing a naturalistic botanic garden. Naturalized areas can serve as nature preserves, especially as the zoo grounds are often more nature-friendly than the surrounding land uses [47], as is the case at the OKC Zoo. Leaving leaf litter under shrubs, among plantings, and in naturalized areas provides shelter for many invertebrates and is a common practice at the OKC Zoo. Less-managed areas that support snails can also be important nesting habitats for ground-dwelling bees, and such habitats are synergistic with pollination gardens in supporting the life cycle of these pollinators. The addition of downed wood, in the form of single logs, log piles, stumps, and weathered tree roots, would add habitat for multiple species, including fungi and many invertebrate taxa [48–51], such as land snails [52–54], as well as adding visual interest.

Having a diverse soil-associated fauna provides a food source for birds, promotes decomposition and nutrient recycling, and provides a new educational opportunity for the public. Public outreach could include an easy-to-incorporate home conservation demonstration area, illustrating the importance of retaining leaf litter under shrubs, providing downed wood (such as small wood piles), and providing simple bee habitats for cavity-nesting species (holes drilled into wood). Such a demonstration area could form the basis of a program for children on hidden biodiversity by using, for example, a scavenger hunt list with items such as 'How many different animals can you find under a log?' or 'Using a blade of grass to test a spider web, are the rays or the circular threads sticky?'. A pictorial key could be used to help identify soil-associated invertebrates (see osf.io/g89cp for a scavenger hunt list and downloadable key). An increased appreciation of local invertebrates would complement the biodiversity of captive animals at the zoo and could encourage local conservation actions.

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Conflicts of Interest: The authors declare no conflict of interest.

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