North American beaver, *Castor canadensis,* and river otter, *Lontra canadensis,* distributions within Texas with a focus on habitat use in the San Marcos River, Texas

by

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INTRODUCTION

North American beavers, *Castor canadensis*, and river otters, *Lontra canadensis*, were driven to near extinction throughout the United States for their pelts. Their populations were driven from urbanized areas where beavers specifically were considered a nuisance (Wilson and Reeder 2005). By 1900, their numbers were critically low and conservationists, landscape designers, and ecologists stepped in to facilitate their recovery. With only about 10% of the beaver population left, and just as many otters, they became a species of greatest concern inciting hunting restrictions and reintroduction/dispersion efforts throughout the country (Bailey et al. 2018). This only lasted until about the 1960s in Texas when the public started to complain about beaver damage. This caused many of the restrictions to be reduced and eventually forgotten (Wade and Ramsey 1984). Over time, reports and sightings of both species have increased within the state of Texas, but there have been few studies that evaluate the status or distribution of these re-dispersed populations.

This study will provide a status report on these species distributions in Texas and include a case study of the San Marcos River (SMR) where both species have recently reoccupied and are integrating into an urban river setting. The SMR presents a unique opportunity to observe beavers modifying two distinct habitats: the protected headwaters at Spring Lake and the main river channel. The SMR provides habitat for the endemic and federally-listed endangered aquatic grass, Texas wild-rice, *Zizania texana,* that may be negatively affected by beaver activity. River otters in the SMR may positively affect a federally listed endangered benthic fish, fountain darter, *Etheostoma fonticola,* by consuming one of their primary predators, largemouth bass, *Micropterus salmoides* (Roberts 2003). Removal of largemouth bass is predicted to reduce fountain darter mortality without causing detrimental cascade effects (Clark et al. 2017). I am

also looking at the efficacy of using citizen-science and crowd-sourced data to document species presence within this river system.

This research addresses the following research questions: (1) What are the historic and current distributions of the North American beaver and river otter in Texas? (2) How are beavers in the San Marcos River system selectively modifying their habitats based on local environmental conditions? and (3) Can crowd-sourced data be a useful and viable tool for determining species presence and range distribution?

My intentions are to provide information that can be used to inform the management of beaver and river otters to conserve valuable riparian ecosystems. These key species are indicative of environmental health. The San Marcos River is recreationally used by humans throughout the year and the importance of monitoring its health not only affects frequent visitors, but also the biodiversity living within it. By understanding the role these two species have within the San Marcos River, management strategies may be implemented to support them.

STUDY SITES

San Marcos is located in the Texas Hill Country situated between San Antonio and Austin along the IH-35 corridor in Hays County, Texas. The absolute city-center location is 29° 53' 26.37" N, 97° 54' 41.50" W. San Marcos is within the Edwards Plateau ecoregion characterized by limestone plateaus dissected by ephemeral and perennial streams. More specifically, it holds an intimate connection between surface and groundwater which created many endemic species dependent on spring flow to survive. There are a number of different flora and fauna, some endemic and endangered, occupying this area such as Texas wild-rice, *Zizania texana,* and the fountain darter, *Etheostoma fonticola*. It supports many deciduous woody plant species such as

bald cypress, *Taxodium distichum,* black willow, *Salix nigra,* and boxelder, *Acer negundo* (Griffith et al. 2004).

San Marcos is home to Texas State University's main campus and the San Marcos River, which runs directly through part of the campus and the city center. This leads to heavy recreational use of the river by residents, students, and tourists, mainly during summer months as the water is 22°C year-round. It is home to numerous threatened and endangered species and is considered one of the most biologically diverse ecosystems in the southwestern United States (Saunders et al. 2001; Earl and Wood 2002). The SMR has its headwaters at Spring Lake where water flows out of artesian springs from the Edwards Aquifer. From Spring Lake, the river flows south where it joins the Blanco River then the Guadalupe River before reaching the Gulf of Mexico.

Spring Lake is a spring-fed lake, dammed in 1849 40 meters downstream from the headwaters (Brune 1981). It was bought by Southwest Texas State University (now Texas State University) in 1994 and was restored from the recreationally-focused Aquarena underwater theme-park to more natural conditions in an effort to focus on cultural and environmental research and education. It has since been converted into an educational destination dedicated to preserving the waters and species who inhabit it, as well as honoring the indigenous cultures that contribute to this site being one of the longest continuously inhabited locations in North America. The Meadows Center for Water and the Environment currently resides here and engages in research and stewardship of this ecologically sensitive and diverse ecosystem (Gregg Eckhardt).

The entire study area within San Marcos for this study encompassed 4.96 km of both the main river and adjacent water bodies (Table 2). The J.C. Kellam Amphitheatre Ponds (JCK) on

Texas State University's campus were added later in the study after beavers were observed colonizing the area (Figure 1). These ponds were historically part of a 43-acre U.S. Federal Fish Hatchery founded in 1893 and later deeded to Texas State University on 1965. These ponds are parallel to the SMR, split by a heavily trafficked roadway subject to frequent aquatic roadkill including turtles and one beaver during the timeframe this study was conducted. There are multiple ponds adjacent to the main building with both old and young bald cypress growing in abundance.

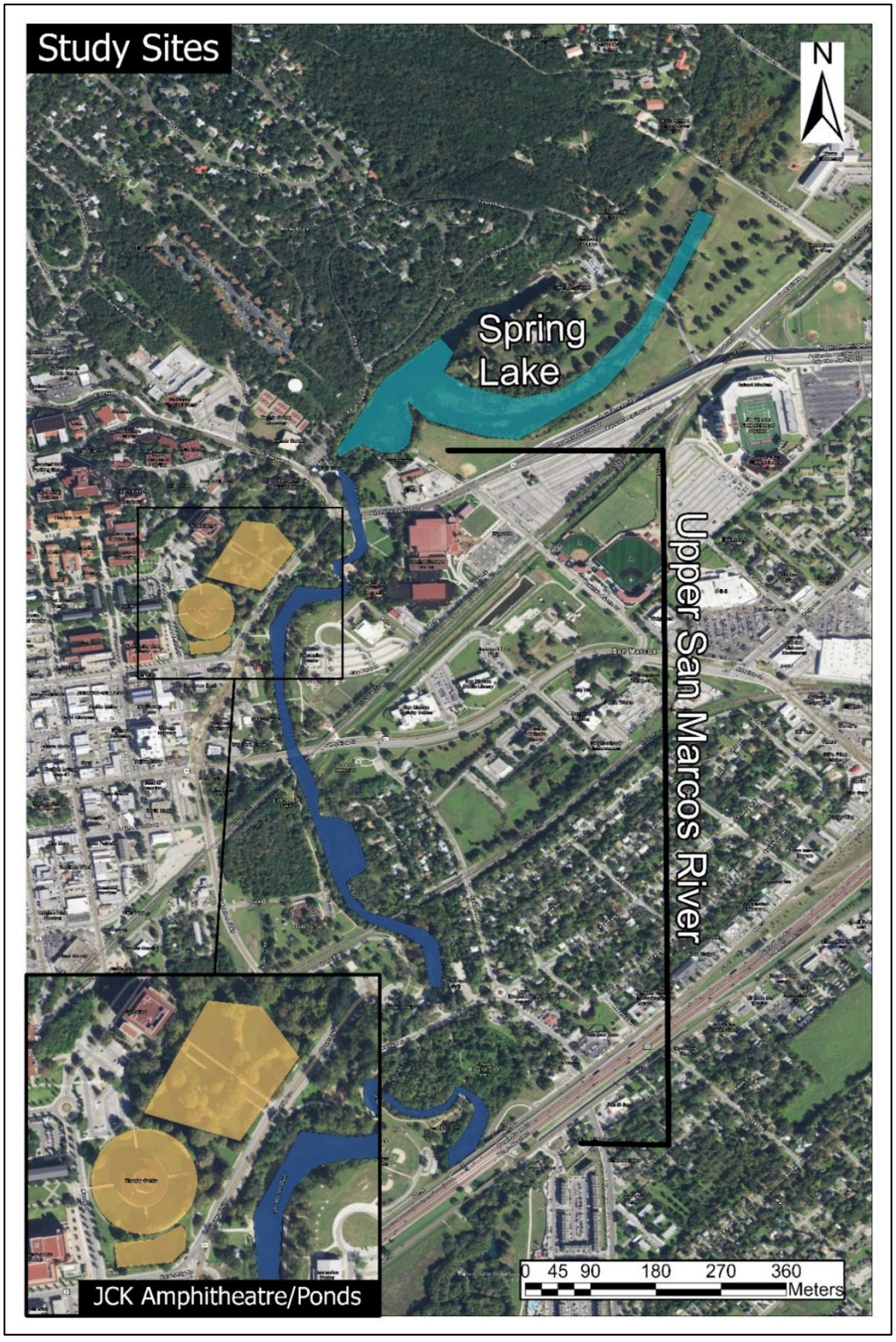

Figure 1. Study sites for both field sign surveys and camera trapping locations in San Marcos, TX.

LITERATURE REVIEW

History of North American Beaver and River Otter Populations

Historic records suggest there was once millions of beavers within the northern hemisphere (Wohl 2021). Over the past century, North American beavers (beavers) and North American river otters (otters) were driven to near extinction by fur trappers and urban development (Toweill and Tabor 1982; Melquist and Dronkert 1987; Lariviere and Walton 1998; Raesly 2001). Beaver populations became isolated in rural and urban areas fragmenting their habitat and dramatically lowering their historical population numbers (Bailey et al. 2018). River otters were reduced to less than 33% of their historic range in North America (Toweill and Tabor 1982). With the combined help of hunting restrictions and reintroductions, both species have made a significant recovery and are now inhabiting areas they were thought to be extirpated (Naiman et al. 1988; Oogjes 1997). Although many states out west and on the east coast have implemented conservation management strategies to support the reintroduced populations, there has been little evidence of management efforts within Texas.

In the past, Central Texas was predicted to host the largest populations of beaver within the state (Fedynich 1986). Reports by the Texas Parks and Wildlife Department (TPWD) found beavers that caused damage were transplanted (i.e., relocated) to other areas of the state and they may have also been brought in from other states to help boost the reduced populations. This all occurred between 1939 and 1973, but the exact number and locations of beaver re-introductions were not recorded (Wade and Ramsey 1984). Historical range maps of river otters show them occurring from east to central Texas, but trapping limited them to the eastern region. Other studies have shown river otter presence in east Texas but there is a lack of information on the

population statuses of either of these two species within the state, let alone in the San Marcos River and how these species use this ecosystem (Baccus et al. 2007; Evans et al. 2009).

Significance of Beavers

Beavers are highly adaptable and will alter their environment to suit their needs. One of the most important components of beaver habitat is suitable den sites (Gable et al. 2016). In small ponds or lakes, they will build lodges or dens surrounded by water (beaver ponds) that provide protection from predators. These ponds create habitat abundance and diversity which, in turn, can denitrify the water, suggesting that more ponds in a riverine environment would maintain higher denitrification rates (Wohl 2021). In fast-flowing rivers they may prefer bank dens which are dug into a river or stream bank with an underwater access hole (Cowan and Guiguet 1965; Naiman et al. 1986; Baker and Hill 2003). Beavers carve out channels or canals to increase accessibility to food and building material. The variety in constructions is determinate upon the environmental conditions present during colonization. While den site-selection is widely studied (Dieter and McCabe 1989; McComb, Sedell, and Buchholz 1990; Barnes and Mallik 1997), there are no known studies examining the difference between den structures along the same river system, or what habitat modifications are a result of these colonized structures in Texas.

The lack of information on distribution of these two species within central Texas is another concern. Beavers are classified as allogenic ecosystem engineers due to their ability to modify habitats by modulating the availability of resources of biotic and abiotic materials (Rosell et al. 2005; Peterson and Schulte 2016). This form of ecosystem engineering has been shown to have direct and indirect effects on aquatic plant communities (Parker, Caudill, and Hay 2007).

They can alter entire geomorphological landscapes and increase heterogeneity and diversity of species living within these ecosystems (Gibson and Olden 2014; Wohl 2021). River otters have been shown to move into areas modified by beavers and have even been known to share their dens (Melquist and Hornocker 1983). While beaver's role as a keystone species (driver of species population and community dynamics) is highly debated, there is no doubt they play an important role in the landscape they occupy (Touihri et al. 2018).

Significance of Otters

River otters are top predators in an ecosystem and are considered keystone and sentinel species for river systems (Estes and Duggins 1995; Roemer et al. 2009). Sentinel species can indicate potential toxin threats to an ecosystem and are normally more sensitive than humans or other native species to exposure of pollutants. River otters and beavers can serve as a unit within freshwater riparian systems, regulating environmental health through their interconnected interactions (Peterson and Schulte 2016).

Previous studies on river otter habitat use tend to focus on coastal populations (Blundell et al. 2002, 2004). Those looking inland observed the interior of North America in the west or the Midwest (Melquist and Hornocker 1983; Gorman et al. 2006), but there have been no investigations into the southcentral area of the United States. Investigations concerning habitat use of beavers in North America tend to be conducted in Canada or the midwestern United States due to the well-established populations (Bloomquist et al. 2012; Mumma et al. 2018). River otters are known to form commensal sympatric relationships with beavers where they occupy the same suitable aquatic habitat. Otters are often associated with inactive beaver bank den structures and have even been recorded occupying the same active lodges as beavers (Melquist and

Hornocker 1983; Dubuc et al. 1990; Waller, 1992; Newman and Griffin 1994; Boege-Tobin 2005; Rosell et al. 2005).

Potential of Citizen Science Data

With the advancement in technology and availability of data, citizen science utilization within peer-reviewed research has become increasingly useful. There are taxonomic gaps in acquisition of scientific data and an economical solution utilized by more and more researchers has been to use non-professional volunteers (citizen scientists) as a source of biodiversity data. Many citizen science programs (iNaturalist, iSpot, Seek, etc.) contribute their information to free online databases (Flemons et al. 2007; Koch et al. 2022).

Occurrence data is more readily available than ever through these databases, such as the Global Biodiversity Information Facility (GBIF). The data provided by GBIF has been used for various purposes such as estimating change in species distribution as well as predicting populations of invasive species (Flemons et al. 2007; Skarpaas and Stabbetorp 2010). The reliability and viability of citizen science reports is still debated. By properly educating and engaging local residents on the flora and fauna present in their backyard, the potential to estimate change in species distribution and population has become possible for the layman.

MATERIALS AND METHODS

Crowd-Sourced/Citizen Science Data

Historic to recent observations of beavers and river otters in Texas were obtained through GBIF. GBIF has developed an infrastructure where various sources can publish their databases on species occurrences to a global network. This information is completely free and easily queried

for download and distribution (GBIF 2022). For this study, datasets were limited to peer-reviewed occurrences and excluded fossil records and occurrences without coordinates. The remaining data were examined to ensure the description of the occurrence matched the coordinates given and each occurrence was considered as one individual sighted to maintain consistency (GBIF, RO 2022; GBIF, B 2022).

Crowd-sourced data was collected via word of mouth and a survey through ESRI's Survey123 program to help with current sightings on the SMR. Coordinates from the GBIF combined datasets and crowd-sourced data were obtained and plotted sequentially in ESRI's ArcGIS Pro 2.9 by 5-year intervals to observe potential trends in movement or locational fidelity. For both species, there were very few sightings (< 10/year) from the first recorded occurrence up to 2012 so those sightings were plotted together. Heat maps were created to illustrate abundance within the state (Figure 4, 5).

Sign Surveys

Surveys were conducted along the SMR, from Spring Lake downstream to Ramon Lucio Park/IH-35 overpass, and at the J.C. Kellam Amphitheatre Ponds on Texas State University's campus between April 1 – April 8, 2022 over the course of 3 days (Table 2). This was done through a combination of walking and kayaking depending on accessibility. These surveys measured presence or absence detection of animal tracks, feces, or other signs such as a den (see Figure 2 and Appendix I (Table 6) for example images and descriptions of beaver and otter signs recorded in this study) and can help determine distribution/geographic range of both species.

Field signs were logged using Esri's ArcGIS Field Maps with an XY resolution of 9 m. Point and line data were collected, where applicable. Mapping and analysis were done in Esri's ArcGIS Pro 2.9.

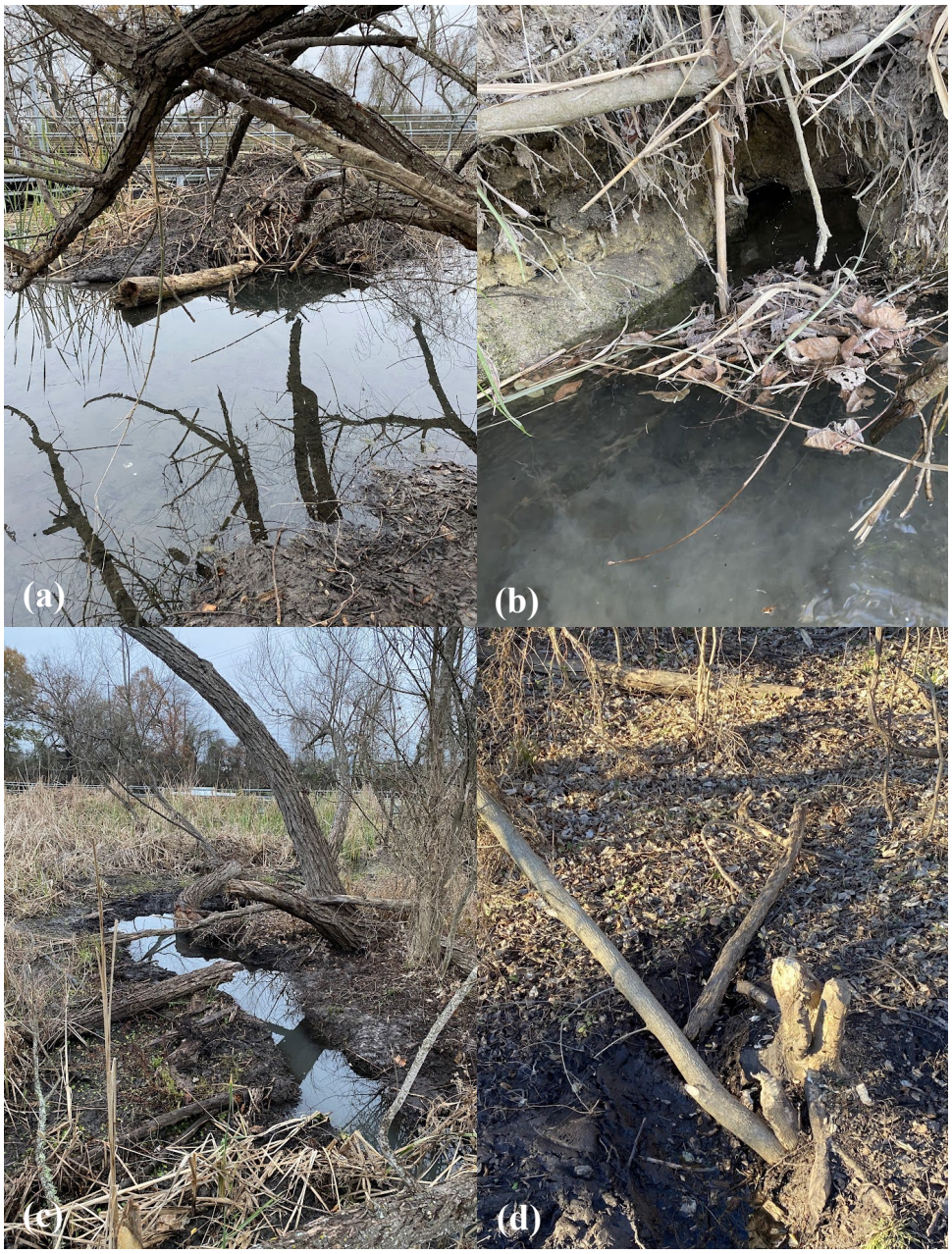

Figure 2. Examples of commonly observed beaver field signs recorded during surveys: (a) beaver lodge, (b) bank den, (c) channel, and (d) woody feeding.

Camera Trapping

Trail cameras ((3) Vikeri E2 and (10) Browning Dark Ops Pro XD) were installed in predetermined locations along the SMR, from Spring Lake downstream to Ramon Lucio Park/IH-35 overpass, and at JCK. These cameras were used to identify home sites for each species as well as common occurrence areas. The Vikeri E2's were able to record images and videos simultaneously. These cameras were programmed to take 3 images and 1 30-second video per movement detection. The Browning Dark Ops Pro XD were only able to take images or videos at once and they were set to take 4 images for per movement detection.

Habitat Modification

To determine how beavers are selectively modifying their habitat, the SMR was split into two study areas based on den structure: (1) Spring Lake and (2) the Upper SMR (Figure 1). After initial surveys, a beaver lodge was observed at the first study site and bank dens were observed along the second. Dimensions of beaver specific modifications such as channels and lodges were measured in situ (Table 5), while the total area of the pond created around the lodge was digitized in Esri's ArcGIS Pro 2.9. Water depth (m) at each of the bank dens/lodges was also measured. It should be noted throughout the entirety of this study a small section of the Upper SMR was closed off for construction purposes and therefore was unable to be surveyed and included in the study.

RESULTS

Crowd Sourced / Citizen Science Data

A total of 38 citizens reached out to me either via email, social media, or submitted a Survey123 form to report beaver and/or otter occurrences. 27 beaver and 9 otter occurrences were reported seen within San Marcos and surrounding counties. 23 of these occurrences were within my study area.

After narrowing down the GBIF datasets to both species within Texas and, excluding fossil records, there were a total of 1,254 beaver occurrences reported from 1982 to April 2022 (Figure 3). All of these occurrences ended up being Research Grade iNaturalist records. For otters, 473 occurrences were reported from 1987 to 2022. For both species, occurrences gradually increased over time with the highest number in 2021: 286 beavers and 112 otters (Table 1, Figure 3; GBIF, B 2022; GBIF, RO 2022).

This resulted in a total of 1,281 beaver occurrences and 482 otter occurrences within Texas from 1982 – 2022. Between 1982 – 2012, 29 beaver occurrences were reported (Table 1, Figure 4; GBIF, B 2022). Between 1987 – 2012, 16 otter occurrences were reported (Table 1, Figure 5; GBIF, RO 2022). From 2013 – 2017, 325 and 114 occurrences were reported for beavers and otters in Texas, respectively. From 2018 – April 2022, 924 and 352 occurrences for beavers and otters were reported, respectively (Table 1, Figure 4, 5). Beaver occurrences gradually moved west across the state, while otter occurrences stayed primarily in the eastern/central portions (Figure 4, 5).

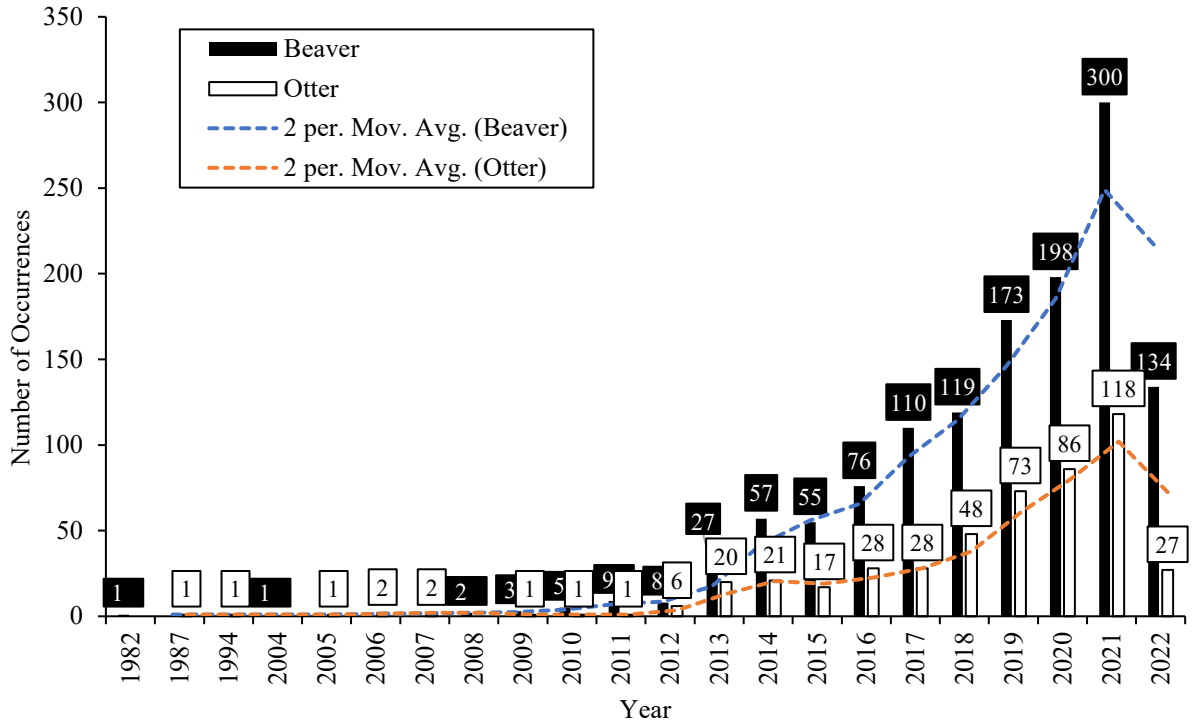

Figure 3. Occurrence data for North American beaver and river otter in Texas from 1982 – 2022 compiled from crowd source data collected by me and GBIF datasets. Moving average trendlines are included for both datasets.

Table 1. Total citizen science occurrences for each species by year with total occurrences and percent change. This data includes GBIF datasets and crowd source data collected by me.

Beaver			Otter		
Year		Percent Change	Year		Percent Change
1982	1		1987	1	
2004	1	0%	1994	1	0%
2008	2	100%	2005	1	0%
2009	3	50%	2006	2	100%
2010	5	67%	2007	2	0%
2011	9	80%	2009	1	-50%
2012	8	-11%	2010	1	0%
2013	27	225%	2011	1	0%
2014	57	119%	2012	6	500%
2015	55	-4%	2013	20	233%
2016	76	38%	2014	21	5%
2017	110	45%	2015	17	-19%
2018	119	8%	2016	28	65%
2019	173	45%	2017	28	0%
2020	198	14%	2018	48	71%
2021	300	52%	2019	73	52%

Apr 2022	134	-55%	2020	86	18%
			2021	118	37%
			Apr 2022	27	-77%

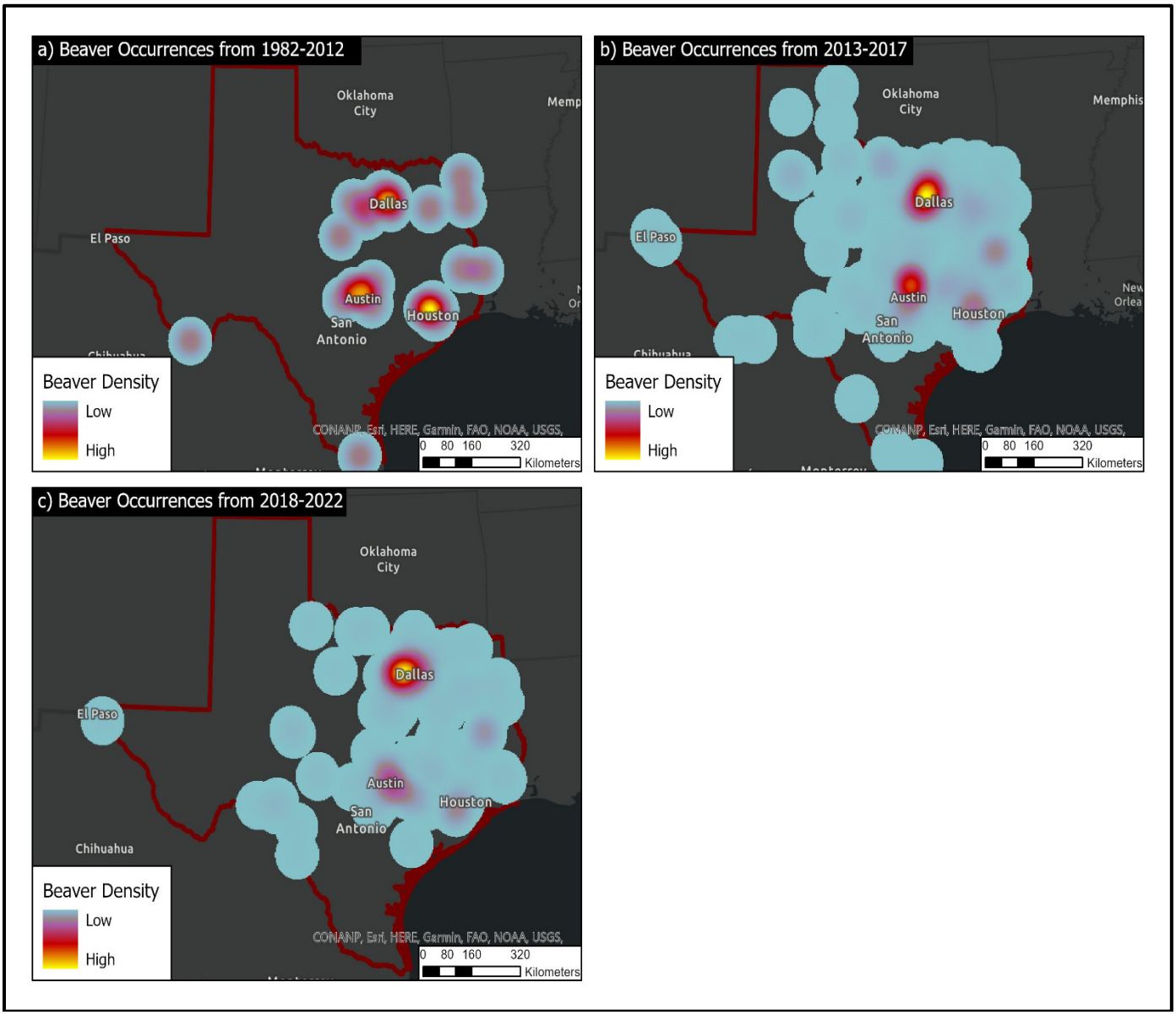

Figure 4. Heat maps of occurrence data for North American beavers in Texas from 1982 – 2022 compiled from crowd source data collected by me and GBIF datasets. Maps b) and c) show occurrences for a period of 5 years. Map a) includes data from 1982-2012 due to the amount of missing years and lack of data.

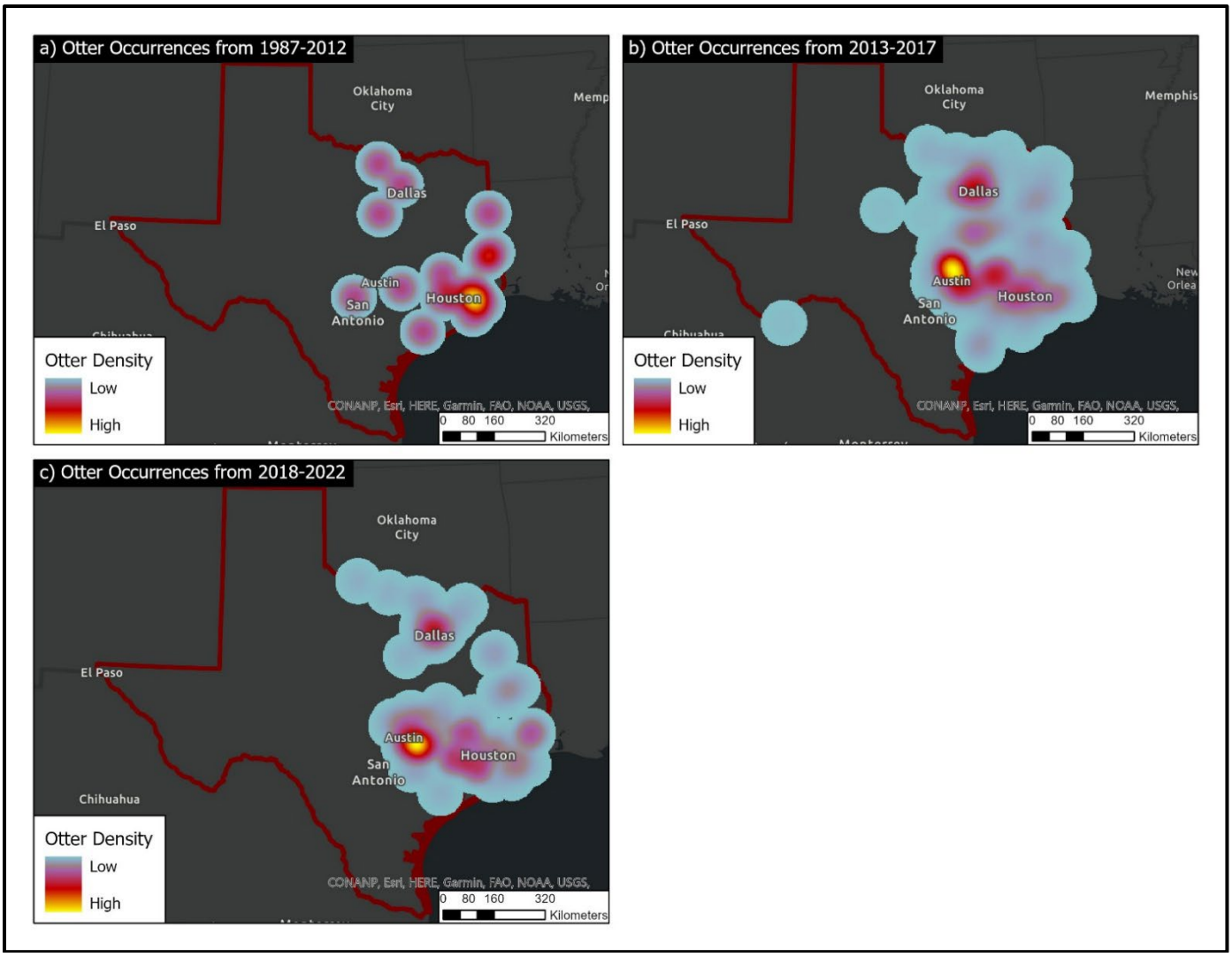

Figure 5. Heat maps of occurrence data for North American otters in Texas from 1987 – 2022 compiled from crowd source data collected by me and GBIF datasets. Maps b) and c) show occurrences for a period of 5 years. Map a) includes data from 1982-2012 due to the amount of missing years and lack of data.

Sign Surveys

Just under 5 km of the San Marcos River and adjacent waterbodies were surveyed over the course of 3 days. A total of 44 GPS locations of various beaver activity were recorded; no otter signs were observed (Figure 6, 8). There were 9 active beaver dens and 2 active lodges across all three sites (Table 2, Figure 7, 8).

Table 2. Field sign surveys of the San Marcos River (Spring Lake Dam and upper SMR) and JCK Amphitheatre Ponds on Texas State University's campus with the dates of survey, location of survey, distance surveyed (km), number of active dens, and number of active lodges found.

Survey Date	Survey Location	Distance Surveyed (km)	Number of Active Dens	Number of Active Lodges
4/1/2022	Upper SMR (Spring Lake Dam to I-35)	1.89	5	0
4/2/2022	JCK Amphitheatre/Fish Ponds	1.59	1	1
4/8/2022	Spring Lake	1.21	3	1

A total of 25 woody feedings were recorded: 6 in Spring Lake, 4 in the Upper SMR, and 15 at JCK. One soft feeding was observed via trail camera in the Upper SMR (Figure 6, 7). Spring Lake had 5 beaver created channels, 3 bank dens/burrows, 1 identifiable scent mound and 1 lodge. Comparatively, the Upper SMR had 5 bank dens while JCK had 1 bank den and 1 lodge (Figure 7).

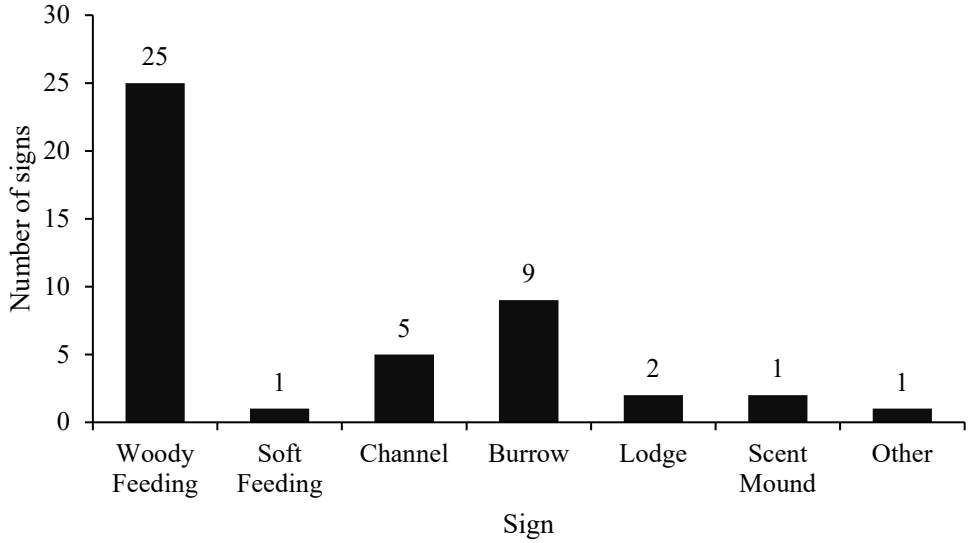

Figure 6. Total number of signs recorded on the San Marcos River (headwaters at Spring Lake and main river stem) and JCK Amphitheatre Ponds on Texas State University's campus with the sign type and the number of signs recorded.

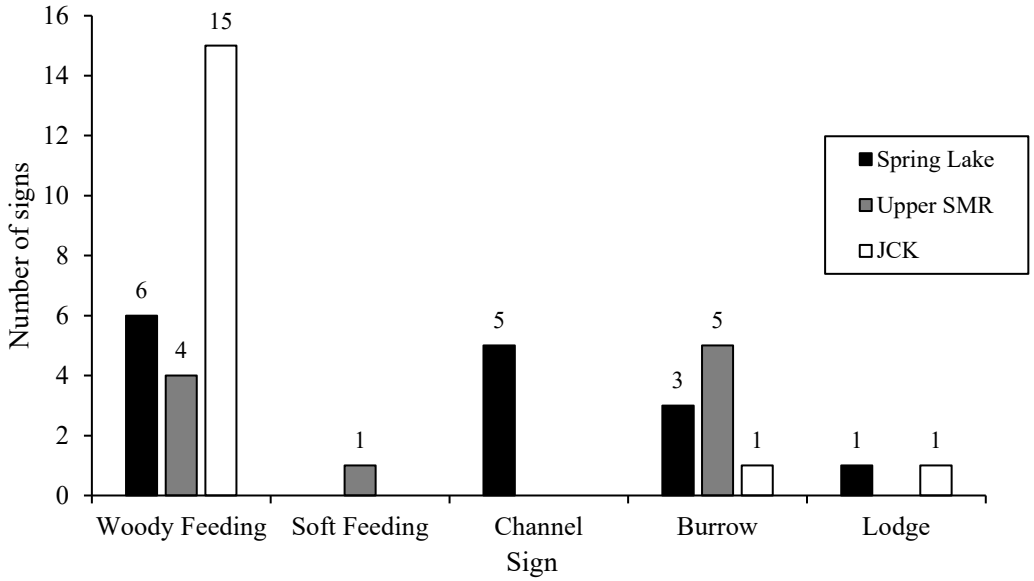

Figure 7. Types of signs recorded on the San Marcos River (headwaters at Spring Lake and main river stem) and JCK Amphitheatre Ponds on Texas State University's campus with the sign type and the number of signs recorded by location.

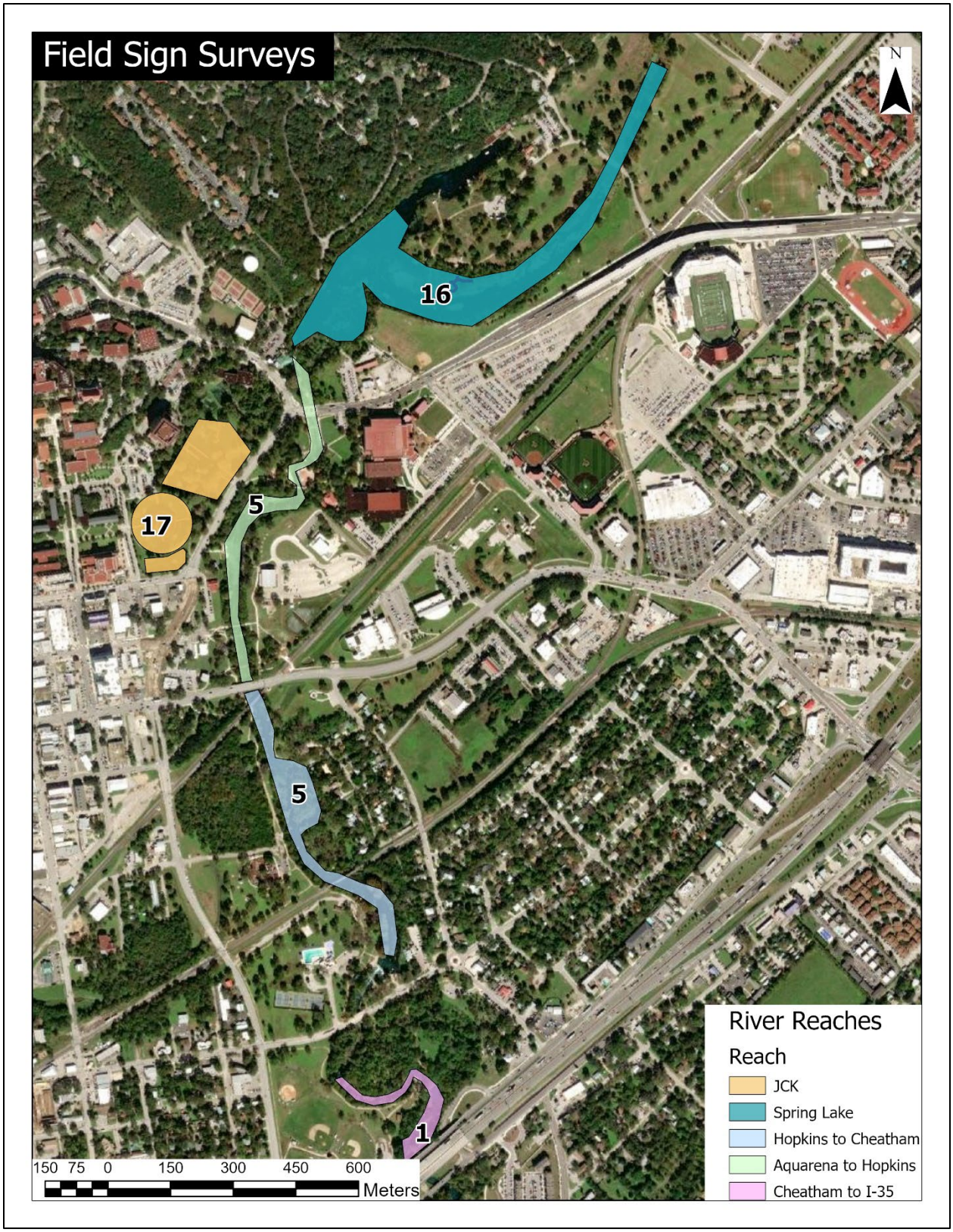

Figure 8. Map of river reaches along with the total recorded signs collected at each reach.

Camera Trapping

I completed a total of 232 camera trapping days between 10/31/2022 – 04/15/2022 at 15 different locations within the three study sites. 115 (49.6%) of those days recorded no activity of either species. During this time, over 6,300 photos/videos of otters and beavers were captured; only 8 (< 1%) were of otters. Beavers were recorded at multiple locations in all three study sites while otters were only seen in two: at the Spring Lake Lodge in Spring Lake and at City Park in the Upper SMR. The max number of beavers captured at one time was 3; the max number of otters at one time was 1 (Table 3). There were 19 images of a single nutria, *Myocastor coypus*, at the Spring Lake Lodge recorded on a single night. No other footage or observational data was observed for nutria (Table 4).

Table 3. Camera trapping locations along the San Marcos River (headwaters at Spring Lake and main river stem) and JCK Amphitheatre Ponds on Texas State University's campus with the number of camera trapping days, minimum/maximum number of beaver captured, and minimum/maximum number of otter captured.

Location	# of Camera Trapping Days	Min number of beaver	Max number of beaver	Min number of otter	Max number of otter
Western Spillway	6	0	0	0	0
Spring Lake Opposing Bank	8	0	0	0	0
Spring Lake Lodge	69	1	3	1	1
Spring Lake Channels	35	1	2	0	0
Sewell Park	18	1	2	0	0
Ramon Lucio	11	0	0	0	0
Purgatory Creek	13	0	0	0	0
JCK Den	9	1	2	0	0
Eastern Spillway	14	0	0	0	0

Discovery Center/Across from Ramon Lucio	8	0	0	0	0
City Park HCP protected area	12	0	0	1	1
City Park	11	0	0	0	0
Childrens Park	2	0	0	0	0
JCK Burrow	5	1	1	0	0
Sink Creek	11	0	0	0	0

Table 4. GPS location of nutria occurrence caught by a camera trap with coordinates, location name, number of days nutria was caught on camera, and max number of nutria recorded.

Latitude/Longitude	Location	# of Camera Trapping Days	Max number of nutria
29.8913750°N/ 97.9311862°W	Western Spillway	1	0

Habitat Modification

The channels at Spring Lake ranged in area from 3.24 m^2 to 62.11 m^2. Total area modified by channels was 110.54 m^2. Total area modified by the pond surrounding the lodge at Spring Lake was 92.70 m^2. This provided a total habitat modification area of 203.24 m^2 (Table 5). Compared to the total area of the wetland boardwalk, only 4% of the immediate area had been altered by beavers.

Table 5. Habitat modification caused by beavers at Spring Lake with the type of modification and dimensions: length (m), width (m), depth (m), and area (m2).

Habitat Modification	Length (m)	Width (m)	Depth (m)	Area (m^2)
Channel Segment				
1	4.05	0.8	1.01	3.24
2	6.47	0.75	0.84	4.85
3	9.65	0.53	0.12	5.11
4	40.96	0.86	1.00	35.23
5	59.72	1.04	0.10	62.11
Pond	11.25	8.24	2.67	92.70
Lodge	4.52	1.64	1.04	7.41

DISCUSSION

Citizen science occurrences have increased over the last decade for both species throughout the state. Occurrences are primarily on the east/central side of the state with the highest concentrations located in Houston, Austin, and the Dallas/Fort Worth area (Figure 4, 5). These current ranges are consistent with data from the earliest occurrences of both species. The occurrences in recent years are reporting beavers in some areas of west Texas. Langlois et al. (2021) observed beavers recolonizing the Llano Estacado region, specifically within lakes in Lubbock. They used trail cameras to confirm presence of beaver in the lakes after viewing citizen science reports on iNaturalist, suggesting beavers are immigrating to areas where they were currently thought to be extirpated from.

The regional citizen science data collected did include observations of both species outside the main study area, but within the boundaries of the City of San Marcos. Three of the reported regional occurrences within San Marcos were of beaver traffic fatalities. Two of these fatalities were on C.M. Allen Parkway and Cheatham Street, respectively, two highly trafficked roadways running alongside the river. The third fatality was reported downstream outside of my

study area in Martindale. Occurrences of both species were recorded in cities, such as New Braunfels and Kyle, within 10 miles north and 20 miles south of San Marcos along the 1-35 corridor. These occurrences are included in the final numbers above (Table 1, Figure 3). Unfortunately, due to time/schedule constraints, these areas were unable to be surveyed, but reports in these areas have been increasing throughout the years (Wilde 2015; Pappas 2021).

As stated previously, there was a small section of river (0.04 km) between Rio Vista Dam and Ramon Lucio Park unable to be surveyed due to construction in the area. With that, I estimate at least 3 distinct beaver colonies with 7 total individuals occupying these three study sites with a mean of 2.33 beavers/colony. This coincides with Denena (2002), who conducted a trapping and radio collar survey on nutria, with anecdotal evidence on beavers, at Spring Lake and in the Upper SMR. They observed two beavers (a male and female) who occupied the entirety of the lake. The male traveled past the dam, but the female never did. The single individual they were able to monitor in the Upper SMR stayed within the river channel (Denena 2002). In long stretches of river, Strong (1982) also estimated the number of beaver colonies based on the mean size of recognizable colonies, but they did not use camera trapping as another method to survey. Reich (2015) found using camera trapping to estimate beavers/colony allowed them to observe natural barriers of movement to beavers. This technique coupled with conducting sign surveys allowed me to also determine likely barriers of movement.

Although two otters were captured via camera trapping, the absence of otter signs suggests they have no permanent population along the Upper SMR. Otters are known to occupy active and abandoned beaver dens. With such a large home range, more time and resources would be needed to determine if they have a permanent den in the SMR system. The latest otter occurrence from crowd source information from residents local to the area was in December

2021. The images of the two otters within the SMR system obtained via camera trapping were in January and February 2022. No sightings have been reported since suggesting the reintroduction of recreational activity along the river led them to be more reclusive.

Habitat modifications observed in Spring Lake and the Upper SMR are consistent with other studies (Cowan and Guiguet 1965; Naiman et al. 1986; Baker and Hill 2003. Beavers build lodges in small ponds, such as Spring Lake and JCK (Figure 6). There is no current way to determine if the pond dimensions were consistent with past research. Butler and Malanson (2005) found pond size was dependent on the physiography of an area and there was no average beaver pond dimensional area. Along the Upper SMR where the flow rate is much faster, they clearly favor bank dens. The lack of woody feeding seen along the riverbanks could indicate the beavers in the Upper SMR are primarily consuming aquatic vegetation.

CONCLUSIONS/RECOMMENDATIONS FOR FUTURE WORK

To my knowledge, no study has ever examined the current or historic beaver and river otter abundance within southeastern Texas, let alone on a small scale such as a single river system. During reduced recreation in the San Marcos River due to river park closings on account of the COVID-19 pandemic, reports of river otter and beaver sightings became more common, and observational evidence collected in this study indicates they are still habiting these areas. This information could be vital for management practices within the San Marcos and surrounding river systems moving forward.

Future monitoring of both species within San Marcos can be conducted using the same methods within this study. Counting field signs has been a tried-and-true method for estimating the number of beavers/colonies in an area (Reich 2015; Campbell et al. 2022). Continued

monitoring and surveying along the SMR of both species over a longer period would yield more conclusive results. Surveying so late in breeding season could have impacted the number of individuals present within the SMR system. Juveniles under 2 years of age have been known to leave the main lodge to occupy bank dens while the new litter is being born. After the kits are born, the juveniles travel back to their family unit (Hartman 1997). Kits can be born as early as April, or as late as June, after this study reached its completion. Hartman (1997) also found beavers will disperse outside their natal territory if there is low population density in the area. Future monitoring would allow for more confident colony numbers.

APPENDIX I

Table 6. Table containing field signs of North American beavers and river otters observed during field sign surveys conducted from April 1, 2022 – April 8, 2022 at Spring Lake, the Upper SMR, and JCK Amphitheatre. This table was adapted from Campbell-Palmer et al. 2020 and Bottini, 2022.

Code	Sign	Description
C	Woody Feeding	Cutting or gnawing of woody vegetation (shrubs, saplings and trees)
H	Soft Feeding	Feeding on herbaceous vegetation
Ch	Channel	Beaver digging into substrate or creation of channels leading inland to access more foraging grounds
Bu	Burrow	Entrances may be below normal water levels and can extend inland forming complex underground systems
L	Lodge	Burrows where the nest chamber has breached the surface and has been built up using sticks and mud
F	Food Cache	Area where a beaver repeatedly takes material obtained elsewhere to consume
Sc	Scent Mound	A pile of material (usually mud) scrapped together by the beaver on which a distinctive scent (castoreum/ anal-gland secretion) is deposited
LS	Latrine Site	Small site cleared of leaf litter that otters visit frequently to leave scat and anal gland secretions
S	Slide	Short, worn paths leading up steep embankments
B	Bed (otter)	Dry, bedding areas created by flattening woody vegetation normally hidden from view
O	Other	Unidentifiable sign possibly caused by either species

REFERENCES

Baccus, JT, Kainer, MA, and Small, MF. 2007. Foraging preferences by American beavers, *Castor canadensis* (rodentia: Castoridae) on central Texas rivers. The Texas Journal of Science. 59(4).

Baker, BW, and Hill, EP. 2003. Beaver (Castor canadensis). Pp. 288-310, in Wild Mammals of North America: Biology, Management, and Conservation (J. A. Champman, G. A. Feldhammer, and B. C. Thompson, eds.). Second Edition. John Hopkins University Press, Baltimore, Maryland, USA.

Bailey, V. 1927. Beaver habits and experiments in beaver culture. USDA Tech. Bull. No. 21. 1-39.

Bailey, DR, Dittbrenner, BJ, and Yocom, KP. 2018. Reintegrating the North American beaver (Castor canadensis) in the urban landscape. WIREs Water. 6(1): 1-15.

Barnes, DM, and Mallik, AU. 1997. Habitat factors influencing beaver dam establishment in a northern Ontario watershed. Journal of Wildlife Management. 61(4): 1371-1377.

Ben-David, M, Bowyer, RT, Duffy, LK, Roby, DD, and Schell, DM. 1998. Social behavior and ecosystem processes: river otter latrines and nutrient dynamics of terrestrial vegetation. Ecology. 79(7): 2567-2571.

Bloomquist, CK, Nielsen, CK, and Shew, JJ. 2012. Spatial organization of Unexploited Beavers (Castor canadensis) in Southern Illinois. American Midland Naturalist. 167(1):188-197.

Blundell, GM, Ben-David, M, and Bowyer, RT. 2002. Sociality in river otters: cooperative foraging or reproductive strategies? Behavioral Ecology. 13(1): 134-141.

Blundell, GM, Ben-David, M, Groves, P, Bowyer, RT, and Geffen, E. 2004. Kinship and sociality in coastal river otters: are they related? Behavioral Ecology. 15(5): 705-714.

Boege-Tobin, DD. 2005. Ranging patterns and habitat utilization of northern river otters, Lontra canadensis, in Missouri: implications for the conservation of a reintroduced species. Dissertation, University of Missouri – St. Louis, St. Louis, Missouri.

Bottini, M. 2022. The Long Island River Otter Project's River Otter Sign and Survey Manual. https://seatuck.org/wp-content/uploads/2022/02/OtterManual.pdf.

Butler, DR, and Malanson, GP. 2005. The geomorphic influences of beaver dams and failures of beaver dams. Geomorphology. 71(1-2): 48-60.

Campbell-Palmer, R, Puttock, A, Wilson, KA, Leow-Dyke, A, Graham, HA, Gaywood, MJ, and Brazier, RE. 2020. Using field sign surveys to estimate spatial distribution and territory dynamics following reintroduction of the Eurasian beaver to British river catchments. River Research and Applications. 1-15.

Clark, MK, Ostrand, KG, and Bonner, TH. 2017. Implications of piscine predator control on the federally listed fountain darter. Fisheries Management and Ecology. 24: 292-297.

Connor, J, and Feeley, B. 1976. Management Report: A study of the beaver (Castor canadensis mexicanus) in Big Bend National Park, Texas.

Cowan, IM, and Guiguet, CJ. 1965. The mammals of British Columbia. Sutton: British Columbia.

Denena, MM. 2002. Home Range and Movement of Nutria (*Myocastor coypus)* at Spring Lake in Central Texas, with Anecdotal Comments on the American Beaver (*Castor canadensis*) of the Same Area. Thesis, Southwest Texas State University, San Marcos, Texas.

Dubuc, LJ, Krohn, WB, and Owen Jr., RB. 1990 Predicting occurrence of river otters by habitat on Mount Desert Island, Maine. Journal of Wildlife Management. 54:594-599.

Eckhardt, G. San Marcos Springs. The Edwards Aquifer Website. https://www.edwardsaquifer.net/sanmarcos.html

Evans, JW, Evans, CA, Packard, JM, Calkins, G, and Elbroch, M. 2009. Determining observer reliability in counts of river otter tracks. Journal of Wildlife Management. 73(3): 426-432.

Estes, JA, and Duggins, DO. 1995. Sea otters and kelp forests in Alaska: Generality and variation in a community ecological paradigm. Ecological Monographs. 65(1):75-100.

Fedynich, AM. 1986. Helminth Fauna of Beaver from Central Texas. Journal of Wildlife Diseases. 22(4):579-582.

Flemons, P, Guralnick, R, Krieger, J, Ranipeta, A, and Neufeld, D. 2007. A web-based GIS tool for exploring the world's biodiversity: The Global Biodiversity Information Facility Mappin and Analysis Portal Application (GBIF-MAPA). Ecological Informatics. 2: 49-60.

Gable, TD, Windels, SK, Bruggink, JG, and Homker, AT. 2016. Where and how wolves (*Canis lupus*) kill beavers (*Castor canadensis*). PLOS One. 11(12): 1-13.

GBIF: The Global Biodiversity Information Facility. 2022. What is GBIF?. https://www.gbif.org/what-is-gbif.

GBIF, RO. 2022. GBIF North American River Otter, *Lontra canadensis,* Occurrence Download. https://doi.org/10.15468/dl.gdtmdf.

GBIF, B. 2022. GBIF North American Beaver, *Castor canadensis*, Occurrence Download. https://doi.org/10.15468/dl.y95hk4.

Gibson, PP, and Olden JD. 2014. Ecology, management, and conservation implications of North American beaver (*Castor canadensis*) in dryland streams. Aquatic Conservation: Marine and Freshwater Ecosystems. 24:391-409.

Griffith, GE, Bryce, SA, Omernik, JM, Comstock, JA, Rogers, AC, Harrison, B, Hatch, SL, and Bezanson, D. 2004. Ecoregions of Texas (color poster with map, descriptive text, and photographs). Reston, Virginia. U.S. Geological Survey (map scale 1:2,500,000).

Godwin, BL, Albeke, SE, Bergman, HL, Walters, A, and Ben-David, M. 2015. Density of river otters (*Lontra canadensis*) in relation to energy development in the Green River Basin, Wyoming. Science of the Total Environment. 532:780-790.

Gorman, TA, Erb, JD, McMillan, BR, Martin, DJ, and Homyack, JA. 2006. Site characteristics of river otter (Lontra canadensis) natal dens in Minnesota. American Midland Naturalist. 156:109-117.

Hartman, G. Notes on age at dispersal of beaver (*Castor fiber*) in an expanding population. Canadian Journal of Zoology. 75: 959-962.

Heinemeyer, KS, Ulizio, TJ, and Harrison, RL. 2008. Noninvasive Survey Methods for Carnivores. Ch. 3 Natural Sign: Tracks and Scats. Eds. Long, RA, MacKay, P, Ray, J, and Zielinski, W. Island Press. Washington, DC, USA.

Koch, W, Hogeweg, L, Nilsen, EB, and Finstad, AG. 2022. Maximizing citizen scientists' contribution to automated species recognition. Scientific Reports. 12: 7648.

Lariviere, S, and Walton, LR. 1998. Lontra canadensis. Mammalian Species. 587:1-8.

Langlois, GD, Cox, RD, Gipson, PS, and Stevens, RD. 2021. The North American Beaver (*Castor canadensis*) is Recolonizing the Llano Estacado. https://doi.org/10.32942/osf.io/vsmka

McComb, WC, Sedell, JR, and Buchholz, TD. 1990. Dam-site selection by beavers in an eastern Oregon basin. The Great Basin Naturalist. 273-281.

Melquist, WE, and Hornocker, MG. 1983. Ecology of river otters in west central Idaho. Wildlife Monographs. 83:1-60.

Melquist, WE, and Dronkert, AE. 1987. River otter. Pp. 625-641 in Wild furbearer management and conservation in North America (M. Novak, J. A. Baker, M. E. Obbard, and B. Mallock, eds.). Ontario Trappers Association, North Bay, Ontario, Canada.

Mumma, MA, Gillingham, MP, and Parker, KL. 2018. Where beavers (*Castor canadensis*) build: testing the influence of habitat quality, predation risk, and anthropogenic disturbance on colony occurrence. Canadian Journal of Zoology. 96:897-904.

Naiman, RJ, Johnston, CA, and Kelley, JC. 1988. Alteration of North American streams by beaver. Bioscience, 38(11):753–762.

Naiman, RJ, Melillo, JM, and Hobbie, JE. 1986. Ecosystem alteration of boreal forest streams by beaver (*Castor canadensis*). Ecology. 67: 1254-1269.

Newman, DG, and Griffin, CR. 1994. Wetland use by river otters in Massachusetts. Journal of Wildlife Management. 58(1):18-23.

Oogjes, G. 1997. Ethical aspects and dilemmas of fertility control of unwanted wildlife: An animal welfarist perspective. Reproduction, Fertility and Development. 9(1):163–168.

Parker, JD, Caudill, CC, and Hay, ME. 2007. Beaver herbivory on aquatic plants. Oecologia. 151(4): 616-625.

Pappas, N. 2021. Beavers in the Comal. Herald-Zeitung. New Braunfels, TX.

Peterson, EK, and Schulte, BA. 2016. Impacts of Pollutants on Beavers and Otters with Implications for Ecosystem Ramifications. Journal of Contemporary Water Research and Education. 157:33-45.

Raesly, EJ. 2001. Progress and Status of River Otter Reintroduction Projects in the United States. Wildlife Society Bulletin. 29(3):856-862.

Reich, H. 2015. Rio Grande Beaver (*Castor canadensis mexicanus*) Survey in Big Bend National Park. Thesis, Texas State University, San Marcos, Texas.

Roberts, NM. 2003. River otter food habits in the Missouri Ozarks. Thesis, University of Missouri-Columbia, Columbia, Missouri.

Robitaille, J, and Laurence, S. 2002. Otter, *Lutra lutra*, occurrence in Europe and in France in relation to landscape characteristics. Anim. Conseru., 5:337-344.

Roemer, GW, Gompper, ME, and Van Valkenburgh, B. 2009. The ecological role of the mammalian mesocarnivore. BioScience. 59(2): 165-173.

Rosell, F, Bozser, O, Collen, P, and Parker, H. 2005. Ecological impact of beavers *Castor fiber* and *Castor canadensis* and their ability to modify ecosystems. Mammal Review. 35(3-4): 248-276.

Skarpaas, O, and Stabbetorp, OE. 2010. Population viability analysis with species occurrence data from museum collections. Conservation Biology. 2(3): 577-586.

Touihri, M, Labbe, J, Imbeau, L, and Darveau, M. 2018. North American Beaver (*Castor canadensis* Kuhl) key habitat characteristics: review of the relative effects of geomorphology, food availability and anthropogenic infrastructure. Ecoscience. 25(1):9-23.

Toweill, DE, and Tabor, JE. 1982. River otter: *Lutra canadensis*. Pp. 688-703, in Wild mammals of North America: Biology, Management, and Economics (J. A. Champman and G. A. Feldhammer, eds.). John Hopkins University Press, Baltimore, Maryland, USA.

Wade, DA, and Ramsey, CW. 1984. Identifying and Managing Aquatic Rodents in Texas: Beaver, Nutria, and Muskrats. Texas Agricultural Extension Service. 1556.

Waller, AJ. 1992. Seasonal habitat use of river otters in northwestern Montana. Thesis, University of Montana, Missoula, Montana.

Wilde, R. 2015. San Marcos Volunteers Clean up Unique Urban Wetlands. Spectrum Local News. San Marcos, TX.

Wilson, DE, and Reeder, DM. 2005. Mammal species of the world: A taxonomic and geographic reference (3rd ed.). Johns Hopkins University Press, Baltimore, MD.