SMALL MAMMAL COMMUNITIES AND URBAN LAND COVER ASSOCIATIONS

IN SAN MARCOS, HAYS COUNTY, TEXAS

by

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DEDICATION

This work is dedicated to my family and friends that pushed me to achieve my goals, especially those who didn't get to see this finished product. Chastity McNiel and Paul Taormina, you are forever in my heart, and I know you would have been proud of me.

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I would first like to thank my advisor, Dr. Randy Simpson. Without his help and expertise, I would not have been able to complete this work, let alone have this project to call my own. The rest of my committee, Drs. Green and Castro, was instrumental in introducing me to the world of small mammals and how important they can be ecologically. Dr. Weckerly was a great help in finalizing my statistical methods. I would also like to thank Bert Stratemann with the City of San Marcos Community Services Department for helping me get this project off the ground, granting me access to the cemetery and other sites owned by the city.

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ABSTRACT

The importance of understanding small mammal diversity in urban areas is multifaceted. Small mammals affect predator population dynamics, habitat structure, and the spread of zoonotic diseases. Small mammal populations can help evaluate habitat fragmentation and quality and can potentially delineate habitat management strategies. My objectives were to determine the composition and diversity of small-mammal communities within the city of San Marcos, and to evaluate relationships between composition and diversity by meteorological seasons and land cover type. I surveyed 20 sites within urban San Marcos between August 2013 and May 2014 for a total of 11,490 trap nights over 4 seasons. I captured 280 small mammals among 12 species; the hispid cotton rat (*Sigmodon hispidus*), house mouse (*Mus musculus*), and northern pygmy mouse (*Baiomys taylori*) were captured more than expected overall ($P \leq 0.001$). The hispid cotton rat was captured more than expected in all seasons, and in all land cover types ($P = 0.007$ for spring, $P \leq 0.001$) except urban developed, where the house mouse was captured more than expected ($P \leq 0.001$). The northern pygmy mouse was also captured more than expected in the fall ($P = 0.004$). An ANOVA and Tukey's post hoc analysis show differences in captures between grassland and woodland sites ($P \leq 0.001$) and between grassland and urban sites ($P = 0.011$). Grassland sites showed the highest trap success in both the fall ($P \leq 0.001$) and winter ($P = 0.001$) seasons. Species richness was higher in urban sites, in the summer season, and at site 10. Site 10, the spring season, and urban sites had higher Shannon-Weiner indices of diversity. An ANOVA and

Tukey's post hoc analysis showed a difference in species diversity between grassland and woodland sites ($P = 0.004$). Analyses for urban sites may have been overinflated by the captures of 2 rock squirrels (*Spermophilus variegatus*) and a Virginia opossum (*Didelphis virginiana*), which are not typical for the size of Sherman trap used. The variety of species captured shows that even small pockets of natural areas and manicured parks in urban areas can support several small-mammal species. More studies should be done to better understand predator/prey population dynamics in urban San Marcos. The presence of species that are reservoirs for zoonotic diseases suggest that these populations should be monitored for disease prevalence, especially due to their proximity to human recreation areas and residences. The presence of non-native house mice and roof rats (*Rattus rattus*) in non-urban sites suggest poorer habitat quality due to habitat fragmentation and degradation. Species such as the hispid cotton rat can also be used to evaluate habitat quality by testing for environmental toxins. Sites that support native species should be protected from habitat degradation, and sites that sustain populations of non-native species should be targeted for the removal of those individuals. Now that areas with high numbers and diversity of small mammals have been identified in San Marcos, these sites can provide opportunities for future surveys and projects, and can be used to further assess and monitor the habitat quality of this urban area.

1. INTRODUCTION

The importance of understanding small-mammal diversity in urban areas is multifaceted. Small mammals are a prey base for many urban predators, including skunks (Mephitidae), grey foxes (*Urocyon cinereoargenteus*), weasels (*Mustela* spp.), coyotes (*Canis latrans*), and domestic cats (*Felis catus*; Baker et al. 2003, Hall 2005, Hervias et al. 2014). Domestic and free-ranging cats preferentially prey on mammals over other taxa, and are responsible for mortality of about 6.9-20.7 billion mammals in the USA (Loss et al. 2013). When urbanization decreases native rodent prey, some predators may shift their diets to a more opportunistic strategy to include other mammals such as rabbits (Leporidae; Schmidt and Ostfeld 2008, Pavez et al. 2010). Birds of prey and mesocarnivore populations mirror population booms in rodents, and decreases in rodent distribution and abundance can negatively affect the population dynamics of these predators (Byrom et al. 2014). The presence of predators is crucial for controlling rodent densities, which can have cascading effects on several ecological processes (Korpimäki et al. 2005).

Alteration of habitat structure such as changes in soil aeration, nutrient availability, and vegetative composition can have profound effects on habitat quality, herbivore and carnivore population dynamics, and infectious disease prevalence (Moloney et al. 1992, Jones et al. 1994, Lehmer et al. 2012). Small mammals are reservoirs for infectious zoonotic diseases, such as Lyme disease and Hantavirus, and transmission events are facilitated by habitat fragmentation and urbanization (Dizney et al. 2010, Friggens and Beier 2010, Peavey et al. 1997). In urban areas, rodents are in closer contact with humans, therefore increasing the risk of disease transmission (Vinetz et al. 1996, Adler et al. 2002). When fragmentation excludes predators or competitors, populations of rodents such as white-footed mice (*Peromyscus leucopus*) and deer mice (*P. maniculatus*) may grow abnormally large. Distributions of coyotes and foxes (Canidae) have been shown to predict the distribution of Lyme disease more accurately than deer distribution and abundance (Mahan and O'Connell 2005, Levi et al. 2012).

Because of our wealth of knowledge about life histories of many small mammal species and their ease of capture and study, small-mammal populations can be a useful resource for evaluating levels of fragmentation, habitat quality in potentially degraded areas, and other landscape ecology questions, with the potential for broader applications to habitat management and restoration (Barrett and Peles 1999). The response of some species to specific modification (e.g. downed wood volume) may indicate important habitat requirements for a broader range of rodents (Pearce and Venier 2005). Species that are normally found in human-modified environments can be used as indicators of poor or degraded habitat, while other species with more restricted distributions can be used to delineate habitat that should be managed for only passive recreation (Bonvicino et al. 2002, Mahan and O'Connell 2005). Small mammals can serve as indicators of pollutant levels in urban habitats, which could be used as a proxy for determining habitat quality for both wildlife and humans (Ieradi et al. 1996, Ceruti et al. 2002, Marcheselli et al. 2010).

Recreation and human disturbance usually negatively affect distribution and abundance of native rodents, but have no change in non-native abundance (Chernousova 2001). Habitat alterations such as roads might have a positive effect on native rodent abundance, possibly by negatively affecting predator movement and abundance

(Rytwinski and Fahrig 2007). Even when habitat alteration has no direct effect on small mammal abundance, indirect effects (e.g. increased invasion potential of ants, decrease in predator abundance) can create varying changes in small-mammal population dynamics (Laakkonen et al. 2001, Ficetola et al. 2007).

Because small mammals can have various roles in their environment (prey base, disease hosts, indicators of habitat quality, etc.), it is important to establish their spatial and abundance distribution within the urban matrix. Studies on fluctuations in predator and herbivore population dynamics can be aided by increased knowledge of small-mammal populations. Information about abundances of rodent species that are reservoirs of zoonotic diseases can influence studies on potential spread of human infection. This knowledge can also help urban planners determine which areas should be maintained as or restored to a more natural state, and which areas are experiencing detrimental effects associated with pollution and habitat degradation. My objectives were to a) determine the composition and diversity of small-mammal communities within the city of San Marcos, b) evaluate relationships between small-mammal communities and habitat (land cover), and c) evaluate interactions between rodent composition and diversity of small-mammal communities by meteorological seasons and land cover.

2. METHODS AND MATERIALS

Study Area

The city of San Marcos is situated on the eastern boundary of the Edwards Plateau in central Texas. Average annual precipitation was about 30 inches and it had a subtropical subhumid climate, with average summer highs of 96°F and winter lows of 39°F (National Weather Service, 2014). San Marcos has twice been named the fastest-growing city in the United States by the US Census Bureau, with an estimated population of over 54,000 (U.S. Census Bureau, 2014). San Marcos includes both the Balcones Canyonland area of the Edwards Plateau ecoregion to the west and the Northern Blackland Prairies ecoregion to the east.

The urban area of San Marcos includes several neighborhoods of varying age, Texas State University’s main campus, a growing business district, and approximately 246 acres of designated parks and 856 acres of natural areas (City of San Marcos, 2014). This presents a unique opportunity to study urban-fragmented populations of small mammals located in both highly disturbed areas (directly next to roads and buildings) and in environments ranging from manicured parks to greenspaces with less human disturbance.

While some areas near San Marcos, such as Freeman Ranch and Bat Conservation International Bracken Preserve (Baccus et al. 2000; L. Cody et al., Texas State University, unpublished report), have been surveyed for small mammals, there have been no published small-mammal surveys of the city of San Marcos and its parks and greenspace system. My study will help define this area’s small-mammal community structure and facilitate future study of the broader ecosystem.

Site Selection

Using ArcGIS 10.0, I modified a map of San Marcos parks and greenspaces (http://www.ci.san-marcos.tx.us/index.aspx?page=281) to include the Texas State University campus, and then randomly selected 25 sites from this map. I maintained a minimum distance of 250 m between each site to sample distinct populations. To obtain an adequate number of trap-nights for each site, I did not include smaller parks for surveying. I also did not include parks that were subject to heavy recreational use (e.g. baseball fields, river entry points) to avoid vandalism of traps. Using these parameters, I was left with 17 sites within San Marcos parks and greenspaces and 3 sites on Texas State University property (Figure 1).

I classified these sites according to their land cover and overall vegetative characteristics using the Texas Ecological Mapping Systems produced by the Texas Parks and Wildlife Department (www.tpwd.state.tx.us/gis/data/downloads#EMS-T). I combined land cover into the following major categories based on existing landscape classifications: urban development, forest/woodland, grassland, and shrubland/herbaceous vegetation (henceforth: urban, woodland, grassland, and shrubland). I did this to determine if differences in small-mammal estimates vary according to land cover, which might affect the diversity, richness, and abundance of small-mammal species (Dickman and Doncaster 1989, Mahan and O'Connell 2005, Ekernas and Mertes 2006, Garden et al. 2007, Croci et al. 2008). Changes in vegetative species in urban areas are less predictive of changes in small-mammal community structure than changes in overall habitat type (Laakkonen et al. 2001, Croci et al. 2008), so I determined land cover to be adequate for site classification.

Study Design

I surveyed the small mammal communities at my sites over four meteorological seasons (summer [Aug – Oct 2013], fall [Oct – Dec 2013], winter [Feb – Mar 2014], and spring [Apr – May 2014]) by trapping with 2 x 2.5 x 6.5 inch Sherman folding live traps (H.B. Sherman Traps, Inc., Tallahassee, Florida) baited with a rolled oats, bird seed, peanut butter, and vanilla mixture. I set approximately 50 traps from sunset to sunrise for three nights per site per season, for approximately 150 trap-nights per site per season, placing them in a manner appropriate for the features and size of the site (e.g. curvilinear transect, grid transects, in proximity to burrows and runways, etc.). I did not leave traps unattended during daytime hours to minimize the risk of overheating trapped individuals and to minimize vandalism. When temperatures were expected to fall below 4°C, I placed cotton inside the trap for bedding material.

I identified all animals captured to species and released them at site of capture (Institutional Animal Care and Use Committee protocol #0416-0520-09). I disinfected traps using 95% ethanol after removal from survey site and before resetting. I wore latex gloves and particle masks to ensure safety and to minimize exposure to pathogens.

Statistical Analyses

I calculated species composition, trap success, richness, and diversity based on site, land cover, season, and overall data. I used the Shannon-Wiener index for species diversity. I used chi-square goodness of fit tests to determine if species composition varied based on land cover, season, and overall data. I conducted analyses of variance (ANOVA) to determine if differences occurred in total captures or species diversity due to land cover and season.

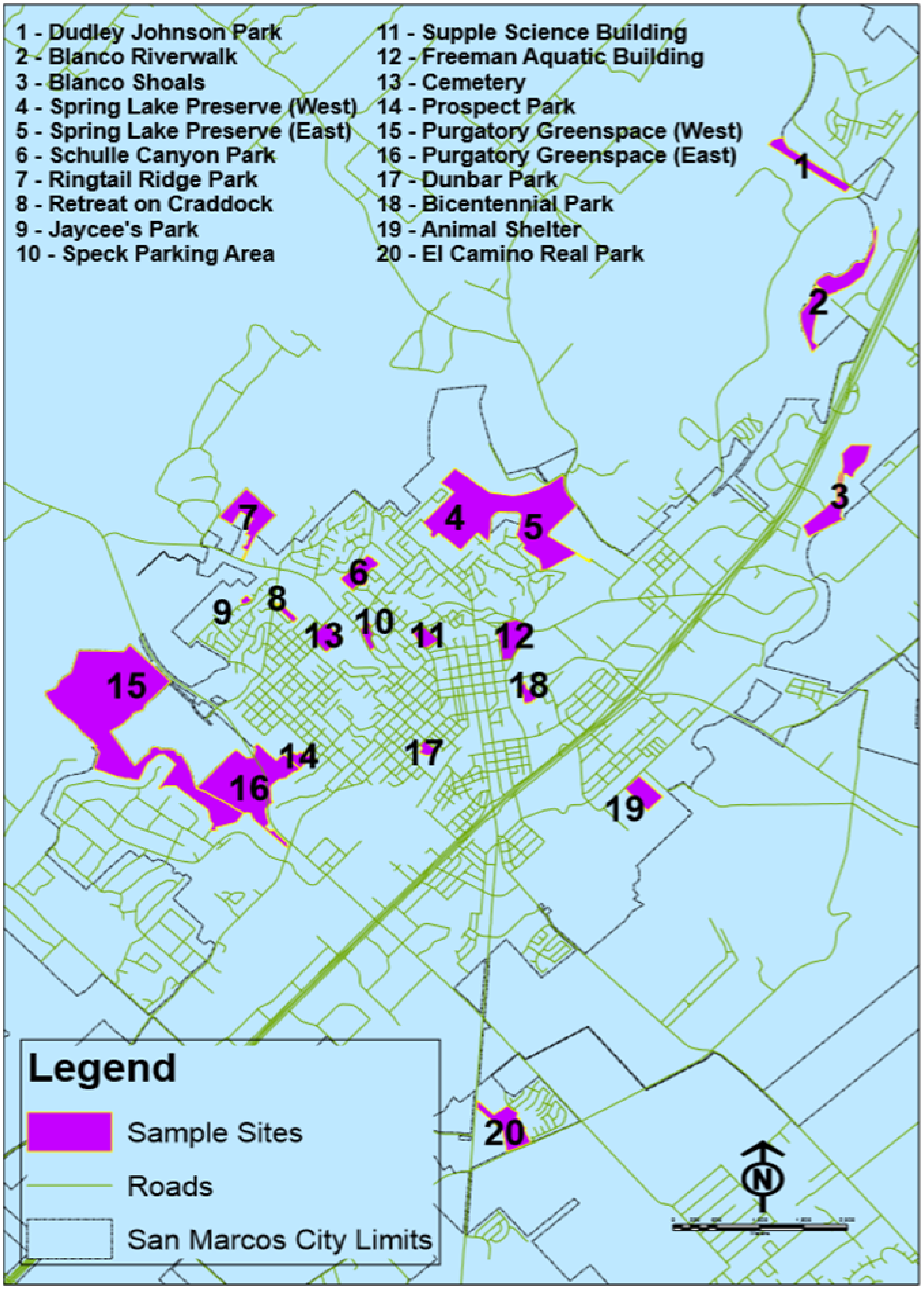

Figure 1. Small-mammal trapping sites in San Marcos, Texas. Each site is shown in purple, and is numbered and labeled according to the names designated by the San Marcos Parks Department and Texas State University (ArcGIS 10.1).

3. RESULTS

According to the classifications provided by the Texas Ecological Mapping Systems, seven of my sites were woodland, seven were urban, three were shrubland, and three were grassland (Table 1). Trap-nights per site varied because of availability of working traps and weather conditions. Trap-nights totaled 11,490 over all seasons, and per site ranged from 522 - 622 (Appendix E).

Table 1. Land cover classification, species richness, and species diversity for trapping sites in urban San Marcos, Texas. Sites were classified into one of four categories based on the Texas Ecological Mapping Systems. Diversity cannot be calculated for site 18 because there were no captures.

Site	Site name	Land cover	Richness	Diversity
1	Dudley Johnson Park	Shrubland/Herbaceous	4	0.96
2	Blanco Riverwalk	Shrubland/Herbaceous	1	0.00
3	Blanco Shoals	Shrubland/Herbaceous	4	1.24
4	Spring Lake Preserve (West)	Forest/Woodland	1	0.00
5	Spring Lake Preserve (East)	Forest/Woodland	2	0.64
6	Schulle Canyon Park	Forest/Woodland	2	0.69
7	Ringtail Ridge Park	Forest/Woodland	2	0.56
15	Purgatory Greenspace (West)	Forest/Woodland	4	0.97
18	Bicentennial Park	Forest/Woodland	0	-
20	El Camino Real Park	Forest/Woodland	1	0.00
8	Retreat on Craddock	Urban Development	1	0.00
9	Jaycee's Park	Urban Development	2	0.50
10	Speck Parking Area	Urban Development	5	1.39
11	Supple Science Building	Urban Development	3	0.95
12	Freeman Aquatic Building	Urban Development	1	0.00
13	Cemetery	Urban Development	2	0.56
19	Animal Shelter	Urban Development	3	0.93
14	Prospect Park	Grassland	2	0.56
16	Purgatory Greenspace (East)	Grassland	4	1.26
17	Dunbar Park	Grassland	1	0.00

Captures and Percent Composition of Species

I captured 280 small mammals representing 12 species (Tables 2 and 3). A deer mouse, an unidentified *Peromyscus* species, a Virginia opossum (*Didelphis virginiana*), and a white-ankled mouse (*P. pectoralis*) had one capture each (Figure 2). The most common species trapped was the hispid cotton rat (*Sigmodon hispidus*) with 129 captures (46.1% of the total; Table 4). It was also the most common species trapped in shrubland (*n* = 33, 73.3%), grassland (*n* = 58, 45.7%), and woodland sites (*n* = 29, 69.0%; Figure 3). In urban sites, the house mouse (*Mus musculus*) was the most common species (*n* = 26, 39.4%). The hispid cotton rat was the most common species found in each season (summer: *n* = 28, 50.9%; fall: *n* = 56, 50.5%; winter: *n* = 31, 42.5%; spring: *n* = 14, 34.1%; Figure 4).

Table 2. Species and number of captures in urban San Marcos, Texas by season from 1 August 2013 – 7 May 2014.

		Season			
Scientific Name	Common name	Summer	Fall	Winter	Spring
Baiomys taylori	Northern pygmy mouse	6	28	6	8
Didelphis virginiana	Virginia opossum	0	0	0	1
Mus musculus	House mouse	13	13	8	10
Peromyscus sp.	*Peromyscus* species	0	1	0	0
Peromyscus attwateri	Texas mouse	0	4	2	1
Peromyscus leucopus	White-footed mouse	1	1	20	6
Peromyscus maniculatus	Deer mouse	1	0	0	0
Peromyscus pectoralis	White-ankled mouse	1	0	0	0
Rattus rattus	Roof rat	2	8	5	0
Reithrodontomys fulvescens	Fulvous harvest mouse	1	0	1	1
Sigmodon hispidus	Hispid cotton rat	28	56	31	14
Spermophilus variegatus	Rock squirrel	2	0	0	0
Total		55	111	73	41

Table 3. Species list and captures in urban San Marcos, Texas by land cover from 1 August 2013 – 7 May 2014. SH = shrubland, FW = woodland, UD = urban, GL = grassland.

		Land Cover			
Scientific Name	Common name	SH	FW	UD	GL
Baiomys taylori	Northern pygmy mouse	3	8	10	27
Didelphis virginiana	Virginia opossum	0	0	1	0
Mus musculus	House mouse	6	0	26	12
Peromyscus sp.	*Peromyscus* species	1	0	0	0
Peromyscus attwateri	Texas mouse	0	0	0	7
Peromyscus leucopus	White-footed mouse	1	2	2	23
Peromyscus maniculatus	Deer mouse	0	0	1	0
Peromyscus pectoralis	White-ankled mouse	0	0	1	0
Rattus rattus	Roof rat	0	1	14	0
Reithrodontomys fulvescens	Fulvous harvest mouse	1	2	0	0
Sigmodon hispidus	Hispid cotton rat	33	29	9	58
Spermophilus variegatus	Rock squirrel	0	0	2	0
Total		45	42	66	127

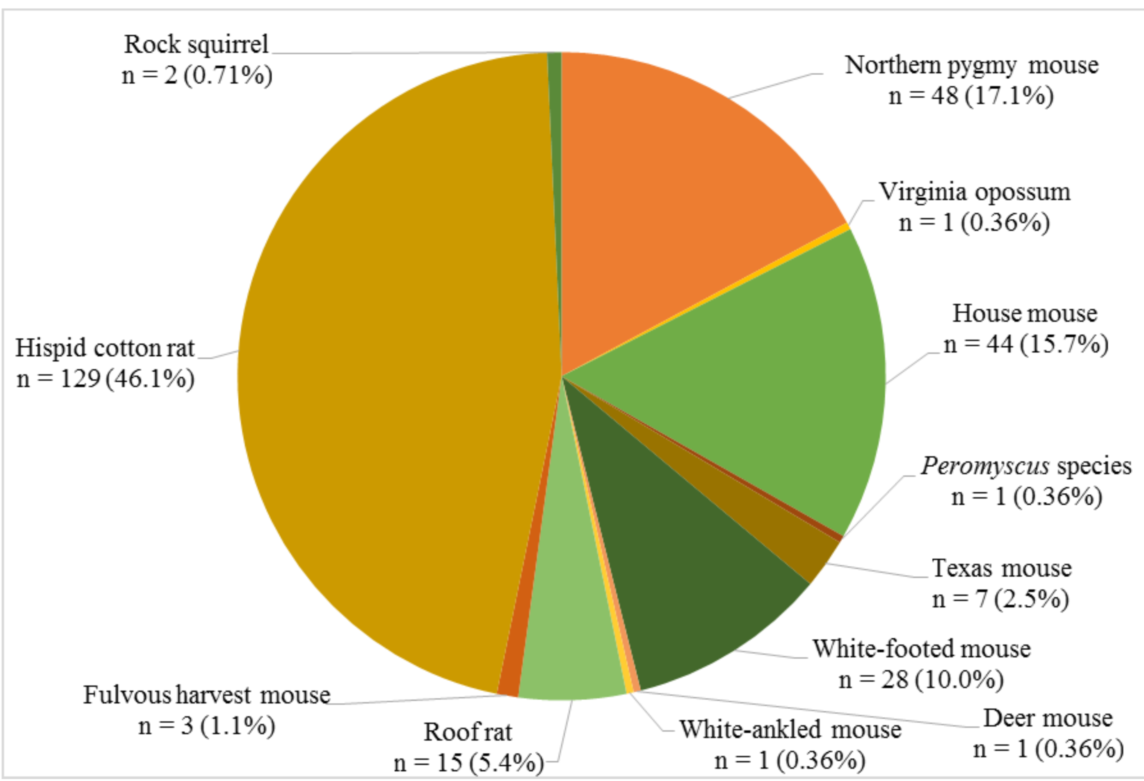

Fig 2. Small mammals captured from 1 August 2013 – 7 May 2014 in urban San Marcos, Texas. Hispid cotton rats were captured in greatest numbers, followed by the northern pygmy mouse and the house mouse. The white-ankled mouse, deer mouse, Virginia opossum, and an unidentified *Peromyscus* were least captured with one individual each.

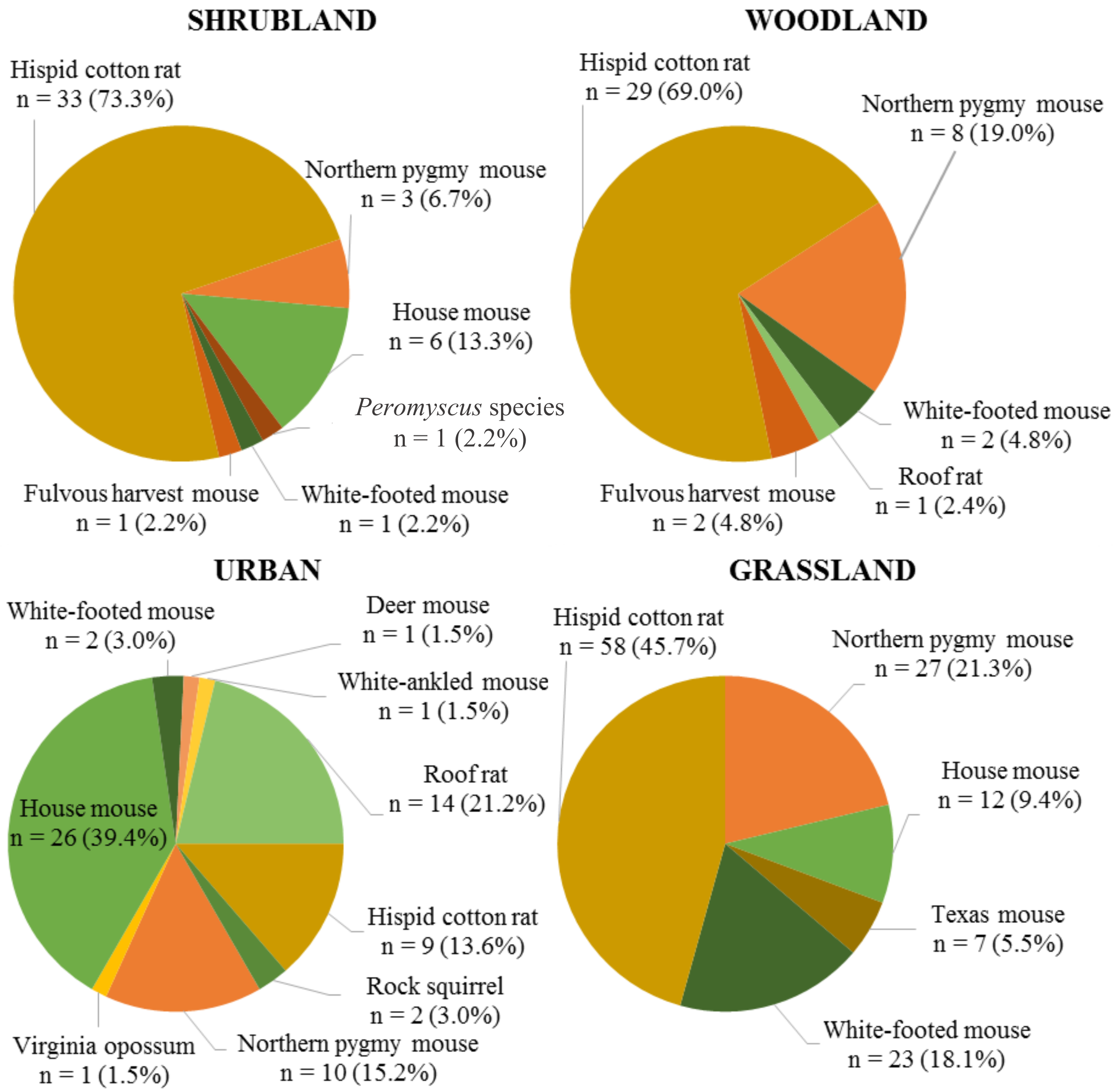

Figure 3. Small mammals captured based on land cover in urban San Marcos, Texas. Hispid cotton rats were captured in greatest numbers in all land cover types except urban, in which case the house mouse was captured most. In every land cover type with the exception of grassland sites, the species with the lowest percent composition had only one capture.

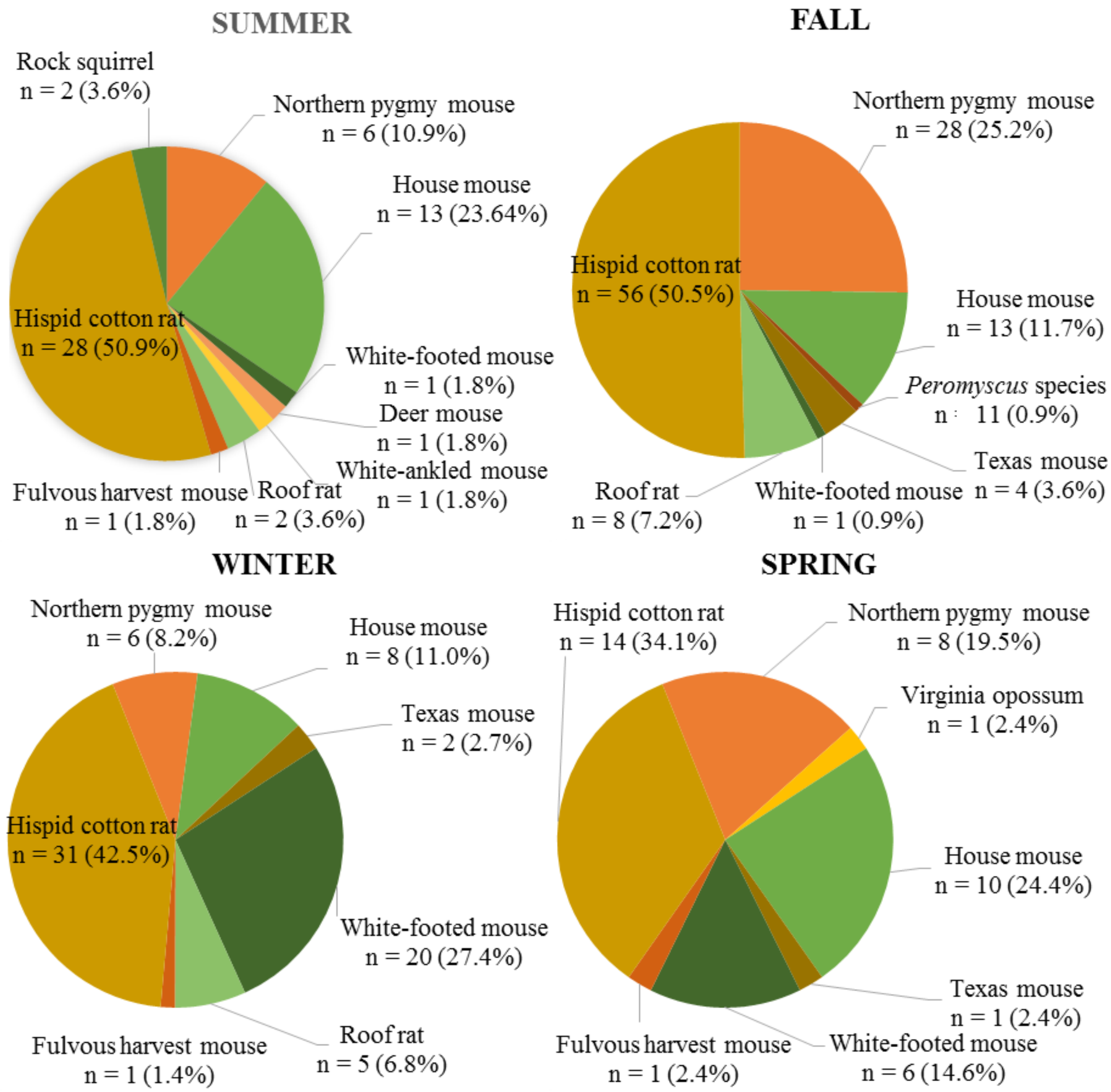

Figure 4. Small mammals captured based on season in urban San Marcos, Texas. Hispid cotton rats were captured in greatest numbers in all seasons. In every season, the species with the lowest percent composition had only one capture.

There were differences among overall species captures ($\chi_{11}^2 = 544.3$, $P \leq 0.001$). Post hoc analyses showed that the hispid cotton rat, the northern pygmy mouse (*Baiomys taylori*), and the house mouse each had more captures than expected ($P \leq 0.001$). When species captures were broken down by land cover or season, the hispid cotton rat had more captures than expected in all land cover types except for urban, and in all seasons ($P = 0.007$ for spring, $P \leq 0.001$ for all other categories; Tables 5 and 6). The house mouse had more captures than expected in urban sites ($P \leq 0.001$). The northern pygmy mouse had more captures than expected in the fall ($P = 0.004$).

Mean number of captures across all species for each site by land cover type and season ranged from 0.7 – 21.0 (Figure 5). Data were natural log transformed, and an ANOVA showed an effect of land cover type on captures ($P = 0.001$, Table 7). No interactions were found between season and land cover ($P = 0.918$). A Tukey's post hoc analysis showed differences between grassland and woodland sites ($P \leq 0.001$) and between grassland and urban sites ($P = 0.011$, Table 8).

Table 4. Post hoc tests for overall species captures. Using the Bonferroni correction, adjusted critical $P \leq 0.004$. ** indicates fewer captures and * indicates more captures.

Species	Total	Composition (%)	χ_1^2	*P*
Hispid cotton rat	129	46.1	429.9	≤0.001*
Northern pygmy mouse	48	17.1	23.4	≤0.001*
House mouse	44	15.7	16.4	≤0.001*
White-footed mouse	28	10.0	0.8	0.360
Roof rat	15	5.4	2.7	0.102
Texas mouse	7	2.5	10.3	0.001**
Fulvous harvest mouse	3	1.1	15.9	≤0.001**
Rock squirrel	2	0.71	17.5	≤0.001**
Virginia opossum	1	0.36	19.2	≤0.001**
Peromyscus species	1	0.36	19.2	≤0.001**
Deer mouse	1	0.36	19.2	≤0.001**
White-ankled mouse	1	0.36	19.2	≤0.001**

Table 5. Chi square and post hoc tests for captures based on land cover. Critical *P* for post hoc χ_1^2 tests were adjusted using Bonferroni's correction. Dashes (-) indicate no captures, ** indicates fewer captures, and * indicates more captures.

	Shrubland		Woodland		Urban		Grassland	
	χ^2	*P*	χ^2	*P*	χ^2	*P*	χ^2	*P*
Land cover	64.0	≤0.001*	41.9	≤0.001*	47.0	≤0.001*	62.6	≤0.001*
df	5		4		8		4	
Deer mouse	-		-		3.7	0.056	-	
Fulvous harvest mouse	4.1	0.044	3.8	0.051	-		-	
Hispid cotton rat	62.4	≤0.001*	39.6	≤0.001*	0.25	0.615	52.3	≤0.001*
House mouse	0.2	0.642	-		31.8	≤0.001*	8.8	0.003**
Northern pygmy mouse	1.9	0.163	0.02	0.903	0.6	0.421	0.13	0.723
Peromyscus species	4.1	0.044	-		-		-	
Rock squirrel	-		-		2.6	0.107	-	
Roof rat	-		5.1	0.024	4.1	0.044	-	
Texas mouse	-		-		-		16.7	≤0.001**
Virginia opossum	-		-		3.7	0.056	-	
White-ankled mouse	-		-		3.7	0.056	-	
White-footed mouse	4.1	0.044	3.8	0.051	2.6	0.107	0.28	0.594
Critical P		≤0.008		≤0.010		≤0.006		≤0.010

Table 6. Chi square and post hoc tests for captures based on season. Critical *P* for post hoc χ_1^2 tests were adjusted using Bonferroni's correction. Dashes (-) indicate no captures, ** indicates fewer captures, and * indicates more captures.

	Summer		Fall		Winter		Spring	
	χ^2	*P*	χ^2	*P*	χ^2	*P*	χ^2	*P*
Season	59.8	≤0.001*	115.6	≤0.001*	47.3	≤0.001*	14.6	0.023*
df	9		7		7		7	
Deer mouse	2.6	0.104	-		-		-	
Fulvous harvest mouse	2.6	0.104	-		6.7	0.010	2.5	0.111
Hispid cotton rat	48.5	≤0.001*	90.1	≤0.001*	32.0	≤0.001*	7.1	0.007*
House mouse	4.8	0.028	0.46	0.499	0.45	0.504	1.8	0.174
Northern pygmy mouse	0.001	0.972	8.2	0.004*	1.5	0.223	0.5	0.482
Peromsycus species	-		12.3	≤0.001**	-		-	
Rock squirrel	1.7	0.191	-		-		-	
Roof rat	1.7	0.191	3.5	0.063	2.2	0.135	-	
Texas mouse	-		7.9	0.005	5.4	0.020	2.5	0.111
Virginia opossum	-		-		-		2.5	0.111
White-ankled mouse	2.6	0.104	-		-		-	
White-footed mouse	2.6	0.104	12.3	≤0.001**	6.9	0.008	0.002	0.963
Critical P		≤0.006		≤0.007		≤0.007		≤0.007

Table 7. Analysis of variance test (two factor ANOVA) on small-mammal captures. A significant effect was found based on land cover. * indicates significant results.

	df	Sum squares	Mean squares	*F*	*P*
Season	3	9.726	3.2419	2.4589	0.071
Land Cover	3	26.456	8.8185	6.6886	0.001*
Season:Land Cover	9	5.017	0.5575	0.4228	0.918
Residuals	64	84.380	1.3184		

Table 8. Tukey's post hoc analysis of the two factor analysis of variance test on small-mammal captures. * indicates significant results.

Land Cover	Difference	Lower CI	Upper CI	*P*
Grassland – Woodland	1.7069	0.6619	2.7520	≤0.001*
Shrubland – Woodland	0.9096	-0.1355	1.9546	0.110
Urban – Woodland	0.4343	-0.3752	1.2438	0.495
Shrubland – Grassland	-0.7973	-2.0339	0.4392	0.332
Urban – Grassland	-1.2726	-2.3177	-0.2276	0.011*
Urban – Shrubland	-0.4753	-1.5203	0.5698	0.629

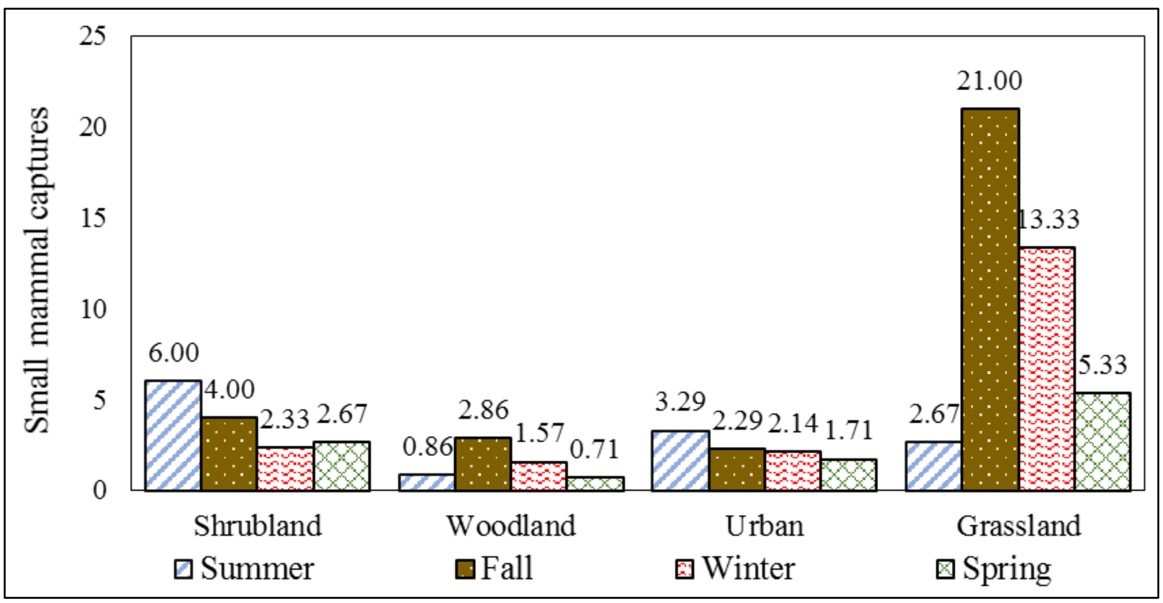

Figure 5. Means of captures for land cover by season. Values for individual sites were averaged by land cover and season. More captures were seen in grassland sites in the fall. Fewer captures were seen in woodland sites in the spring.

Trap Success

Trap success by land cover per season ranged from 0.48 – 18.0% with differences present (χ_{15}^2 = 103.2 $P \leq 0.001$; Fig 6). Post hoc analyses show that grassland sites had higher trap success in both the fall (χ_1^2 = 66.6, $P \leq 0.001$) and winter (χ_1^2 = 13.6, $P = 0.001$) seasons (Table 9). Site 16 had the highest trap success over all seasons (15.9%) and during an individual season (fall: 41.0%; Appendices B). Shrubland sites had a trap success of 2.6%, and woodland and urban sites had even lower trap success (1.0% and 1.6%, respectively). Site 18 had the lowest trap success (0.0%). Overall trap success was 2.4%.

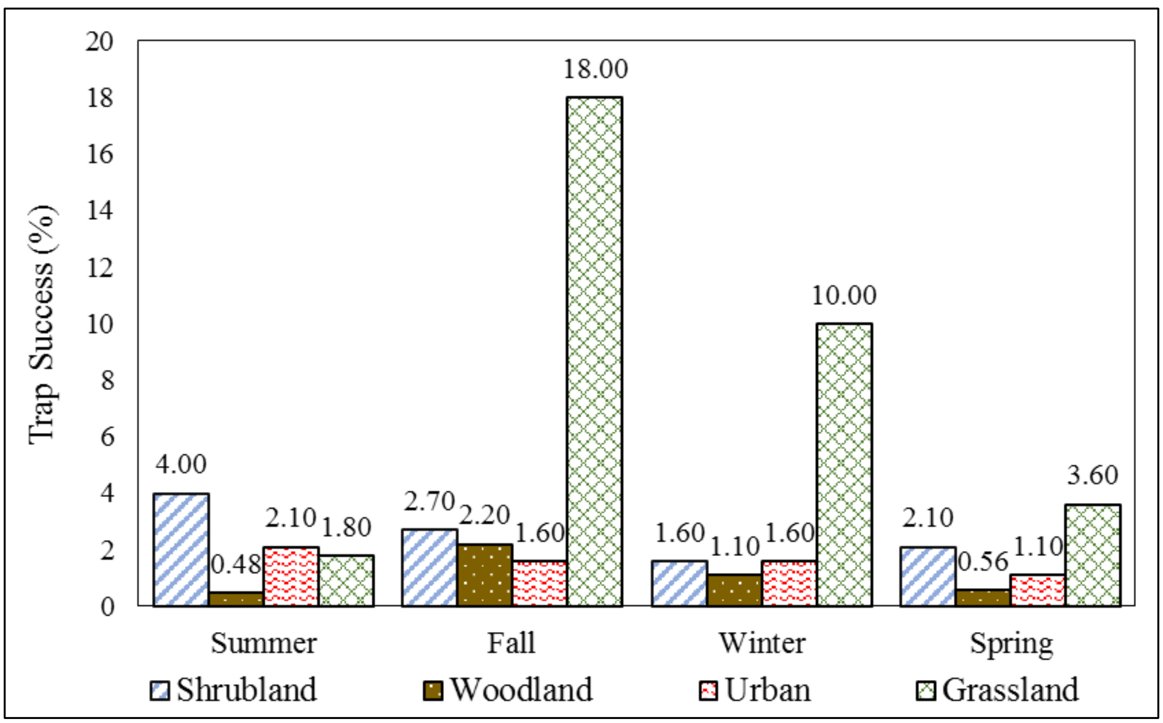

Fig 6. Trap success (%) by land cover and season. Lowest trap success was found in woodland sites in summer, and highest trap success was found in grassland sites in fall.

Table 9. Post hoc tests for trap success by land cover and season. Using the Bonferroni correction, adjusted critical $P \leq 0.003$. * indicates significant results.

	Land cover							
	Shrubland		Woodland		Urban		Grassland	
	χ_1^2	P	χ_1^2	P	χ_1^2	P	χ_1^2	P
Summer	0.109	0.947	2.68	0.261	0.536	0.765	0.810	0.667
Fall	0.157	0.924	0.457	0.796	1.02	0.599	66.6	3.41^{-15}*
Winter	1.02	0.599	1.67	0.434	1.02	0.599	13.6	0.001*
Spring	0.536	0.765	2.54	0.281	1.67	0.434	0.011	0.994

Species Richness and Diversity

Species richness was 9 in urban sites, 5 in both woodland and grassland sites, and 6 in shrubland sites. Across seasons, species richness was 9 in summer and 7 in all other seasons. Site 10 had the highest species richness of 5. Shannon-Weiner indices of diversity ranged from 0.00-1.39 for sites, 1.34-1.58 for seasons, and 0.93-1.66 for land cover types (Appendices A-E). Site 10 had the highest index for sites, spring had the highest index for seasons, and urban had the highest index for land cover type. The means of Shannon-Weiner indices for each site by land cover and season ranged from 0 – 0.59 (Figure 7). Many sites had no captures in individual seasons so diversity could not be calculated; data were therefore analyzed using a rank transformation, where sites with no captures were given the lowest rank. An ANOVA showed a significant effect of land cover on diversity (Table 10). No interaction was found between season and land cover type ($P = 0.699$). A Tukey's post hoc analysis showed a difference between grassland and woodland sites (Table 11).

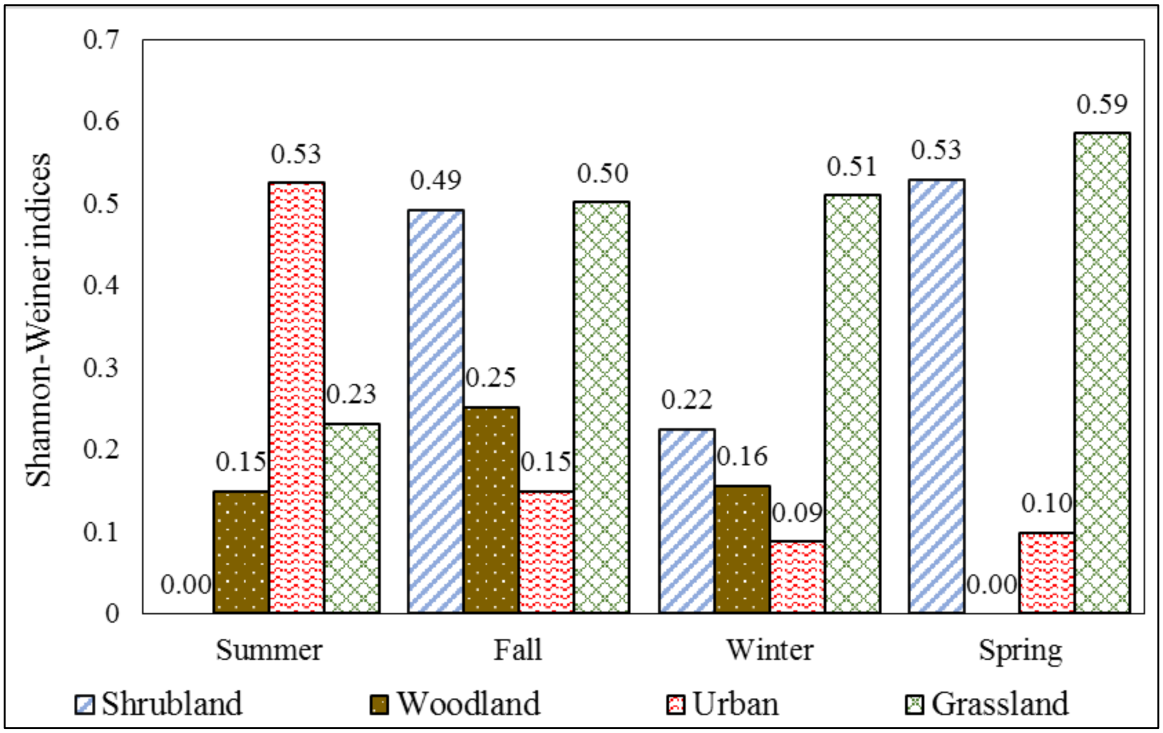

Figure 7. Means of Shannon-Wiener indices for land cover by season. Highest diversity was seen in grassland sites in spring. Lowest diversity was seen in shrubland sites in summer and in woodland sites in spring.

Table 10. Results of an analysis of variance test (two factor ANOVA) on Shannon-Wiener indices of species diversity. * indicates significant results.

	df	Sum squares	Mean squares	*F*	*P*
Season	3	2578	859.2	2.012	0.121
Land Cover	3	5974	1991.3	4.663	0.005*
Season:Land Cover	9	2721	302.3	0.708	0.699
Residuals	64	27328	427.0		

Table 11. Tukey's post hoc analysis of two factor analysis of variance on species diversity. * indicates significant results.

Land Cover	Difference	Lower CI	Upper CI	*P*
Grassland – Woodland	25.006	6.199	43.813	0.004*
Shrubland – Woodland	16.256	-2.551	35.063	0.114
Urban – Woodland	8.643	-5.925	23.211	0.406
Shrubland – Grassland	-8.750	-31.003	13.503	0.728
Urban – Grassland	-16.363	-35.170	2.444	0.110
Urban – Shrubland	-7.613	-26.420	11.194	0.710

4. DISCUSSION

Both captures and diversity of small mammals were significantly affected by land cover type, with grassland sites exhibiting more captures than urban sites and more captures and greater diversity than woodland sites. Grassland site 16 had more than 30% of all total captures and contained 4 different species; this site is not directly affected by road traffic, and while it is used for recreation such as hiking and bicycling, there are large areas of this greenspace that do not have trails and are not subjected to human activity. Grassland site 14 is similar to 16 in regards to road traffic and recreational use. Woodland site 18 and urban site 8 had thick stands of privet trees (*Ligustrum* spp.), with very little ground vegetation and leaf litter underneath these trees. These conditions might explain the lack of captures in these areas, as removal of privet trees has resulted in increases of small-mammal abundance (Hanula et al. 2011). Woodland sites 7 and 20 had high numbers of fire ant mounds; the presence and odor of fire ants near or inside the traps may affect rodents' desire to enter, and can cause small mammals to avoid otherwise high-quality habitat (Lechner and Ribble 1996, Orrock and Danielson 2004).

Urban sites had the highest overall species richness; however, the Virginia opossum, the deer mouse, and the white-ankled mouse were only captured once and only in this land cover type. Site 8 is next to a neighborhood and a newer apartment complex, and its only capture was the Virginia opossum near a backyard area. Site 9, which provided the white-ankled mouse, is a manicured playground park in a neighborhood, with a small natural area abutting residential fences. The only other captures at this site were 4 northern pygmy mice. Site 13 is a manicured cemetery surrounded by a neighborhood, and other than the deer mouse captured near a brush pile, the only other captures were 3 roof rats (*Rattus rattus*) by fences bordering backyard areas. Two juvenile rock squirrels (*Spermophilus variegatus*) were also captured in urban sites, but since Sherman live traps are not meant to capture opossums or squirrels I cannot accurately determine how common these species are or in what other sites and land cover types they are present.

Two urban sites comprised the majority of the species richness and 66% of all captures for this land cover type. Site 10 is bordered by a well-trafficked road and a student parking lot, and is a relatively unmanicured area containing a disc golf field; however, out of the 5 species found in this site, only the house mouse was captured more than once. Site 19 is located near an animal shelter and had large grassy patches next to non-residential structures. These sites had nearby human sources of additional food (e.g. refuse, dog food, etc.), and the nearby roads could prevent emigration of small mammals while also excluding predators.

The house mouse made up a significant percent of overall species composition, even though none were captured in any woodland sites. The roof rat was only captured in woodland and urban sites; woodland site 6 is completely surrounded by a neighborhood close to Texas State University, and only 1 individual was captured near a house. Over 60% of the community composition for urban sites was house mice and roof rats. This was not unexpected due to the land cover type; however, the variety of species, including deer mice, northern pygmy mice, and hispid cotton rats, was surprising. This indicates that even small pockets of natural areas and manicured parks with an edge habitat can support a variety of small mammals. Future survey efforts may find that the unique captures in these urban sites are actually more common than shown by my study.

My results suggest that urban predators in the San Marcos area might have adequate numbers and variety of small-mammal prey with which to maintain their populations. Raptors, foxes, snakes, and cats were observed at many sites. At sites with few or no captures, rodents might be experiencing high predation pressure resulting in lower abundances and possible local extirpations. However, it is possible that predation pressure is actually lessened in urban areas and on species that are either more abundant or more adept at avoiding predators (Fischer et al. 2012). Overall, the role of urban predators and their effect on small-mammal populations in urban San Marcos is unclear. This should be studied further in an attempt to understand these urban predator and prey population dynamics.

Rodents known to be vectors for Lyme diseases and Hantavirus were captured in San Marcos. The hispid cotton rat was found in significant numbers and in 13 out of 20 sites, including 2 urban sites. The white-footed mouse, although not found in significant numbers, was present in all land cover types and made up 18% of the composition of grassland species. Along with the deer mouse captured in site 10, my study shows that these species live in very close proximity to residences and other areas where they may come into contact with humans. Rodents are also reservoirs for other diseases such as leptospirosis. There is a real risk for human infection if these particular populations of rodents become carriers of infectious zoonotic diseases. Information about rodent distribution in urban areas might be effectively used to monitor and prevent diseases.

Habitat fragmentation may be excluding rodents from some areas that are suitable habitat. Several shrubland and woodland sites that appeared to have sufficient ground cover and vegetation had low captures of small mammals. Some of these sites were completely surrounded by roads and neighborhoods with small patches of manicured grass. While this might prevent emigration from these sites and stabilize or increase population sizes, many rodents may have already left or been subject to predation or human pest-control efforts. The presence of house mice in shrubland and grassland areas can indicate poor habitat quality (Bonvicino et al. 2002), even though other species were present in greater numbers. While the presence of house mice and roof rats in urban sites is not unexpected, it is also an indication of habitat degradation (Cavia et al. 2009). All roof rats were captured in traps set very close to buildings, but this was not the case for almost all of the house mouse captures. Species such as the hispid cotton rat can be used as bioindicators of environmental pollutants, which could provide another way to assess habitat quality and the impact of San Marcos' increasing urbanization on small mammals and, potentially, on humans and other species (McMurry et al. 1999).

Weather may have had a negative effect on trap success. Temperatures at the end of the fall season through the start of the spring season (Dec 2013 – Feb 2014) were low, including several freezes, and there were heavy rains and flooding in the San Marcos area on 31 October 2013 (National Weather Service 2013, 2015). The rain and flooding removed nearly all of the ground vegetation and leaf litter, exposing sandy soils and rock at shrubland sites 1 and 2 (Figure 1). While one site began to show improvement by the spring season, the other site did not show signs of recovery, and no individuals were captured in those areas after those weather events.

While trap disturbance was minimal in most areas, with the exception of some curious raccoons, several traps were removed overnight from site 3. While this most likely did not affect captures overall, this is an important, albeit undesirable, facet of conducting urban surveys. Markus Clarin et al. (2014) have found that adding a personalized, friendly message can reduce public interaction with field equipment. I affixed laminated personalized signs with contact information to the traps, but they suggest that adding a juvenile picture of target species may add to the friendly nature of the message and help minimize vandalism.

This survey identified sites in different land cover types in the urban area of San Marcos that can sustain populations of various native and non-native small mammals. While most of these sites are close to traffic and have moderate recreational use, some are less disturbed compared to other park areas in close proximity. More surveys should be done using these sites to make a stronger conclusion about the influence of land cover on small-mammal populations in urban environments. These sites should be evaluated over a long-term study to also examine potential fluctuations in species richness and composition, especially with increasing urbanization and subsequent habitat loss and degradation.

5. MANAGEMENT IMPLICATIONS

To maintain native small-mammal species in urban areas, sites should be protected from habitat degradation. Existing trails and visitor parking can be maintained without loss of either human enjoyment or small-mammal presence in these areas. Even small, manicured parks can sustain populations of small mammals if areas of edge habitat are allowed to persist. Other sites should be targeted for the removal of non-native species. This was unintentionally carried out in sites 12 and 17 when areas of ground cover and debris were removed. These areas had been providing all captures of non-native species in these sites, and none were captured after the removal. Even though baited poison traps were already installed near the building on site 12, these individuals were able to persist in a relatively small area only a few meters away.

In several sites and in all land cover types, species that contribute to the spread of infectious zoonotic diseases were captured. These rodents should be evaluated for disease prevalence, which could not only provide a novel study, but could also help predict and prevent future outbreaks in human populations. Those areas closest to neighborhoods and businesses should especially be monitored, as the urban sites showed a presence and, in some cases, relatively high numbers of these rodents. The sites included in this study can also be evaluated for harmful pollutants and toxins. The hispid cotton rat is a useful proxy species for measuring environmental toxins, and is found in all land cover types in abundance.

A few sites in urban San Marcos have been identified that yield very high trap success and species diversity. If it is desired, continued cooperation by the San Marcos Parks Department and Texas State University could provide local survey areas for

Mammalogy trips and local urban projects. Small-mammal surveys can be conducted with little to no disturbance of existing habitat and can provide a multitude of project opportunities for many students or agencies. These would be excellent sites for long-term evaluation of small-mammal populations, other wildlife species, and the effects of urbanization.

APPENDIX SECTION

Appendix A. Species captured, trap-nights, trap success, and species richness during the summer season (August – October 2013).

	Land cover																				
	Shrub/herb			Forest/woodland							Urban developed							Grassland			
	1	2	3	4	5	6	7	15	18	20	8	9	10	11	12	13	19	14	16	17	Total
Common Name																					
Deer mouse	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Fulvous harvest mouse	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Hispid cotton rat	2	16	0	0	0	0	0	1	0	1	0	0	1	0	0	0	5	1	1	0	28
House mouse	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	6	0	0	5	13
Northern pygmy mouse	0	0	0	0	0	0	0	2	0	0	0	3	0	0	0	0	0	0	1	0	6
Rock squirrel	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	2
Roof rat	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
White-ankled mouse	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
White-footed mouse	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Captures																					
Site	2	16	0	0	0	1	0	4	0	1	0	4	4	2	0	2	11	1	2	5	55
Land cover		18					6							23					8		
Trap-nights																					
Site	150	149	150	150	150	150	150	150	149	150	150	149	150	164	150	172	150	150	150	150	3033
Land Cover		449					1049							1085					450		
Trap success (%)																					
Site	1.3	10.7	0.0	0.0	0.0	0.67	0.0	2.7	0.0	0.67	0.0	2.7	2.7	1.2	0.0	1.2	7.3	0.67	1.3	3.3	1.8
Land cover		4.0					0.57							2.1					1.8		
Species Richness																					
Site	1	1	0	0	0	1	0	3	0	1	0	2	3	2	0	2	2	1	2	1	9
Land cover		1					4							8					3		
S-W Index																					
Site	0.0	0.0	0	0	0	0.0	0	1.04	0	0.0	0	0.56	1.04	0.69	0	0.69	0.69	0.0	0.69	0	1.46
Land Cover		0.00					1.33							1.74					0.90		

Appendix B. Species captured, trap-nights, trap success, and species richness during the fall season (October – December 2013).

	Land cover																			
	Shrub/herb			Forest/woodland							Urban developed							Grassland		
	1	2	3	4	5	6	7	15	18	20	8	9	10	11	12	13	19	14	16	17	Total
Common name																					
Hispid cotton rat	7	1	1	1	2	0	6	6	0	0	0	0	0	0	0	0	0	12	20	0	56
House mouse	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	4	0	0	6	13
Northern pygmy mouse	0	0	1	0	1	0	2	2	0	0	0	1	0	0	0	0	0	4	17	0	28
Roof rat	0	0	0	0	0	0	0	0	0	0	0	0	1	3	3	1	0	0	0	0	8
Texas mouse	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4
Unknown deer mouse	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
White-footed mouse	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Captures																					
Site	8	1	3	1	3	0	8	8	0	0	0	1	4	3	3	1	4	16	41	6	111
Land cover		12					20							16					63		
Trap-nights																					
Site	150	150	150	149	150	150	150	100	149	100	150	150	150	150	150	150	100	100	100	150	2748
Land Cover		450					948							1000					350		
Trap success (%)																					
Site	5.3	0.67	1.0	0.67	2.0	0.0	5.3	8.0	0.0	0.0	0.0	0.67	2.7	2.0	2.0	0.67	4.0	16.0	41.0	4.0	4.0
Land cover		2.7					2.1							1.6					18.0		
Species Richness																					
Site	2	1	3	1	2	0	2	2	0	0	0	1	3	1	1	1	1	2	3	1	7
Land cover		4					2							4					4		
S-W Index																					
Site	0.38	0.0	1.10	0.0	0.64	0	0.56	0.56	0	0	0	0.0	1.04	0.0	0.0	0.0	0.0	0.56	0.94	0.0	1.34
Land cover		0.84					0.56							1.06					1.11		

Appendix C. Species captured, trap-nights, trap success, and species richness during the winter season (February – March 2014).

	Land cover																				
	Shrub/herb			Forest/woodland							Urban developed							Grassland			
	1	2	3	4	5	6	7	15	18	20	8	9	10	11	12	13	19	14	16	17	Total
Common name																					
Fulvous harvest mouse	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Hispid cotton rat	2	0	3	0	0	1	0	6	0	0	0	0	0	0	0	0	3	6	10	0	31
House mouse	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	1	8
Northern pygmy mouse	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	1	0	6
Roof rat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	0	0	0	0	5
Texas mouse	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
White-footed mouse	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	18	0	20
Captures																					
Site	2	0	5	0	0	1	0	10	0	0	0	0	0	0	4	1	10	8	31	1	73
Land cover		7					11							15					40		
Trap-nights																					
Site	149	150	150	150	150	150	150	150	100	150	95	100	150	150	150	150	149	150	150	100	2793
Land Cover		449					1000							944					400		
Trap success (%)																					
Site	1.3	0.0	3.3	0.0	0.0	0.67	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0	2.7	0.67	6.7	5.3	20.7	1.0	2.6
Land cover		1.6					1.1							1.6					10.0		
Species Richness																					
Site	1	0	2	0	0	1	0	4	0	0	0	0	0	0	1	1	2	2	4	1	7
Land cover		2					4							3					5		
S-W Index																					
Site	0.0	0	0.67	0	0	0.0	0	1.09	0	0	0	0	0	0	0.0	0.0	1.61	0.56	0.97	0.0	1.51
Land cover		0.60					1.03							1.04					1.16		

Appendix D. Species captured, trap-nights, trap success, and species richness during the spring season (April – May 2014).

	Land cover																				
	Shrub/herb			Forest/woodland							Urban developed							Grassland			
	1	2	3	4	5	6	7	15	18	20	8	9	10	11	12	13	19	14	16	17	Total
Common name																					
Fulvous harvest mouse	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Hispid cotton rat	0	0	1	0	0	0	0	5	0	0	0	0	0	0	0	0	0	2	6	0	14
House mouse	3	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	10
Northern pygmy mouse	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	1	1	0	8
Texas mouse	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Virginia opossum	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
White-footed mouse	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	6
Captures																					
Site	5	0	3	0	0	0	0	5	0	0	1	0	0	0	0	0	11	3	13	0	41
Land cover		8					5							12					16		
Trap-nights																					
Site	150	73	150	149	150	150	150	150	149	150	149	150	149	150	150	150	148	150	149	150	2916
Land Cover		373					1048							1046					449		
Trap success (%)																					
Site	3.3	0.0	2.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.67	0.0	0.0	0.0	0.0	0.0	7.4	2.0	8.7	0.0	1.4
Land cover		2.1					0.48							1.1					3.6		
Species Richness																					
Site	3	0	2	0	0	0	0	1	0	0	1	0	0	0	0	0	2	2	4	0	7
Land cover		4					1							3					4		
S-W Index																					
Site	0.95	0	0.64	0	0	0	0	0.0	0	0	0.0	0	0	0	0	0	0.69	0.64	1.12	0	1.58
Land Cover		1.07					0							0.92					1.14		

Appendix E. Species captured, trap-nights, trap success, and species richness during all seasons (August 2013 – May 2014).

	Land cover																				
	Shrub/herb			Forest/woodland							Urban developed							Grassland			
	1	2	3	4	5	6	7	15	18	20	8	9	10	11	12	13	19	14	16	17	Total
Common Name																					
Deer mouse	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Fulvous harvest mouse	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	3
Hispid cotton rat	11	17	5	1	2	1	6	18	0	1	0	0	1	0	0	0	8	21	37	0	129
House mouse	4	0	2	0	0	0	0	0	0	0	0	0	4	0	0	0	22	0	0	12	44
Northern pygmy mouse	0	0	3	0	1	0	2	5	0	0	0	4	0	0	0	0	6	7	20	0	48
Rock squirrel	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	2
Roof rat	0	0	0	0	0	1	0	0	0	0	0	0	1	3	7	3	0	0	0	0	15
Texas mouse	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	7
Unknown deer mouse	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Virginia opossum	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
White-ankled mouse	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
White-footed mouse	1	0	0	0	0	0	0	2	0	0	0	0	1	1	0	0	0	0	23	0	28
Captures																					
Site	17	17	11	1	3	2	8	27	0	1	1	5	8	5	7	4	36	28	87	12	280
Land cover		45					42							66					127		
Trap-nights																					
Site	599	522	600	598	600	600	600	550	547	550	544	549	599	614	600	622	547	550	549	550	11490
Land Cover		1721					4045							4075					1649		
Trap success (%)																					
Site	2.8	3.3	1.8	0.17	0.50	0.33	1.3	4.9	0.0	0.18	0.18	0.91	1.3	0.81	1.2	0.64	6.6	5.1	15.9	2.2	2.4
Land cover		2.6					1.0							1.6					7.7		
Species Richness																					
Site	4	1	4	1	2	2	2	4	0	1	1	2	5	3	1	2	3	2	4	1	12
Land cover		6					5							9					5		
S-W Index																					
Site	0.96	0.0	1.24	0.0	0.64	0.69	0.56	0.97	0	0.0	0.0	0.50	1.39	0.95	0.0	0.56	0.93	0.56	1.26	0.0	1.59
Land Cover		0.93					0.95							1.66					1.42		

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