DISTRIBUTION, HABITAT, AND CONSERVATION STATUS OF MUSKRATS (*ONDATRA ZIBETHICUS*) ALONG THE CANADIAN RIVER DRAINAGE OF THE NORTHERN TEXAS PANHANDLE

By

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DISTRIBUTION, HABITAT, AND CONSERVATION

STATUS OF MUSKRATS (*ONDATRA ZIBETHICUS*)

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NORTHERN TEXAS PANHANDLE

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INTRODUCTION

Muskrats are distributed throughout most of North America from Alaska to the southern United States. They are semi-aquatic and occur in both brackish and freshwater lakes, ponds, streams, rivers, and marshes. They are absent from parts of the southern United States, including some places in Texas, where tidal fluctuation, periodic flooding, or drought limit distribution (Wilson and Ruff 1999). Muskrats are geographically variable with 16 subspecies recognized throughout their range (Hall 1981, Willner et al. 1980).

In Texas muskrats have been recorded only in suitable aquatic habitats in northern, southeastern, and southwestern parts of the state (Schmidly 2005). Three subspecies occur in Texas: *O. z. cinnamominus* in the north (including the northern Texas Panhandle), *O. z. ripensis* along the Rio Grande and Pecos River in the Trans-Pecos region, and *O. z. rivalicius* on the Gulf Coast Plain as far west as Brazoria County (Schmidly 2005).

In some regions of Texas, muskrats appear to have declined or even disappeared during the 20th century, whereas in other regions they have invaded new areas and increased in abundance. Today, they are reasonably common along the upper Texas coast, but they have completely disappeared from the springs and tributaries associated with the Pecos River and the Rio Grande. It has been speculated that they have declined or totally disappeared along tributaries of the Canadian River in the Texas Panhandle

(Schmidly 2002, 2005). Decline of permanent natural surface water, especially the drying up of freshwater springs as a result of irrigation, followed by reduction of tule marsh habitat, has been advanced as the primary cause for their demise in these regions.

The situation with regards to muskrats in the Texas Panhandle has been a particular enigma. Vernon Bailey and other field agents working for the U.S. Biological Survey found them to be abundant at the end of the 19th century in the Canadian River drainage (Bailey 1905). Frank Blair in 1954 reported a dense population in the tule marshes of Moore and Bugby Creeks in Hutchinson County. J. Knox Jones, Jr., Clyde Jones, and associates (1988), while conducting an extensive survey of the mammals of the northern Texas Panhandle during the 1980s, did not find any evidence of muskrats at sites where they had been previously reported, but they assumed that the muskrats were still present in the area. Jones et al. (1988) listed specimens examined of muskrats in their paper from Sanford Dam on Lake Meredith along the Canadian River in Hutchinson County. They did not collect the specimens but located them in the mammal collection at West Texas State University (now West Texas A&M University).

Clyde Jones (per. comm..), one of the authors of the mammal survey of the Texas Panhandle, told David Schmidly that he actually suspected that muskrats might have completely disappeared from the area by the time of their study because most of the creeks, by that time, were dry and the tule marshes had been greatly reduced in scope. Fred Stangl and his associates reported finding the bones of a muskrat in the regurgitated pellets of a great-horned owl near a stream in the vicinity of Clarendon in Donley Country (Stangl et al. 1989), indicating that a few muskrats remained in the Panhandle.

In the fall of 2002, while working along Tallahone Creek in Roberts County, colleagues and I found muskrats living in newly developed ponds, lakes and riparian areas constructed during dredging activities on the Mesa Vista Ranch. This study focuses on the distribution, habitat preferences and variation in this recently discovered population of muskrats. More specifically, the objectives include:

1. Assess the current distribution of muskrats in the Canadian River basin of the Panhandle of northern Texas, their relative abundance, habitat preferences, and conservation status;
2. Assess morphological variation within muskrat populations in the Texas Panhandle and compare patterns of intrapopulational variation (individual, age, and sex) to other populations in their range;
3. Evaluate morphological similarity of muskrats obtained at the beginning of the 20th century with those recently collected in the 21st century; and
4. Determine whether muskrats currently present in the Panhandle of Texas represent remnant populations or a recent invader.

STUDY AREA

This study was conducted on 9 ranches in Hemphill and Roberts counties in the Panhandle of Texas, although some other aspects encompassed Ochiltree, Lipscomb, and Hutchinson counties (Fig 1). All sites are situated along the Canadian River and its sloughs and creeks (Fig. 2) and their selection was based on access to the private properties (see Table 1 for a list of ranches and site locations).

Figure 1. Overview Map of Study Area in the Panhandle of Texas.

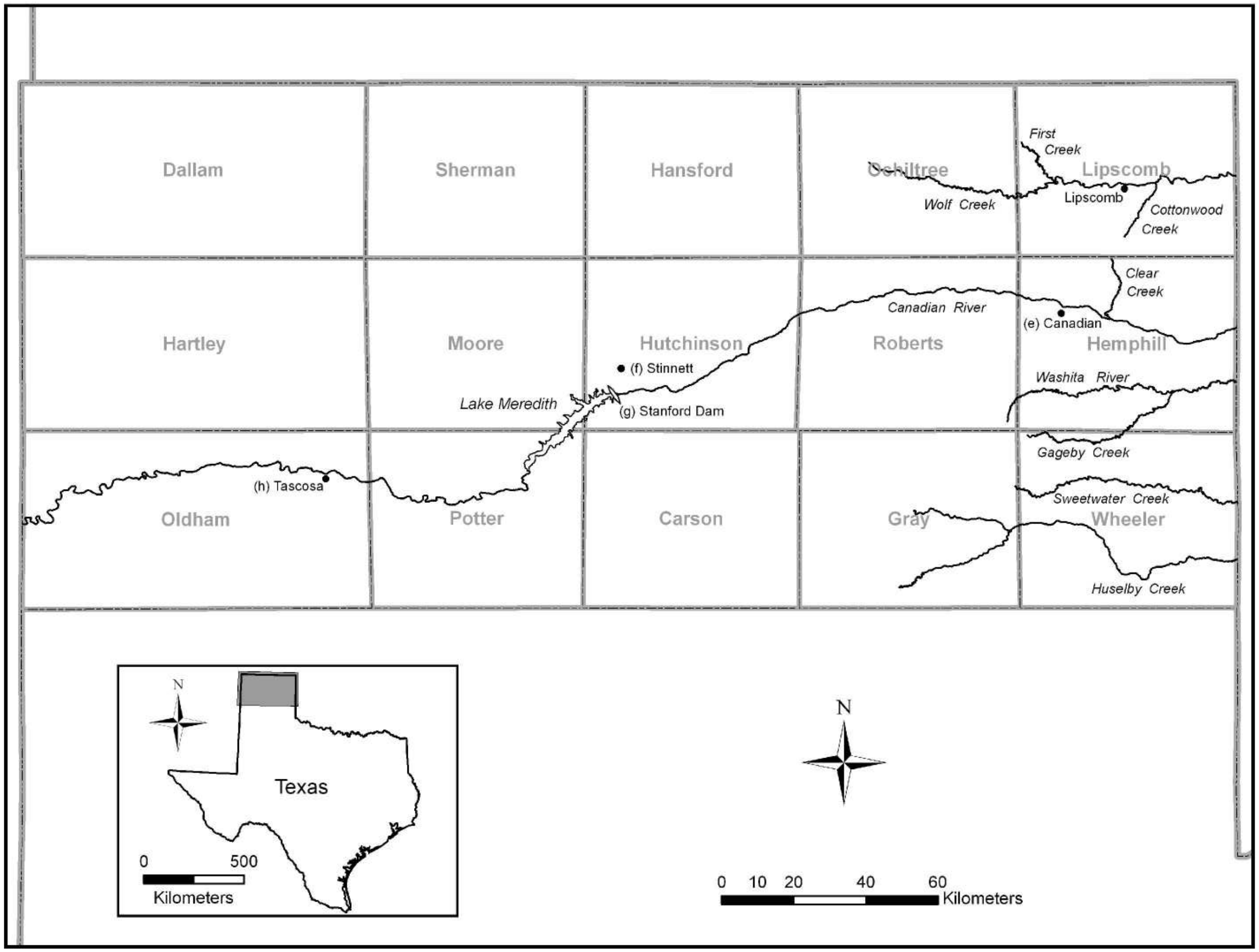


Figure 2. Ranches and collection sites in the study region of the Texas Panhandle.

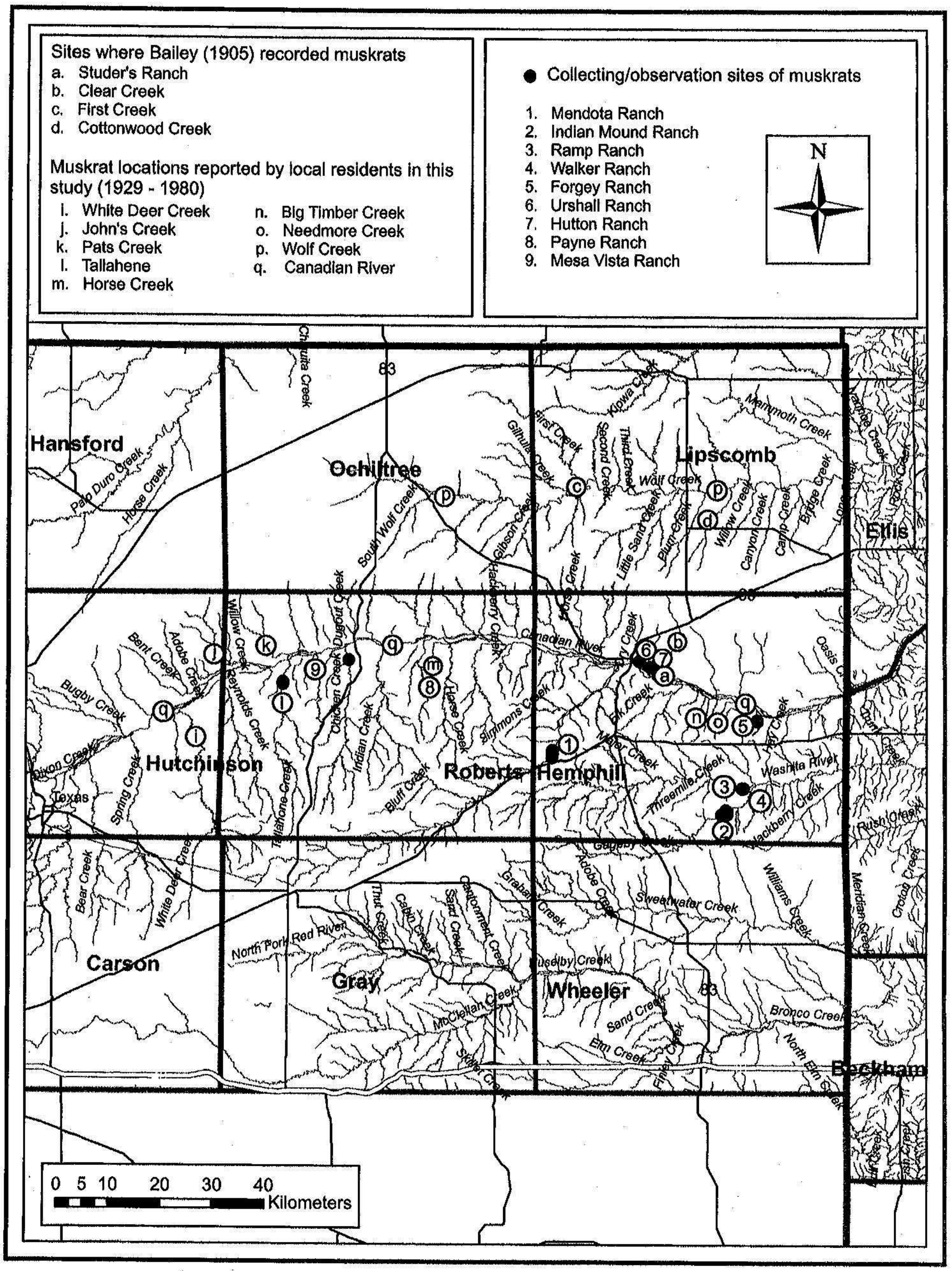


Table 1. Part A. Collecting and observation sites visited during this study. Part B. Sites where archival/literature records document occurrence of muskrats. (See Fig. 1 or 2 for a map depicting the location of these sites).

PART A. Collection/Observation Sites in this Study

	Site Names	County	Drainage Body	Site Location
1.	Mendota Ranch	Hemphill	Red Deer Creek	13 km S, 11 km W Canadian
2.	Indian Mound Ranch	Hemphill	Gageby Creek	27 km S, 15 km E Canadian
3.	Ramp Ranch	Hemphill	Washita River	22 km S, 18 km E Canadian
4.	Walker Ranch	Hemphill	Washita River	22 km S, 17 km E Canadian
5.	Forgey Ranch	Hemphill	Cabin Creek	8 km S, 21 km E Canadian
6.	Urshall Ranch	Hemphill	Canadian River and sloughs	3 km N, 2 km E Canadian
7.	Hutton Meadow	Hemphill	Canadian River and sloughs	3 km N, 5 km E Canadian
8.	Payne Ranch	Roberts	Canadian River and sloughs	3 km N, 33 km W Canadian
9.	Mesa Vista Ranch	Roberts	Tallahone Creek/Chicken Creek	1 km S, 54 km W Canadian

PART B. Archival/Literature Records*

Location	County	Documentation Source	Comments
a. Studer's Ranch	Hemphill	Bailey (1905)	
b. Clear Creek	Hemphill	Bailey (1905)	Specimen deposited at USNM[1]
c. First Creek, 15 mi. W Lipscomb	Lipscomb	Bailey (1905)	Specimen deposited at USNM
d. Cottonwood Creek, 5 mi. E Lipscomb	Lipscomb	Bailey (1905)	Specimen deposited at USNM
e. 6 mi. E Canadian	Hemphill	Jones et al. 1988	Specimen deposited at UMMZ[2]
f. 9-11 mi. E Stinnett	Hutchinson	Blair (1954)	Specimens deposited at TTU[3]
g. vicinity Sanford Dam, Lake Meredith	Hutchinson	Jones et al. 1988	Specimens deposited at WTAM[4]
h. Tascosa	Oldham	Bailey field notes, 1899	

1 = National Museum of Natural History, Smithsonian Institution; 2 = University of Michigan Museum of Zoology; 3 = The Museum Texas Tech University; 4 = West Texas A&M University.

* = Stangl etal. (1989) reported finding muskrat remains in owl pellets as well as observing an individual near a stream, 7 mi. N Clarendon, Donley County, on 10 September 1988, which is about 55 miles from the nearest site where muskrats were collected in this study.

The entire northern Panhandle lies in the High Plains physiographic section of the Great Plains Province which is a flat to gently rolling landscape, mostly with little relief except where cut by flowing water, sloping gradually downward from west to east (Gould 1978). Elevations range from about 762 m to 1,372 m. The major drainage basin of the region is the Canadian River, which forms the Canadian River Breaks, one of the dominant topographical features of the region (Jordan et al. 1984).

As noted, the study area is bisected by the Canadian River, which heads in New Mexico and has cut a relatively wide valley across the Texas Panhandle. This cutting action and that of creeks and intermittent streams draining into the Canadian has exposed the rocky layers beneath the High Plains. The geologic age of surface material is Late Cenozoic High Plains Alluvium and the soil type is Mollisols – characterized by dark loamy soils with soft granular surface matter originating from alluvial origin overlaying a bed of calcareous sediments (Jordan et al. 1984).

The northern Panhandle has a dry steppe climate, not unlike that of many of the world's interior grasslands, with a high evaporation rate. Summers are hot and winters relatively cold, resulting in a growing season of approximately 200 days. January is the coldest month and July the warmest. Average daily maximum and minimum temperatures are 34^{o} C and -7^{o} C, respectively, with an average annual precipitation of 50.8 cm (Jordan et al. 1984). Rainfall occurs mostly in the form of thundershowers, which reach a peak in late spring and early summer.

Most of the land covered by the Canadian breaks and some 25-30% of that on the High Plains to the north is utilized as cattle range. Sandy to sandy-loam soils predominate in these areas. On clay-loam and other loamy soils, croplands have been established, some irrigated and some dry. Winter wheat is by far the most important seed crop, but corn and milo also are grown. Many areas on both sides of the Canadian also produce oil and natural gas of considerable importance to the local economy.

Discounting the large areas now under cultivation, major vegetation types (McMahan et al. 1984) consist of cottonwood-hackberry-saltcedar association along the Canadian, mesquite-juniper bush along the scarps, blue gramma-buffalograss grasslands in the northwest, sand-sage-Havard shin oak brush, and mesquite-shrub grassland (Jones et al 1988). Grasses dominate the vegetation of the study area followed by various forbs, woody species, and cacti. A list of the common plants is provided in Table 2.

Of considerable importance to muskrats are the wetland/tule habitats that reside in the watershed basin. They provide the primary habitat for these semi-aquatic rodents, and there is indication that throughout the 20th century there was a consistent decline in the quality and quantity of this type of habitat (for an extensive discussion about changes on the Panhandle throughout the 20th century see Schmidly 2002).

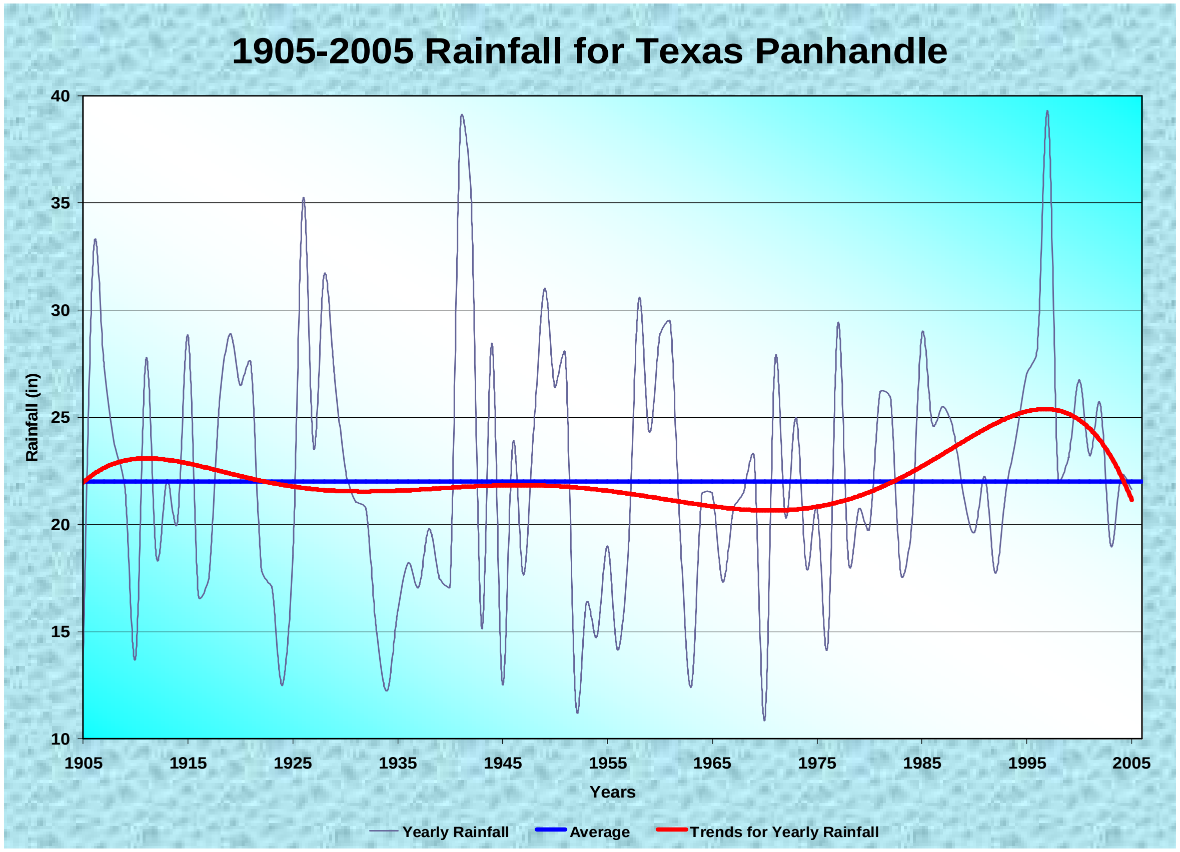
Rainfall patterns for the Texas Panhandle have varied considerably over the 20th century (see Fig 3). At the beginning of the century, when Bailey and federal agents worked in the region, until around 1920, rainfall patterns averaged above normal. For about the next 60 years, until around 1980, rainfall patterns were below average with extreme periods of lower than average rainfall from around 1950 until 1980.

Several land use and water use trends in the region during the 20th century have impacted the riparian habitats. These include an increase in man-made hydrologic features (e.g., bass ponds, earth tanks, and irrigation features); a gradual increase in the

Table 2. A list of the common plants found in Panhandle of Texas.

Grasses	Forbs	Wetland Plants	Woody Species
Common Name (Species)	Common Name (Species)	Common Name (Species)	Common Name (Species)
Buffalograss (*Buchloe dactyloides*)	Annual Buckwheat (*Eriogonum annuum*)	Cattails (*Typha spp.*)	Cottonwood (*Populus deltoides*)
Western Wheatgrass (*Agropyron smithii*)	Thistle spp. (*Asteraceae spp.)*	Southern Cattail	Salt Cedar (*Tamarix gallica*)
Indian Grass (*Sorghastrum nutans*)	Indian Blanket (*Gaillardia pulchella*)	(*Typha domingensis*)	SandSagebrush (*Artemisia filifolia*)
Prairie Cordgrass (*Spartina pectinata*)	Camphorweed (*Heterotheca pilosa*)	Common Cattail	Sand Plum (*Prunus agustifolia*)
Little Bluestem (*Schizachyrium scoparium*)	Hartweg Evening Primrose (*Calylophus hartwegii*)	(*Typha latifolia*)	Broom Snakeweed
Tall Fescue (*Festuca arundinacea*)	Sandlily (*Mentzelia nuda*)	Sedges (*Carex spp.*)	(*Gutierrezia sarothrae*)
Big Bluestem (*Andropogon gerardii*)	Ground cherry (*Physalis spp.*)	Rushes (*Juncus spp.*)	Skunkbush Sumac (*Rhus aromatic*)
Giant Sandreed (*Calamovilfa gigantean*)	Queen's Delight (*Stillingia sylvatica*)	Horsetail (*Equisetum spp.*)	Willow (*Salix spp.*)
Japanese Brome (*Bromus japonicus*)	WesternRagweed (*Ambrosia psilostachya*)	Three-cornered Sedge	Button Willow (*Cephalanthus occidentalis*)
Prairie Sedge (*Carex festucacea*)	Sagewort (*Artemisia ludoviciana*)	(*Scirpus americanus*)	Dogwood (*Cornus* spp.)
Canada Wildrye (*Elymus Canadensis*)	Dayflower (*Commelia spp.*)		Grapevine (*Vitis* spp.)
Dropseed spp. (Sporobolus spp.)	Beebalm (*Monarda citriodora*)		
Annual Threeawn (*Aristidia oligantha*)	Silverleaf Nightshade (*Solanum elaeagnnifolium*)		
Sideoats Grama (*Bouteloua curtipendula*)	Gaura (*Gaura spp.*)		
Grama spp. (*Bouteloua spp.*)	Bladderpod (*Lesquerella gordonii*)		
Longspine Sandbur (*Cenchrus incertus*)	Texas Croton (*Croton texensis*)		
Vine Mesquite (*Panicum obtusum*)			
Switchgrass (*Panicum virgatum*)			

Figure 3. Rainfall from 1905-2005 in the Texas Panhandle.



Source: Weather Source, LLC. 10 Woodson Drive, Amesbury, MA 01913 intensity of livestock grazing in riparian areas; a noticeable increase of dredging activities in the form of "stream cleanings" to improve the flow of water to newly constructed bass ponds or long-standing/earth tanks; and heightened oil and gas drilling activities which impact riparian areas by the direct spilling or indirect leaching of drilling containments into dry washes, rivers, streams, riparian areas, springs and sloughs.

METHODS

There were several components to this study, including an assessment and description of the general ecology and archival natural history of the Texas Panhandle to determine the present and past distribution of muskrats in the region; collecting of a sufficient number of specimens to allow for a morphometric assessment of population variation in current muskrat populations including a comparison to specimens collected at the beginning of the 20th century (Bailey's specimens) with those collected during the 21st century (Richards' specimens); and development of a site assessment form to evaluate the presence/absence and habitat parameters at several sites on ranches visited during this study to search for muskrats.

Archival Documentation

In 1905 Vernon Bailey published the *Biological Survey of Texas*, an account of more than 20 years of field work in the state by federal agents working under his direction from 1885-1905. Schmidly (2002) has written a history of the survey with a complete reprinting of the original book annotated with updates to reflect changes in the distribution and abundance of mammals during the 20th century. Arthur Holmes (A.H.) Howell was the federal agent who spent considerable time working for Bailey in the

Texas Panhandle. Howell made a two month visit to Hemphill and Lipscomb counties in 1903 collecting and recording observations about mammals in this region, and Bailey, himself, worked in the vicinity of Tascosa, Oldham County, in June of 1899.

In the process of preparing his book, Schmidly archived and copied all of the original field notes and landscape photographs made by federal agents who participated in the biological survey. I was provided access to these original notes and photographs including all of the areas and places the agents visited in the Texas Panhandle. This information is the basis for interpretations about the distribution and habitat of muskrats at the beginning of the 20th century. Also, I conducted an extensive literature review about muskrat natural history and distribution throughout the range of the species in North America and Europe.

During the course of my field work, I encountered several residents and landowners in the region who had resided there for several decades and were familiar with the local natural history. These individuals provided me with observations about where they had seen, trapped, or otherwise documented muskrats in the area.

Collection of Specimens

Muskrats were collected from August through October of 2004 at several sites within the designated study area (see Fig. 2). A nonresident trapping license and a Texas Parks and Wildlife Collection Permit were required to obtain specimens. Specimens were obtained using either firearms or traps. Trapping involved the use of body-gripping style traps, with a 4.5”x4.5” jaw spread (Model 110-2; Victor Oneida, Euclid, Ohio, USA). The use of these techniques was approved by the Oklahoma State University Institutional Animal Care and Use Committee (OSU-IACUC). All specimens were deposited in the Oklahoma State University Collection of Vertebrates housed in the Zoology Department.

Site Monitoring Form

A Site Monitoring Form (SMF) was developed to assess the presence/absence of muskrats at each site visited and to quantify habitat characteristics and/or muskrat sign denoted at each site. The SMF consisted of a subjective site evaluation sheet that included 13 basic parameters with a different array of variables associated with each parameter (Figs. 4, 5). The 13 basic parameters were: Location (7 different ranches); County (either Lipscomb or Hemphill); Approximate Size of Riparian Area (3 categories from 1-5 acres); Presence/Absence of Muskrats (4 categories); Habitat Codes (13 categories); Vegetation Density (5 categories); Habitat Modification (3 categories); Physical Sign (11 categories); Age of Sign (2 categories); Water Body (8 categories); and Water Depth (3 categories). A brief description of these parameters is given below and the manner in which they were coded on the SMF is depicted in Figure 5.

Data were obtained by visiting and completing a subjective site evaluation sheet for sites on 7 of the 9 ranches surveyed. Due to difficulties in accessibility, the Mesa Vista Ranch/Tallahone and Chicken Creek and Walker Ranch/Washita River sites were not visited. Muskrats at each site were assessed using a fixed width transect of 200 m x 5 m, according to the method developed by Freeman (1945) and Quayle and Westereng (1998). This technique is suitable to assess habitats that exist in the form of strips along waterways and riparian areas where conventional survey methods cannot be applied. There was only one transect conducted per site/ranch. At each location, the observer, location, county, date, temperature, and local weather were noted. The transect start and

Figure 4. A sample site monitoring form (SMF) used at locations on property surveys to document occurrence, habitat, and sign of muskrats on the northern Texas Panhandle. See Figure 5 for an explanation of codes.

Site Monitoring Form

Date: 26-Oct-2004

Observer: Jeff Richards

Location: 1 **County:** 2

UTM Coordinates: X = 0363325 Y = 3958992

Start of Transect: X = 0363328 Y = 3958985

End of Transect: X = 0363328 Y = 3958989

Total Length of Transect: 200m x 5m

Comments: Narrow cattail strip, numerous beaver in area and sign

Start Time: 13:45

End Time: 14:08

Weather: Sunny, warm, partly cloudy,wind 5-10 mph, gust 15+ mph

Temperature: Hi = 84ºF Lo = 59ºF

Pic. #s of Location:

Apprx. Size of Riparian Area: 3 = >5 acres

Presence/Absence: 1 = Rare

Pictures: 1=Physical Sign 2=Close/Immediate Area 3=Overview of Area

Observation Points	X Coordinate	Y Coordinate	Habitat	Habitat Modif.	Veg. Density	Physical Sign	Age of Sign	Water Body	Water Depth	Pic # 1	Pic # 2	Pic # 3	Comments
1	0363366	3958997	11	1	2	6	R	R	1				Camera broke
2	0363407	3958994	1	1	1	6	R	R	1				Sedges and grasses
3	0363418	3959007	1	1	0	8	R	R	1				Log
4	0363467	3958997	1	1	1	6	R	R	1				Rushes, sedges, grasses, forbs
5	0363491	3958995	7	1	1	6	R	R	1				

Figure 5. Explanation of the various codes used to complete the SMF surveys.

Parameters	Key Codes				
Approx. Size of Riparian Area:	1 = < 1 acre 2 = 1-5 acres 3 = >5 acres	Presence/Absence:	0 = Absent 1 = Rare 2 = Common 3 = Numerous	Pictures:	1 = Physical Sign 2 = Close/Immediate Are 3 = Overview of Area
Site Parameters					
Habitat Codes:	1 = Other 2 = Trees and Shrubs 3 = Open Water 4 = Shoreline 5 = Horsetail 6 = Rushes/Sedges	7 = Sedges 8 = Rushes 9 = Cattails intermixed with Rushes and Sedges 10 = Cattails intermixed with Sedges 11 = Cattails intermixed with Rushes 12 = Cattails		13 = Island	
Relative Scale of Vegetation Density:	0 = Absent	1 = Sparse 2 = Reasonably Sparse	3 = Abundant 4 = Very Abundant		
Habitat Modification:	1 = Natural/No Modifications 2 = Limited Modification/Slight Alteration (Minimal Dredging) 3 = Significant Modification/Permanently Altered (Extensive Dredging/Construction)				
Physical Sign:	1 = House 2 = Dens/Bank Burrows 3 = Pushups	4 = Nests 5 = Runways/Trails 6 = Feeding Remains	7 = Feeding Platforms 8 = Scat 9 = Tracks	10 = Visuals 11 = Vocalizations	
Age of Sign:	R = Recent/Within the Year	O = Old/Historic			
Water Body:	N = Natural Pond R = Stream/River	M = Man Made Structure or Disturbance (i.e. Dredging) D = Ditch	B = Beaver pond/dam	C = Beaver Channel	S = Slough O = Other
Water Depths:	0 = Deep water > 51 cm	1 = Shallow water 0 - 30 cm	2 = Intermittent water 31 - 50 cm		

end times were recorded in addition to the start and end points which were taken as Universal Transverse Mercator (UTM) coordinates. At each point where muskrat sign was located along the transect, a GPS waypoint was recorded along with the habitat type and modification, physical sign and age of muskrat presence, water body and depth, and three photographs (one of the physical sign, a second of the immediate area, and the third an overview of the area). Data were tabulated for each variable per site.

Presence or absence of muskrats at a site was categorized as absent, rare, common, or numerous according to the extent of physical sign observed (houses, dens/bank burrows, “pushups”, nests, runways/trails, feeding remains, feeding platforms/feeding beds, scat, tracks, visual observation, or vocalizations). The age of the sign was noted as either R for recent (within the year) or O for old/historic following the procedure of Quayle and Westereng (1998).

Because of the lack of lodges and distinctive burrows at the transect sites, feeding platforms were used as indices of muskrat abundance. Relative abundance of muskrats was assigned per site by the number of fall feeding platforms located in each individual survey transect.

Habitat use was assessed according to vegetation, water body, and water depth in conjunction with physical sign and age of sign at various points along the transect. For example, if the predominant habitat where physical sign occurred along a transect was cattails, then that was coded as the habitat type preferred by muskrats in the area. Water body and water depth were incorporated into the habitat analysis by categorizing a site as N (natural pond), M (man-made structure or disturbed site), S (slough), R (river or stream), D (ditch), B (beaver channel) and O (other). Water depth was coded as 0 for deep water (> 51 cm), 1 for shallow water (0-30 cm), and 2 for intermittent water (31-50 cm) following the protocol of Virgil and Messier (1997, 2000).

Habitat modification was assessed according to one of three categories. The first category represented habitats that had been significantly modified or permanently altered because of extensive dredging or construction. A second category represented habitats that had been modified or slightly altered in a limited manner such as a wetland in mid to early natural successional stages. A third category represented a natural riparian area in an early successional stage capable of sustaining a large population of muskrats (Bishop et al. 1979, Clark 1994).

Relative scale of vegetation density was coded from 0-4, where a score of 0 indicates an absence of vegetation, 1 sparse vegetation, 2 moderate amounts of vegetation, 3 abundant vegetation, and 4 dense vegetation (Pankakoski 1983).

Morphometrics

External and Cranial Measurements. Eighteen measurements were taken on 67 muskrats to ascertain patterns of morphological variation within muskrat populations from the Texas Panhandle. Additional specimens were examined for purposes of geographic comparisons from the National Museum of Natural History, Smithsonian Institution, Washington, D.C., the Museum of Natural History, University of Kansas, Lawrence, Kansas; and the Oklahoma State University Collection of Vertebrates, Stillwater, Oklahoma.

Five external measurements were recorded for each specimen, including TL, total body length; TAIL, tail length; BL, body length; HL, hind-foot length; and EL, ear length (Virgil and Messier 1997, 2000). Thirteen cranial measurements were recorded from each skull, including 3 from the mandible and 10 from the cranium (see Fig. 6). All bilateral measurements were taken from the right side of the specimen and skull to avoid problems related to asymmetry (Hall 1981, Boulenge et al. 1996). Cranial measurements were recorded from each specimen with a digital caliper to the nearest 0.1 mm as follows: CL, condylobasal length; ZB, zygomatic breadth; RW, rostrum width; NL, nasal length; LIC, least interorbital constriction; MB, mastoid breadth; LMT, length of maxillary toothrow; DL, length of diastema (including incisor); SD, skull depth (excluding LMT); BW, braincase width. Mandibular measurements included MF, mandibular diastema; MA, length of mandibular toothrow; and MD, mandibular height.

Aging Technique. Specimens were aged by use of the key molar technique described by Olsen (1959) and assigned to one of five age classes as follows (Table 3): age class I (juveniles, less than 7 months old), class II (juveniles/subadults, approximately 7 months old), class III (subadults, 8-11 months old), class IV (subadults/adults, approximately 12 months old), or class V (adults, greater than 12 months old).

Statistical Analysis. Individual, age, and secondary sexual variation were analyzed with the Statistical Analysis System 9.1 (SAS 2004). Means were calculated for each character and a one-way analysis of variance was used to test for differences among age classes and between sexes. Coefficients of variation (CV) were calculated to determine the extent of variability for each character. The General Linear Model (GLM) procedure was employed to test for significant variation among age classes within each sex (see Engstrom et al. 1982). Analysis of variance (ANOVA) was coupled with

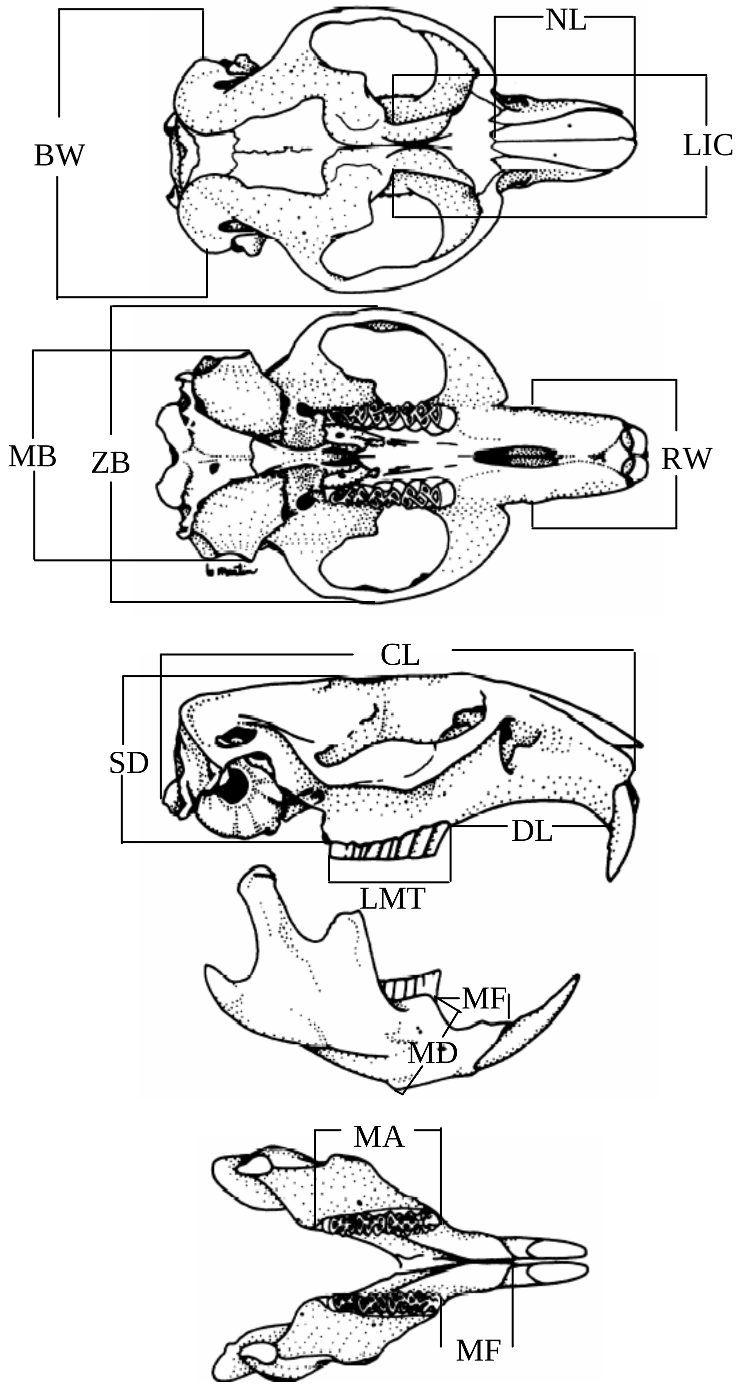


Figure 6. The dorsal, ventral, and lateral views of skull and lateral and dorsal views of mandible of Ondatra zibethicus depicting cranial measurements taken. Skull drawing adapted from a drawing by Wilma Martin, Appalachian Environmental Laboratory, the American Society of Mammalogists, Nov. 20, 1980.
CL = Condylobasal Length, ZB = Zygomatic Breadth, RW = Rostrum Width, NL = Nasal Length, LIC = Least Interorbital Construction, MB = Mastoid Breadth, LMT = Length of Maxillary Toothrow, DL = Length of Diastema (including incisor), SD = Skull Depth (excluding LMT), BW = Braincase Width.
MF = Mandibular Diastema, MA = Length of Mandibular Toothrow, MD = Mandibular Height.
MF = Mandibular Diastema, MA = Length of Mandibular Toothrow, MD = Mandibular Height.

Table 3. The five age classes, as defined by morphological characteristics, used in the study of non-geographic variation. (adapted from Olsen 1959).

Age Class	Age in Months	Cranial and Dental Characters
I (Juveniles)	< 7	Typical juvenile; very little root development; fluting extends deep into alveolar socket; palatal and sagittal sutures not tightly fused; temporal ridge, sagittal crest, and lambdoidal crest not detectable; Pre-intramembranous ossification (transluscent appearance).
II (Juveniles/Subadults)	7	Progressive root development; end of fluting visible but still extending into the alveolar socket; palatal and sagittal sutures fused; temporal ridge, sagittal crest, and lambdoidal crest are visible but not pronounced; Progressive intramembranous ossification (opaque appearance).
III (Subadults)	8-11	Typical subadult; moderate root development; end of fluting at point of emergence at bone line; palatal and sagittal sutures are moderately fused and visible; temporal ridge, sagittal crest, and lambdoidal crest are well defined but not pronounced; intramembranous ossification (eggshell appearance).
IV (Subadults/Adults)	12	Prominent root development; end of fluting just below bone line; palatal and sagittal sutures are tightly fused and visible; temporal ridge, sagittal crest, and lambdoidal crest well defined and detectable; intramembranous ossification (moderately dense bone structure); Lack noticeable tooth wear
V (Adults)	>12	Typical adult; roots well developed; end of fluting extruded well below bone line; palatal and sagittal sutures are tightly fused and some sections may no longer be as defined; temporal ridge, sagittal crest, and lambdoidal crest highly pronounced; post-intramembranous ossification (highly dense bone structure); noticeable tooth wear.

Boneferroni adjustment to pair-wise comparisons for each of the sexes and the five age classes and least square means were calculated for the 5 external and 13 cranial measurements. Duncan's Multiple Range Mean Test (DUNCAN) was employed to evaluate significant differences among age classes with sexes separated. A t-test was used to test for significant differences between sexes of the same age class (Schmidly and Read 1986).

Statistical analysis of muskrat measurements from specimens collected during the Bailey survey (1903) were compared to those collected during this study to determine if any significant changes in morphology had occurred over the century. Univariate and multivariate techniques were used to evaluate trends. To assess discrimination between the Bailey and the Richards' specimens, a multivariate stepwise discriminant function analysis was performed using SAS. This program calculates discriminant function coefficients for each variable used to classify groups, calculates an F matrix and U statistic to test the hypothesis of equality of group means, and produces a classification matrix that indicates the number of specimens properly classified into the *a priori* groups (Engstrom et al. 1982).

RESULTS

Archival Documentation

Bailey and the federal agents documented muskrats at 3 sites during the biological survey in the Texas Panhandle (Fig. 2). Perusal of field notes and photographs reveal considerable suitable habitat and a relatively high density of these animals. Bailey (1905: 120) recorded muskrats as "numerous at Clear Creek [Hemphill County], living in fish ponds and irrigation ditches, where they cause considerable trouble by tunneling into the banks and thus releasing water." He went on (pp. 120-121) to comment on the habitat of *O. zibethicus* on Cottonwood and First creeks, tributaries of Wolf Creek in Lipscomb County.

Arthur Howell, one of the federal agents who worked with Vernon Bailey on the biological survey, documented evidence of muskrats at these sites. He visited Studer's Ranch on 9-12 April 1903, a site located along Clear Creek where it flows into the Canadian River near the town of Canadian in Hemphill County, and he wrote an extensive account in his field notes about the region near the river and its tributaries where muskrats were trapped:

"Canadian is situated on the south bank of the Canadian River, which at this season is a very insignificant stream. But which in high water covers an area of half a mile in width. The soil in the valley is very sandy, and supports only a scanty growth of sagebrush, wild plum bushes, 'skunk brush', various grasses and wild flowers, and a few cottonwood trees. The wind has piled the sand into curiously shaped hills on many of which there is no vegetation whatever. In the bottoms, between the sandhills and the prairie which rises gradually from the valley, are numerous ponds, mud flats and meadows. Considerable hay is cut from the meadows, some of them being wet nearly all summer, others dry for most of the year. The sandhills described above are principally on the south shore of the river, at a point where the river makes a bend. On the north shore the conditions are somewhat different. The meadows are broader, and there are extensive marshy areas grown up to rushes. There are also good sized tracts of timber on this side, most of it on more or less swampy ground. The cottonwood is the prevailing tree, with a few elms, hackleberries and willows. Shrubs noticed were *Cephalanthus occidentalis, Cornus asperifolia* [=*Cornus foemina*], *Prunis angustifolia*. Just back of the meadows the sandhills begin, the soil being of a more or less yellow color and grown over sparsely with sagebrush (*Artemisia filifolia*) and a few small shrubs. Clear Creek flows into the Canadian from the north, and several fine ranches are located along its lower course, the water being used for irrigating the fields and gardens. I spent 4 days at Mr. Studer's ranch close to the river, and trapped in the sandhills and about the borders of the fields. Mesquite grows sparingly on the western slopes of some of the hills west of Canadian. The largest brush seen was about 10 feet high" (see Schmidly 2002, Fig. 94, p. 361).

Howell visited Lipscomb, Lipscomb County, from 20 June – July 10 1903 and recorded the following conditions where he found muskrats:

> "They [muskrats] are found in small numbers in nearly all the small grassy creeks throughout this region. I secured two on Cottonwood Creek, 5 miles east of here, and a man who went fishing there a few days later saw three more. He approached near enough to one, which was feeding on the bank, to hit it with his fishing pole, and after it had retreated into a hole in the bank he prodded it until it came out and swam away. I set traps at the place later, but caught nothing. In a creek known as First Creek, flowing into Wolf Creek from the north 15 miles west of Lipscomb, I found the muskrats really abundant, the local conditions being peculiarly favorable for them. This stream consists of a series of wide and deep holes, with abundance of marsh grass growing on their borders, and partially filled with a flowering water plant (*Batrachium divaricatum*) upon which the muskrats feed. Their trails could be seen leading in every direction through this mass of floating vegetation, and one could hardly walk a half mile along the creek at any time of day without seeing one or more of the rats. Their favorite feeding times are about sundown and sunrise, and at these times I

> sometimes see eight or ten in a short distance. They swim out from the bank into the water plant, and rest quietly on the surface while they feed. Several which I shot had the flowers of this plant in their mouths. These rats do not build nests, as their eastern cousins do, but live entirely in holes in the banks, entering either below or just at the surface of the water. When alarmed they dive and take refuge in one of these hidden retreats. When I first began to hunt them they were much less wary than after several had been killed, and if one were to sit quietly on the bank they would feed and move about unconcernedly. I secured seven in two evenings' hunting, besides wounding several which got away. I failed to catch any in traps, except one, which got away with the trap. I was told that they are common for miles up this stream, and, if so, there must be hundreds of them. (June 19 to July 10, 1903) (see Schmidly 2002, Fig. 93, p. 360).

Studer's Ranch is <1 mile from two of the areas (Urshal Ranch and Hutton Meadow sites) where I found muskrats to be abundant. Also, the photographs that Howell took look very similar to the habitats that I have documented there today. Lipscomb is about 15 miles from the ranches where I worked and the habitats along First Creek also closely resemble the places where I worked.

Although he did not write about this site in his 1905 *Biological Survey of Texas,* Bailey's field notes deposited in the archives of the U.S. Biological Survey at the Smithsonian Institution, in Washington, D.C., contain references to muskrats in his species accounts for June 4-6, 1899, at Tascosa, Oldham County: "*Fiber* [*Ondatra*] *zibethicus*. There are said to be plenty of muskrats in a slough a mile up the river." Bailey did not obtain any specimens at this site, and apparently his written comments refer to information passed to him by local residents. Oldham County is located adjacent to the state of New Mexico, and Tascosa is situated along the Canadian River in the far northeastern part of the county about 100 miles SSE of my study site. I was unable to visit the Tascosa area during my study so I do not know if muskrats still remain in that region of the Canadian drainage system.

As part of my study I did record information told to me by long time residents and landowners concerning their observations of muskrats in the Canadian River basin. Discussion with former muskrat trappers who lived near the study region from 1920 – 1980 confirmed the presence of muskrats in the Canadian River drainage well into the 1980s (Fig. 2). Bill Miller, a Canadian, Texas, resident and former local muskrat trapper, recalls trapping muskrats with his father in the late 1920's through the mid 1930's along White Deer Creek, Johns Creek, and Pats Creek in Hutchinson County; Tallahone Creek and Horse Creek in Roberts County; Big Timber Creek and Needmore Creek in Hemphill County; Wolf Creek in Ochiltree and Lipscomb counties; and the Canadian River in Hutchinson, Roberts, and Hemphill counties. Bill Miller and associates reported trapping approximately 100 muskrats on White Deer Creek in 1955. Salem and Eddie Abraham of the Mendota Ranch recalled observing a muskrat on Red Deer Creek in the late 1980's.

Occurrence, Relative Abundance, and Habitat

<u>Occurrence and Relative Abundance</u>. – Muskrat occurrence and sign was assessed on 6 ranches and 1 meadow in Hemphill County and on 2 ranches in Roberts County (Table 4). Muskrats were trapped at 7 of the locations and shot at 3; 63 specimens were obtained by trapping and 5 by shooting (Table 4).

Seven of the 9 locations were surveyed using the SMF protocols (Tables 5, 6 for a summary of documentation for each location and for all locations combined). Most of the physical sign documenting muskrats appeared to be recent (within the year) as opposed to old or historic. Of the seven SMF surveys conducted, three were performed on stream/river, three on sloughs, and one in a mixture of half slough and half dredge pond. The 7 SMF surveys produced a total of 147 observations/sign documenting

Table 4. Summary of the number of muskrats trapped and/or shot at the 9 sites used in this study.

Names	Trapping Sites	Specimens Per Site	Shooting Sites	Specimens Per Site
Mendota Ranch	1	2	1	1
Indian Mound Ranch	1	13	0	0
Ramp Ranch	2	8	0	0
Walker Ranch	1	1	0	0
Forgey Ranch	1	9	0	0
Urshall Ranch	1	8	0	0
Hutton Meadow	3	22	0	0
Payne Ranch	0	0	0	0
Mesa Vista Ranch	0	0	2	4
Total	**10**	**63**	**3**	**5**

muskrats (Table 6). Muskrat observations were most common on the Ramp Ranch (Washita river) and Payne Ranch (slough off the Canadian River); less common at the Indian Mound Ranch (Gageby Creek), Forgey Ranch (Cabin Creek), Urshal Ranch (slough off Canadian River), and Hutton Meadow (slough off Canadian River); and rare on the Mendota Ranch (Red Deer Creek) (Table 5). The most common physical signs were feeding remains, feeding platforms, and scat.

Habitat. – Natural, dense, abundant cattail stands in streams/rivers or sloughs with a water depth of <30 cm constituted the preferred habitat of muskrats (see Tables 5,6). In all the surveys the greatest amount of physical sign was noted in shallower waters at depths of <30 cm (Table 6). Observations were most common in streams, rivers, and sloughs with fewer observations made in man-made structures or disturbed areas (i.e., dredged areas). Less preferred habitat included a mixture of shoreline, sedges, and rushes intermixed with sedges. Natural habitat was far preferred to modified habitats. The vast

Table 5. Summary of site monitoring form (SMF) surveys per each of the 7 observation sites.

Habitat		Habitat Modification		Vegetation Density		Physical Sign		Age of Sign		Water Body		Water Depth	
Observations	Parameter	Observations	Parameter	Observations	Parameter	Observations	Parameter	Observations	Parameter	Observations	Parameter	Observations	Parameter
						Mendota Ranch/Red Deer Creek							
1	Other	5	Natural/No Modification	1	Absent	4	Feeding Remains	5	Recent/Within the Year	5	Stream/River	5	Shallow water (0-30 cm)
7	Sedges			3	Sparse	1	Scat						
11	Cattails intermixed with rushes			1	Reasonably Sparse								
						Indian Mound Ranch/Gageby Creek							
10	Other	10	Natural/No Modification	7	Sparse	6	Dens/Bank Burrows	7	Recent/ Within the Year	10	Stream/River	10	Shallow water (0-30 cm)
				3	Reasonably Sparse	4	Feeding Remains	3	Old/Historic				
						1	Scat						
						1	Tracks						
						Forgey Ranch/Cabin Creek							
1	Other	17	Natural/No modification	10	Abundant	11	Feeding Remains	18	Recent/Within the Year	18	Slough	14	Shallow Water (0-30 cm)
4	Cattails intermixed with rushes	1	Limited Modification/ Slight Modification (Minimal dredging)	8	Very Abundant	9	Feeding Platforms					4	Intermittent Water (31-50 cm)
13	Cattails					1	Scat						
						Payne Ranch/Slough off Canadian River							
1	Rushes/ Sedges	19	Natural/No modification	1	Reasonably Sparse	8	Feeding Remains	19	Recent/Within the Year	19	Slough	10	Deep Water (>51 cm)
3	Cattails intermixed with rushes			3	Abundant	11	Feeding Platforms					4	Shallow Water (0-30 cm)

Table 5. continued

15	Cattails			15	Very Abundant	3	Scat					5	Intermittent Water (31-50 cm)
Hutton Meadow/Slough off Canadian River													
9	Other	9	Natural/No modification	1	Abundant	3	Feeding Remains	9	Recent/Within the Year	9	Slough	9	Shallow Water (0-30 cm)
				8	Very Abundant	4	Feeding Platforms						
						3	Scat						
Urshall Ranch/Slough off Canadian River													
10	Shoreline	11	Natural/No modification	1	Reasonably Sparse	16	Feeding Remains	22	Recent/Within the Year	11	Slough	5	Deep Water (>51 cm)
9	Rushes/ Sedges	11	Significant Modification/ Permanently Altered (Extensive dredging)	10	Abundant	1	Feeding Platforms			11	Man-made Structure or Disturbance (i.e. Dredging)	16	Shallow Water (0-30 cm)
13	Sedges			11	Very Abundant	1	Scat					1	Intermittent Water (31-50 cm)
						4	Vocalization						
Ramp Ranch/Washita River													
6	Other	64	Natural/No modification	1	Sparse	44	Feeding Remains	64	Recent/Within the Year	64	Stream/River	1	Deep Water (>51 cm)
2	Cattails intermixed with sedges			9	Abundant	16	Feeding Platforms					37	Shallow Water (0-30 cm)
1	Cattails intermixed with rushes			54	Very Abundant	5	Scat					26	Intermittent Water (31-50 cm)
55	Cattails												

Table 6. Summary of Site Monitoring Form (SMF) Surveys[1] for all 7 sites combined.

Habitat[2]		Habitat Modification		Vegetation Density		Physical Sign[3]		Age of Sign		Water Body[4]		Water Depth	
Observations	Parameter	Observations	Parameter	Observations	Parameter	Observations	Parameter	Observations	Parameter	Observations	Parameter	Observations	Parameter
29	Other	135	Natural/No Modification	1	Absent	6	Den/Bank burrows	144	Recent/ Within the Year	79	Stream/ River	16	Deep Water (>51 cm)
10	Shoreline	1	Limited Modification/ Slight alteration (Minimal dredging)	11	Sparse	90	Feeding Remains	3	Old/Historic	11	Man-made Structure or Disturbance (i.e. dredging)	95	Shallow Water (0-30 cm)
10	Rushes/ Sedges	11	Significant Modification/ Permanently altered (Extensive dredging)	6	Reasonably Sparse	41	Feeding Platforms			57	Slough	36	Intermittent Water (31-50 cm)
14	Sedges			33	Abundant	15	Scat						
2	Cattails intermixed with sedges			96	Very Abundant	1	Tracks						
9	Cattails intermixed with rushes					4	Vocalizations						
83	Cattails												

[1]Summary based on SMF surveys done on Mendota Ranch/Red Deer Creek, Indian Mound Ranch/Gageby River, Forgey Ranch/Cabin Creek, Payne Ranch/Slough off Canadian River, Hutton Meadow/Slough off Canadian River, Urshall Ranch/Slough off Canadian River, and Ramp Ranch/Washita River.

[2]Habitat - There were no observations at the following parameters: Trees and shrubs, open water, horsetail, rushes, cattails intermixed with rushes and sedges, and island

[3]Physical Sign - There were no observations at the following parameters: House, pushups, nests, runways/trails, and visuals

[4]Water Body - There were no observations at the following parameters: Natural pond, ditch, beaver channel, beaver pond/dam, and other

majority of observed muskrat physical sign was found in the denser stands of vegetation.

Population Variation

Three types of nongeographic variation (secondary sexual, age, and individual) were assessed using the morphometric data from external and cranial measurements. To my knowledge, information of this type is not available in the literature for populations of *O. z. cinnamominus* from Texas. With the exception of length of mandibular toothrow (MA), no significant differences were found between sexes and the sex versus age comparison, but significant differences were found among age classes (Table 7). In the measurement MA, males and females were not significantly different in age class I but they were significantly different in the other age classes.

Age Variation. – Generally, juveniles (age class I) were significantly smaller than were subadults or adults (age classes II-V). With the exception of LIC, age class I completely separated from the other age classes (Table 8). External measurements revealed little difference between age classes II – V and five cranial measurements (MA, MD, LIC, MB, and LMT) revealed no significant difference among these 4 age classes. The other cranial measurements revealed varying patterns of variation with little statistical consistency other than age class V differed significantly from age class II. For purposes of assessing secondary sexual and individual variation, age classes III – V were combined to form a single sample.

Secondary sexual variation. – No measurements revealed significant differences between males and females (Table 7). Males averaged slightly larger than females in all 5 external measurements and in 4 cranial measurements (LB, NL, LIC, MF). Females

Table 7. Results of analysis of variance (p< 0.05) between adult male and female specimens of *Ondatra zibethicus* on the Texas Panhandle.

Variate	Males N	Males Mean ± 2 SE	Males CV	Females N	Females Mean ± 2 SE	Females CV	*F*	|t|	P-Value	S/NS
TL	28	478.60 ± 8.91	8.31	38	470.70 ± 8.54	8.44	0.41	0.64	0.5249	NS
BL	28	293.04 ± 5.27	8.02	38	286.12 ± 5.05	8.21	0.90	0.95	0.3474	NS
TAIL	28	185.56 ± 4.19	10.06	38	184.58 ± 4.01	10.11	0.03	0.17	0.8662	NS
HFL	28	70.52 ± 0.81	5.12	38	70.28 ± 0.78	5.14	0.04	0.20	0.8360	NS
EL	28	18.78 ± 0.28	6.66	38	18.47 ± 0.27	6.77	0.61	0.78	0.4388	NS
CL	27	60.48 ± 0.73	4.58	36	61.01 ± 0.60	4.54	0.31	0.56	0.5803	NS
LB	27	37.35 ± 0.58	5.86	35	37.03 ± 0.47	5.91	0.18	0.42	0.6731	NS
RW	28	12.71 ± 0.15	5.27	37	12.76 ± 0.14	5.25	0.06	0.24	0.8086	NS
NL	28	19.08 ± 0.29	6.76	37	19.07 ± 0.28	6.76	0.00	0.00	0.9765	NS
LIC	28	6.49 ± 0.07	4.62	37	6.40 ± 0.06	4.69	0.86	0.93	0.3567	NS
MB	27	26.36 ± 0.34	4.93	37	26.46 ± 0.28	4.91	0.07	0.26	0.7985	NS
LMT	28	15.06 ± 0.15	4.45	38	15.08 ± 0.14	4.44	0.01	0.10	0.9420	NS
SD	28	22.22 ± 0.27	5.40	38	22.45 ± 0.26	5.35	0.36	0.60	0.5522	NS
DL	28	24.46 ± 0.35	6.30	37	24.63 ± 0.33	6.25	0.12	0.35	0.7316	NS
BW	28	25.39 ± 0.31	5.40	38	25.48 ± 0.29	5.38	0.05	0.22	0.8235	NS
MF	27	12.78 ± 0.16	4.77	38	12.72 ± 0.13	4.80	0.09	0.30	0.7682	NS
MD	28	14.52 ± 0.15	4.68	38	14.83 ± 0.15	4.59	2.05	1.43	0.1582	NS
MA	28	14.96 ± 0.30	4.21	38	15.15 ± 0.28	4.16	0.91	0.95	0.3433	NS

Table 8. Variation with age in external and cranial measurements of *Ondatra zibethicus* from the Texas Panhandle. Age classes are defined in Table 4. Statistics given are number, mean, range, coefficient of variation, F, and F_s. Symbols along side age classes indicate nonsignificant subsets according to DUNCAN tests.

Age Class	N	Mean ± 2 SE	Range	CV	F/F_s	Duncan Results
		Total Length (TL)				
I	27	410.16 (±7.78)	275.00-506.00	9.69	17.11	
II	17	485.17 (±10.09)	452.00-530.00	8.19	<0.0001	
III	5	490.00 (±18.14)	446.00-520.00	8.11		
IV	5	480.17 (±18.14)	437.00-505.00	8.28		
V	12	507.75 (±11.47)	462.00-550.00	7.83		
		Body Length (BL)				
I	27	251.03 (±4.60)	180.00-295.00	9.36	18.52	
II	17	296.20 (±5.96)	275.00-340.00	7.93	<0.0001	
III	5	293.92 (±10.73)	262.00-314.00	8.00		
IV	5	293.67 (±10.73)	269.00-305.00	8.00		
V	12	313.08 (±6.78)	279.00-341.00	7.51		
		Tail Length(TAIL)				
I	27	159.13 (±3.66)	95.00-211.00	11.73	11.77	
II	17	188.97 (±4.74)	171.00-205.00	9.88	<0.0001	
III	5	196.08 (±8.52)	184.00-212.00	9.52		
IV	5	186.50 (±8.52)	168.00-203.00	10.01		
V	12	194.67 (±5.39)	175.00-209.00	9.59		
		Hind Foot Length (HFL)				
I	27	67.20 (±0.71)	53.00-75.00	5.37	5.24	
II	17	71.12 (±0.92)	68.00-74.00	5.08	0.0006	
III	5	69.83 (±1.65)	68.00-72.00	5.17		
IV	5	72.00 (±1.65)	70.00-75.00	5.02		
V	12	71.83 (±1.04)	68.00-78.00	5.03		

Table 8. Continued.

Age Class	N	Mean ± 2 SE	Range	CV	F/F$_s$	Duncan Results
			Ear Length (EL)			
I	27	17.24 (±0.25)	13.00-20.00	7.27	8.95	
II	17	19.21 (±0.32)	18.00-20.00	6.52	<0.0001	
III	5	18.58 (±0.57)	17.00-20.00	6.74		
IV	5	18.75 (±0.57)	17.00-20.00	6.68		
V	12	19.33 (±0.36)	17.00-20.00	6.48		
			Condylobasilar Length (CL)			
I	25	54.42 (±0.56)	43.73-59.63	5.09	30.57	
II	17	60.07 (±0.70)	57.69-63.30	4.61	<0.0001	
III	4	61.93 (±1.60)	61.22-63.94	4.47		
IV	5	63.44 (±1.26)	61.24-65.24	4.37		
V	13	63.87 (±0.80)	59.43-67.25	4.34		
			Zygomatic Breadth (LB)			
I	24	32.03 (±0.45)	25.00-37.37	6.84	32.34	
II	17	36.47 (±0.56)	33.99-38.36	6.01	<0.0001	
III	4	38.76 (±1.27)	38.30-38.97	5.66		
IV	5	38.68 (±1.00)	36.86-39.56	5.67		
V	13	40.00 (±0.63)	37.58-43.00	5.48		
			Rostral Length (RW)			
I	26	11.06 (±0.13)	8.95-12.96	6.04	41.67	
II	17	12.42 (±0.17)	11.67-13.41	5.38	<0.0001	
III	5	12.94 (±0.30)	12.22-13.50	5.16		
IV	5	13.46 (±0.30)	13.04-13.71	4.96		
V	13	13.79 (±0.19)	13.00-15.19	4.84		

Table 8. Continued.

Age Class	N	Mean ± 2 SE	Range	CV	F/F_s	Duncan Results
		Nasal Length (NL)				
I	26	16.74 (±0.26)	12.96-19.79	7.73	20.93	
II	17	18.34 (±0.33)	17.06-19.35	7.05	<0.0001	
III	5	20.15 (±0.59)	19.53-21.32	6.42		
IV	5	19.76 (±0.59)	18.20-21.08	6.55		
V	13	20.37 (±0.37)	18.08-23.50	6.35		
		Least Interiorbital Construction (LIC)				
I	26	6.44 (±0.06)	6.02-7.00	4.61	0.38	
II	17	6.48 (±0.08)	5.97-7.20	4.59	ns	
III	5	6.32 (±0.14)	5.94-6.72	4.70		
IV	5	6.53 (±0.14)	6.25-7.12	4.55		
V	13	6.46 (±0.09)	5.99-7.15	4.60		
		Mastoid Breadth (MB)				
I	26	23.83 (±0.26)	18.78-26.66	5.40	22.86	
II	17	26.24 (±0.33)	24.51-27.82	4.95	<0.0001	
III	4	26.94 (±0.75)	26.62-27.40	4.82		
IV	5	27.46 (±0.59)	26.64-28.29	4.73		
V	12	27.56 (±0.38)	25.86-29.24	4.72		
		Length of Maxillary Toothrow (LMT)				
I	27	14.03 (±0.13)	12.23-15.48	4.75	14.14	
II	17	14.89 (±0.17)	14.18-15.61	4.47	<0.0001	
III	5	15.30 (±0.30)	14.55-16.21	4.35		
IV	5	15.71 (±0.30)	14.76-16.44	4.24		
V	13	15.43 (±0.19)	14.29-17.10	4.32		

Table 8. Continued.

Age Class	N	Mean ± 2 SE	Range	CV	F/F_s	Duncan Results
		Skull Depth (SD)				
I	27	19.72 (±0.24)	15.87-22.27	6.10	32.38	
II	17	21.84 (±0.31)	21.12-23.13	5.51	<0.0001	
III	5	22.66 (±0.55)	21.64-23.67	5.31		
IV	5	23.40 (±0.55)	22.25-24.45	5.14		
V	13	24.07 (±0.35)	22.09-27.03	5.00		
		Length of Diastema, Including Incisor (DL)				
I	26	20.87 (±0.31)	16.01-23.85	7.37	35.87	
II	17	24.06 (±0.39)	22.75-26.75	6.40	<0.0001	
III	5	25.22 (±0.70)	24.68-26.08	6.10		
IV	5	25.97 (±0.70)	25.26-27.19	5.92		
V	13	26.61 (±0.44)	24.57-28.36	5.78		
		Braincase Width (BW)				
I	27	22.77 (±0.27)	17.61-25.36	6.01	23.32	
II	17	25.17 (±0.35)	23.39-26.51	5.44	<0.0001	
III	5	25.91 (±0.62)	24.43-26.66	5.28		
IV	5	26.60 (±0.62)	25.15-27.45	5.14		
V	13	26.73 (±0.39)	25.26-28.25	5.12		
		Mandibular Diastema Length (MF)				
I	27	11.04 (±0.12)	9.60-12.62	5.55	52.74	
II	17	12.01 (±0.16)	11.24-13.10	5.10	<0.0001	
III	4	13.31 (±0.35)	12.74-13.44	4.60		
IV	5	13.57 (±0.28)	13.18-13.90	4.51		
V	13	13.81 (±0.18)	12.86-15.00	4.44		

Table 8. Continued.

Age Class	N	Mean ± 2 SE	Range	CV	F/F_s	Duncan Results
Length of Mandibular Toothrow (MA)						
I	27	14.57 (±0.12)	12.63-15.94	4.29	4.94	
II	17	15.34 (±0.16)	14.51-16.19	4.08	0.0003	
III	5	14.83 (±0.28)	14.36-15.48	4.21		
IV	5	15.53 (±0.29)	15.04-15.98	4.03		
V	12	14.98 (±0.18)	13.66-16.25	4.17		
Mandibular Height (MD)						
I	27	13.43 (±0.13)	11.38-14.57	5.07	21.53	
II	17	14.63 (±0.17)	13.76-15.18	4.66	<0.0001	
III	5	14.67 (±0.31)	14.24-15.16	4.64		
IV	5	15.30 (±0.31)	14.46-16.40	4.45		
V	13	15.35 (±0.20)	14.18-16.59	4.44		

averaged larger than males in 9 cranial measurements (CL, RW, MB, LMT, SD, DL, BW, MD, MA). Because of the relatively small amount of statistical difference, the sexes were combined for analysis of variation between specimens taken at the beginning of the 20th century (Bailey's specimens) and those obtained at the beginning of the 21st century (Richards' specimens).

Individual variation. – Coefficients of variation (CVs) for males and females and for the various age classes are provided in Tables 7 and 8, respectively. The average CV for 18 measurements was 6.05, and CV's of females (5.87) were almost identical to those of males (5.86). CVs of external measurements averaged larger (7.2) than those of cranial measurements (5.33). TL, BL, TAIL had the largest CVs among external measurements, and NL, DL, LB were the highest among the cranial measurements.

Average CV's for the age classes were: I, 6.57; II, 5.88; III, 5.74; IV, 5.68; and V, 5.56 (males and females were combined). Thus, younger animals were slightly more variable than older ones. Age class V exhibited the lowest CVs with the exception of 3 measurements (TAIL, HFL, MA).

Comparison of 20th and 21st Century Populations

Comparison of Bailey's specimens with those collected in this study (Richards' specimens) revealed statistically significant differences in external and cranial features using both univariate and multivariate approaches. Overall, Bailey's specimens were larger than Richards' in all external measurements, although only BL and TAIL were significantly different between the two groups (Table 9). Bailey's specimens averaged smaller than Richards' in all cranial measurements except LIC, in which it was slightly but not significantly larger, and in all but 4 cranial measurements (LIC, DL, MF, and MD) there was statistically significant differences between the two groups (Table 9).

A discriminant function analysis using 31 specimens for which complete measurements existed revealed that only 2/10 Bailey specimens were misclassified as Richards' specimens and only 1/21 Richards' specimens were misclassified as Bailey specimens. This suggests a high degree of difference in external and cranial measurements between the two groups, and that from a classification viewpoint they represent two different populations.

Table 9. Results of univariate analysis between Bailey's specimens and Richards' specimens.

	Bailey			Richards						
Variate	N	Mean ± 2 SE	CV	N	Mean ± 2 SE	CV	*F*	|t|	P-Value	S/NS
TL	10	500.20 ± 8.29	4.92	21	497.14 ± 6.49	4.95	0.06	0.24	0.8151	NS
BL	10	289.67 ± 5.58	5.72	21	304.31 ± 4.37	5.45	6.16	2.48	0.0220	S
TAIL	10	210.53 ± 4.25	5.99	21	192.83 ± 3.33	6.54	7.83	2.80	0.0111	S
HFL	10	72.40 ± 1.08	4.42	21	71.39 ± 0.84	4.48	0.65	0.81	0.4295	NS
CL	8	60.82 ± 0.72	3.17	21	63.08 ± 0.51	3.06	6.57	2.56	0.0195	S
LB	8	37.49 ± 0.49	3.71	21	39.15 ± 0.37	3.55	7.22	2.69	0.0146	S
RW	8	12.87 ± 0.21	4.20	21	13.44 ± 0.14	4.02	4.87	2.21	0.0406	S
NL	11	18.61 ± 0.34	5.91	21	20.10 ± 0.29	5.47	11.31	3.36	0.0029	S
LIC	10	6.52 ± 0.12	5.52	21	6.50 ± 0.10	5.54	0.01	0.10	0.9137	NS
MB	5	25.52 ± 0.45	3.72	21	27.32 ± 0.25	3.48	12.27	3.50	0.0027	S
LMT	11	14.75 ± 0.22	5.02	21	15.47 ± 0.19	4.78	4.41	2.10	0.0480	S
SD	8	22.19 ± 0.43	5.18	21	23.46 ± 0.30	4.90	5.83	2.41	0.0266	S
DL	10	25.23 ± 0.32	3.77	21	25.96 ± 0.25	3.66	3.23	1.80	0.0875	NS
BW	6	25.13 ± 0.35	3.38	21	26.60 ± 0.22	3.20	12.64	3.56	0.0023	S
MF	11	13.33 ± 0.16	3.98	21	13.56 ± 0.14	3.91	0.98	0.99	0.3346	NS
MD	11	14.69 ± 0.19	4.22	21	15.09 ± 0.16	4.11	0.95	0.97	0.3400	NS
MA	11	14.42 ± 0.17	3.95	21	15.11 ± 0.15	3.77	5.40	2.32	0.0303	S

DISCUSSION

Archival Documentation

Schmidly (pers. comm.) described the approach and importance of archival natural history as follows: "Archival natural history adds the important concept of change over time periods from 50 to 150 years as documented through historical notes and publications, archives, photographs, and interviews Archival natural history provides useful perspectives about landscape and land use changes beyond the career and experience of individuals. It teaches that time and history, landscape and community are tightly intertwined." As such, it addresses what Diamond (2005: 425) has termed "landscape amnesia," or the phenomena of forgetting how different the surrounding landscape looked 50-100 years ago because the change from year to year has been so gradual. Grant (2000) coined the phrase "shifting baseline syndrome" to describe the situation whereby "…each succeeding generation of biologist has markedly different expectations of what is natural because they study increasingly altered systems that bare less and less resemblance to the former, pre-exploitation versions. This direct loss of perspective is accompanied by fewer direct human experiences (or even memories) of once undisturbed systems."

Archival natural history approaches were used in this study to build a solid profile of muskrat occurrence and habitat preferences at the beginning of the 20th century as it related to local landscapes and land-uses along the Canadian River drainage in the northern Texas Panhandle. A gap of scientific documentation of muskrats in this region occurred until the middle of the 20th century when Frank Blair (1954) recorded them and described their habitat in Hutchinson County. In the late 1980s, Knox and Clyde Jones and associates (1988), although they did not collect any specimens or observe any muskrat sign, assumed they still occurred along the Canadian River and some of its immediate tributaries, and Wolf Creek, and elsewhere in the northern Panhandle where permanent water was present, particularly in eastern counties. I was able to fill in some of these gaps based upon information provided to me by local residents who had spent a lifetime in the region and took the time to inform me of locations where they trapped muskrats in the study region during the 1920s, 1930s, 1950s, and late 1980s.

From these observations, it seems clear that muskrat populations persisted in the northern Texas Panhandle throughout the 20th century and into the 21st century. This is not true for every part of Texas where muskrats formerly ranged. During the time of the biological survey, muskrats occurred in numerous areas of the Trans-Pecos in far western Texas, along both the Pecos River and the Rio Grande, and at springs such as those at Fort Stockton and Balmorhea (Bailey 1905). As human populations and irrigation wells increased, many of the springs of the Pecos River drainage were destroyed. As the springs dried up, muskrat populations died out. Today, the drainage ditches near El Paso represent the last strong-hold of the muskrat in the Trans-Pecos (Schmidly 2002).

Merritt Cary and Ned Hollister, two other federal agents who assisted Bailey with the biological survey of Texas, in 1902 secured a series of Pecos River muskrats (_O_. _z_. _ripensis_) at Comanche Springs near Ft. Stockton (see Fig. 31, p. 312 in Schmidly 2002). Cary wrote the following description of the springs, which are dry today and no longer harbor muskrat, in 1902: "Comanche Creek, a beautiful stream of clear water running some thirty miles in a northeasterly direction, has its source in some extremely large springs at Stockton, and is bordered with a heavy growth of tules. This stream is utilized for irrigation purposes by several ranchmen and some fine cornfields and alfalfa meadows were noted. Fine grassy meadows along this creek afford fine pasturage." So it is obvious that muskrat populations in Texas can be subjected to local extinction if habitats are dramatically altered or totally disappear.

Occurrence, Relative Abundance, and Habitat

Estimating whether a species is present or absent at a given site is imperative for conservation. Although detection is indicative of species presense at a site, lack of detection does not translate into species absence. Fortunately, I documented muskrats in sufficient abundance in the sites I visited to be able to make solid observations about their occurrence, relative abundance, and habitat.

The SMF protocols indicate that vegetative density, structure, and adequate surface water are important elements for muskrat sustainability. Fluctuation in water level is one of the most important environmental factors affecting muskrat populations (Bellrose 1950). Riparian habitat that provides substantial surface water year round provides optimum habitat conditions in contrast to seasonal surface water which does not meet aquatic requirements of the species. Major fluctuations in water levels result in habitat deprivation. Bellrose and Brown (1941: p. 207) found "six times as many houses per acre of emergent vegetation in stable water as in semi-stable, and two times as many per unit area in semi-stable than in fluctuating ones". Riparian habitat with water present for less than 9 months constitutes less suitable muskrat habitat, regardless of the amount of persistent emergent vegetation. Wetlands with water present for less than 6 months are assumed to be unsuitable year-round muskrat habitat (Allen and Hoffman 1984).

Water permanence seems to have a greater effect on habitat quality than does water depth or type of emergent vegetation (Hamerstrom and Blake 1939). Errington (1939) found that low water levels result in reduced food and cover availability. Wilson (1949) reported in North Carolina coastal marshes that fluctuating water depths was a critical factor limiting muskrat with water depths between 46-120 centimeters being most favorable for muskrats. Conversely, Lay and O'Neil (1942) and Lay (1945) reported coastal marshes in Gulf of Mexico required water depths of 2-30 centimeters year-round for optimum muskrat habitat.

Muskrats cannot withstand drying up of their habitats because it increases their vulnerability to predators (e.g., mink, *Mustela vision;* foxes, *Vulpes* spp; raccoons, *Procyon lotor;* dogs, *Canis familiaris;* and various avian predators (e.g., *Buteo spp*., *Circus cyaneus*, and *Bubo virginianus;* Errington 1939, Errington 1954).

Vegetative density and structure are other corner stones in the viability of muskrat populations. Denser vegetation of cattails and three-cornered sedge may act as not only indicators of quality habitats, but also serve as an advantage against predation by avian and mammalian predators. Gilfillan (1947) found that ponds in Ohio with "good" vegetative cover produced an average of 9.6 muskrats/0.4 ha (9.6/acre) and ponds with "fair" vegetative cover yield an average of 8.7 muskrats/0.4 ha (8.7/acre). Ponds with no vegetative cover produced no muskrats. In ideal muskrat habitat, ≥50% of the area is covered with dense, emergent vegetation (Allen and Hoffman 1984).

In riverine habitats, the availability of cover and backwater seems strongly related to muskrat abundance (Brooks 1980). Muskrats inhabiting riverine areas establish burrows within river and stream banks and are less dependent upon emergent vegetation for providing adequate cover due to lack of nest construction.

The scarcity of muskrats in the study region during portions of the past 100 years may be correlated with several factors. Lack of detection during previous surveys may have resulted from surveys being conducted in dry years when overall numbers had been decimated. Drought decreases muskrat survival rates (Errington 1939, 1941, 1954) because of the increased affect of predation. Drought effects also increase incidences of intraspecific strife mortality by older or larger muskrats killing or incapacitating juveniles and subadults (Errington 1939, 1940, 1954).

Intensive grazing of livestock also can have detrimental effects (e.g., decreased vegetative cover, increased bank erosion, and trampling of burrow systems) on muskrat density (Errington 1937). Based on muskrat harvest data from Iowa, twice as many animals were captured along streams with ungrazed banks than were along streams with grazed banks (Gilfillan 1947).

In my study region, muskrats seem to prefer shallow water and sloughs dominated by dense stands of cattails and three-cornered sedge. They do not seem to suffer freeze outs or mink predation that affects habitat selection, which is contrary to most other studies reported in the literature (Errington 1939, Bellrose 1950, Errington 1954).

Man-made hydrologic features (e.g., bass ponds, earth tanks, dredging activities, and irrigation features) may augment muskrat population and dispersal rates (Walters 2001). At the same time, it is also possible that dredging of native riparian habitats can diminish preferred habitat and increase population density because immigration from altered areas confines both sexes to a smaller area thereby forcing shared use of space that increases intraspecific strife as evidenced by scarring from biting by individuals along the belly and flanks on specimens of all age classes (Errington 1940, Errington 1954, Ostfeld 1985).

I found evidence of scarring on most of my specimens including even the youngest of juveniles, suggesting intense intraspecific strife in the populations I sampled where dredging had occurred. What remains at a dredged location is a reduced population with higher incidences of intraspecific strife, resulting in the manifestation of “social fences” (Wolff et al. 1997, Clobert et al. 2004) which limit resources and possible partitioning of remaining riparian habitat by older adult males and females (Wolff et al. 1997, Lambin et al. 2004, Long et al. 2005).

Muskrat populations in my study area seem to display classic “source-sink” metapopulation dynamics. Many species of small mammals are predisposed towards metapopulations because they show spatial population structure as a result of sociality or habitat fragmentation (Stacey et al. 1997).

In the case where a population exhibits a patchy distribution and environmental stressors within the habitat patches cause population growth rates to decline, then population numbers decrease and a population “sink” forms (Levins 1970, Hanski and Simberloff 1997). Under such circumstances in muskrat populations, disease has the potential to act on remaining stressed individuals, resulting in either extremely depleted numbers of the remaining individuals or extinction (Errington 1939, Errington 1940, Errington 1954). In such a scenario, muskrats would be difficult to catch and observe. Thus, lack of detection in survey attempts may relate to surveys being conducted in dry years where overall numbers may have been decimated or eradicated due to the initial drought effect followed by an outbreak of disease on environmentally stressed individuals (Errington 1939, Errington 1954, Keeling et al., 2004).

Environmental stressors, such as drought, often operate at a regional scale (Echrlich et al. 1972, Echrlich et al. 1980, Shaffer 1981). This results in a lack of available surface water and a subsequent reduction in riparian habitat that causes, in turn, low survival (increase in disease and predation), thereby decreasing the source population, and reduced dispersal (Errington 1939, 1941, 1954) which decreases the likelihood of a rescue effect from a source population to the metapopulation (Kawecki 2004).

From my personal observations, the landscape dynamics observed in this study would suggest the main river drainages (Canadian, Washita, and Gageby) act as source populations (originating from the sloughs along these waterways) that contribute to the formation of metapopulations, such as those on Red Deer Creek, Cabin Creek, Tallahone Creek, and Chicken Creek. Such a model would presume that dispersal from "source" populations is associated with high quality habitat, which may permit "relative sink" populations to exist in inferior habitat (Pulliam 1988, Harrison and Taylor 1997, With 2004, Long et al. 2005). Sinks associated with marginal habitats are occupied only during favorable conditions (e.g., wet years) and in areas where populations flourish most of the time, but they cannot survive catastrophes, such as subsequent droughts (Errington 1939, 1954, Harrison and Taylor 1997, Walker et al. 2003).

A good example in this study of muskrats existing as a metapopulation in a marginal habitat was seen at Hutton Meadow (trapping site C) where six individuals were trapped in a ditch approximately 2 meters at its deepest point and 20 meters at the widest point and extended approximately 274 meters. Any prolong exposure to drought on this site would result in a drying up of the available surface water, removing riparian habitat and thereby resulting in either the extinction or displacement of muskrats. Occupancy of habitat after loss of visible surface water varies from three to 20 weeks depending on their survival, although muskrats may choose to disperse (Errington 1939, 1954).

The factors discussed above all have the potential impact of exacerbating the fragmented nature of muskrat populations. The main concern with habitat fragmentation is that it threatens stability/persistence of metapopulations because size and isolation of remaining habitats increases probability of extinction through demographic, environmental, or genetic stochasticity. Habitat fragmentation is compounded by habitat reduction, patch size, and isolation. Social biology and behavioral ecology of species must be taken into consideration when predicting/interpreting how species will respond to fragmented landscapes (Wolff et al. 1997).

Non-geographic Variation

Analysis of variation within muskrat populations in the northern Texas Panhandle revealed significant variation due to age for each character but no significant sexual dimorphism. Other authors have been divided in their opinion about the extent of sexual dimorphism in muskrat skull dimensions. On the one hand, Gould and Kreeger (1948), in examining a series of muskrats in Louisiana (*O. z. rivalicius*), found slight but statistically significant differences in the larger skull dimensions of males, and Sather (1956) found higher average values for male skull dimensions in populations of *O. z. cinnamominus* on the northern Great Plains. On the other hand, other authors noted differences in cranial measurements between male and female muskrats to be weak and to concern mostly the general factor of size (Hollister 1911, Willner et al. 1980, and Ruprecht 1974). Pankakoski and Nurmi (1986) found that in muskrats from Finland, the skulls of males averaged 1.5% larger than those of females. According to Pankakoski (1983), the general size of the skull depends so strongly on habitat quality that it fails as a criterion for sex identification. Ruprecht (1974: p. 496) concludes "the muskrat's skull is thus distinguished by a slight degree of differentiation in dimensions depending on sex, and this degree depends to a great extent on the quality of the given sample."

Skull dimensions in muskrat populations from the northern Texas Panhandle change significantly with age, and the degree of change varies depending on the measurement. These results compare favorably with age related variation reported in muskrat populations from other geographic areas in North America and Europe (Gould and Kreeger 1948, Ruprecht 1974, Pankakoski and Nurmi 1986, and Boulenge et al. 1996). Collectively, the studies in the literature support the view that the muskrat's skull, like that of other species of rodents, is distinguished by age changes, certain of which would appear to be continuous, but the basic growth of the skull in these animals takes place rapidly within a relatively short time (Ruprecht 1974).

According to Ruprecht (1974), differential growth rate of skull dimensions within local populations is a major source of geographic and microgeographic variation among populations which is highly pronounced in this species. There appears to be a considerable amount of environmental influence on size and dimensions of muskrats. Pankakoski (1983) presents evidence that habitat quality has a considerable effect on muskrat size, and Boyce (1978) has proposed connections between climate and muskrat body size. Animals are largest in regions of high annual precipitation and low seasonality in rainfall. Highly variable precipitation patterns result in low rates of germination and survivorship for preferred aquatic plants, which in turn reduces the average total food availability for muskrats. In large individuals nutritive demands may exceed supply; thus, selection favors smaller body size in areas of low food availability (Boyce 1978).

With respect to individual variation, as reflected by CV calculations, muskrats from the northern Texas Panhandle appear to be more variable than other populations studied in the geographic range of *O. z. cinnamominus* on the Great Plains. For example, in Nebraska the average CV of cranial measurements for adults was 3.6 (Sather 1956) compared to 5.33 in this study. Females had smaller CVs than males, whereas in the northern Panhandle population the CVs of males and females were virtually identical.

Measurements of the skull in the youngest animals have relatively high CV values, and they tend to decrease with age. This trend was apparent in my sample as well as the one from Nebraska. Higher CV values characterizing skull dimensions in younger animals, according to Yablokov (1966), can be explained by the lack of uniformity in conditions for growth and development of the various individuals composing this age class.

The pattern of nongeorgaphic variation documented in this study, and that reported elsewhere in the literature, would argue for careful consideration of age and sexual variation in any future study of geographic variation in this species. Hollister (1911) has conducted the only comprehensive taxonomic revision of muskrat in North America but his assessment was not statistical in nature. There is a need to reassess variation across the species range using appropriate statistical techniques to clearly ascertain variation patterns.

Comparison of 20th and 21st Century Populations

Statistically significant differences among external and cranial measurements are clearly evident when comparing Bailey's (collected at the beginning of the 20th century) with Richards' specimens (collected in this study). It is possible that sampling error could account for some of this difference. Bailey's sample (6-11 specimens) is substantially smaller than the Richards' sample (21 specimens), and it has fewer individuals in the older age classes (6 compared to 12).

Significant morphological difference, as expressed in cranial measurements, has been found among local muskrat populations in Europe over narrow geographic areas (1.5 – 7 km; Le Boulenge et al. 1996). Reasons postulated for this extreme microgeographic variation include population isolation, genetic drift, and a small amount of socially-induced gene flow among local populations that mainly are connected to one another through a river network. Furthermore, it has been demonstrated that habitat quality can have a large impact on muskrat size and cranial dimensions (Pankakoski and Nurm 1986, Pankakoski 1983). It is possible that the same combination of factors that account for significant microgeographic changes also could account for changes in skull measurements over time. In other words, habitat differences over time could produce changes in skull measurements analogous to those produced by geographic habitat differences.

Although it was not a major part of this study, I did examine specimens of muskrats from other populations of *O. z. cinnamominus* on the Great Plains. In external and cranial dimensions, specimens from the Texas Panhandle clearly differ in some respects from those in surrounding areas. In most measurements, they are significantly larger, suggesting there could be considerable geographic variation in this subspecies. This trend is similar to the situation in another subspecies, *O. z. rivalicius*, which varies geographically within its range in Louisiana (Gould and Kreeger 1948).

CONCLUSIONS

The following conclusions are evident from this study as they relate to the objectives outlined in the introduction:

1. There is no evidence that muskrats have disappeared or are endanger of disappearing along the Canadian River drainage of the northern Texas Panhandle.
2. To the contrary, the information from this study taken in combination with that obtained by Vernon Bailey and his federal agents at the beginning of the 20^{th} century suggest that muskrats have always been present as metapopulations in the Texas Panhandle but that their relative numbers likely have changed over time.
3. An increase of rainfall over the past 20 years has produced an increase in available surface water to riparian habitats which is the most likely reason for the seemingly recent, large increase in the number of muskrats.
4. Lack of detection of muskrats during previous survey attempts may have resulted from surveys being conducted in dry years when overall numbers have been low due to lack of available surface water and essential riparian habitat.

5. The notable increase in dredging activities in the study region over the past six years in the form of "stream cleanings" to improve the flow of water to newly constructed "bass ponds" or long-standing ponds/earth tanks is potentially a double edged sword for muskrats. On the one hand, it promotes the persistence of muskrat populations by increasing the stability of aquatic habitat and decreasing the potential negative impacts of drought; on the other hand, it also has the potential to negatively impact the overall quality and quantity of available riparian habitat by reducing both vertical and density characteristics of valuable riparian plant species (e.g., cattails and three-cornered sedge).
6. The SMF surveys suggest that natural, dense, abundant cattail stands in streams/rivers or sloughs with a water depth of 0-30 cm constitute the preferred habitat for muskrats. Less preferred habitat includes a mixture of shoreline, sedges, and rushes intermixed with sedges. Natural habitat is far preferred to modified habitats. The majority of muskrat physical sign is found in denser stands of vegetation.
7. Analysis of nongeographic variation within muskrat populations reveals significant variation due to age for each character but no significant sexual dimorphism. Coefficients of variation for both external and cranial measurements are within the range reported for other populations of muskrats and for other species of rodents.
8. Specimens collected from the beginning of the 20th century differ significantly in external and cranial measurements from those collected at the beginning of

the 21st century as part of this study. Archival natural history information would suggest that muskrats have always occupied the northern Texas Panhandle, so the difference in measurements are not thought to reflect recent invasions of muskrats from other geographic areas with a different cranial morphology. The differences could be the result of sampling error, since the sample size from the beginning of the 20th century was about half of the one from this study or it could result from the impact of habitat changes over time. Confirming the real reasons for this difference will require further study and probably a different methodology.

9. Studies such as this demonstrate the usefulness of archival natural history as an important tool in conservation assessments. Combining detailed natural history studies of species that span the careers and experiences of individual mammalogists allows for trend assessments over longer time horizons that are more meaningful in developing conservation strategies.

10. Archival studies of muskrats in Texas reveal that local extinction of populations has occurred in the past (e.g. in the Pecos River drainage) and will be possible in the future without careful monitoring of surface water and riparian habitat.

CONSERVATION STATUS

There is no reason for concern about the immediate survival of muskrat populations along the Canadian River drainage of the northern Texas Panhandle. Populations appear to be widely distributed within available habitat and population numbers appear to be high.

However, some conservation threats are evident. Heightened oil and gas drilling activities over the past several years in the region have dramatically impacted riparian areas by the direct spilling or indirect leaching of drilling containments into dry washes, rivers, streams, riparian areas, springs, and sloughs. For example, I am aware of two oil spills into Gageby Creek and seepage of improperly lined catch ponds into various springs of the area. Water quality is known to impact muskrat occurrence and abundance so local events such as this could impact local muskrat populations.

Probably the most significant long-term threat to muskrat populations in the southwestern United States, including the northern Texas Panhandle, is climate change which could significantly impact or even greatly reduce available habitat. Seager et al. (2007) indicate there is a broad consensus among climate change scientists and climate models that the southwestern U.S. will dry significantly in the 21^{st} century and that this transition to a more arid climate is already underway. According to these authors, this trend is unlike any climate state previously seen in the record and the predicted drought will severely impact the hydrology in the region for the next 100 years and possibly as early as 2021.

Global warming could have dramatic impacts on both muskrat habitat and populations in Texas. Muskrats in the Panhandle of Texas prefer natural, dense, abundant cattail stands in the streams, rivers, or sloughs with a water depth of 30 cm or less. These preferred habitats provide substantial surface water year round. Fluctuations in surface water levels have been found to be one of the most critical environmental factors affecting muskrat populations (Bellrose 1950). Relative abundance depends greatly on the persistence of suitable habitat throughout the year and over time (Bellrose

1950). Reduction of critical habitat over time leads to crowding of remaining habitats, resulting in increased intraspecific strive, erection of social fences, increased predation risk, and disease effects in the form of epizootics.

Comanche Spring near Fort Stockton, which is dry today and no longer harbors muskrats, may be an early indication of things to come. It is obvious that muskrat populations in Texas can be subjected to local extinction if habitats degrade over time. Ditches near El Paso represent the last strong hold of the muskrats in the Texas-Pecos region of the state (Schmidly 2002). Although muskrat may be present now their status should be watched very carefully over the next 15 – 50 years.

Finally, the commitment of local land owners in Texas will be crucial to the future survival of muskrats on the region. Most land in Texas is privately owned. There is a need to inform and educate landowners about the conservation of muskrats, which may be a valuable water quality indicator species. Monitoring muskrats in the future will provide valuable information about their ecology, current distribution and abundance, habitat requirements, and vulnerabilities. These findings would aid in the conservation of both the muskrats and their riparian habitats as well as providing insights about the possible impacts of dredging and drilling practices on the Texas Panhandle. Texas landowners need to be educated about the nature of conservation if the future of natural resources in this region of the state is to retain its natural heritage for future generations to enjoy. "To understand what we have today and what we want for tomorrow, we need to know what we had in the past" (Schmidly 2002).

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