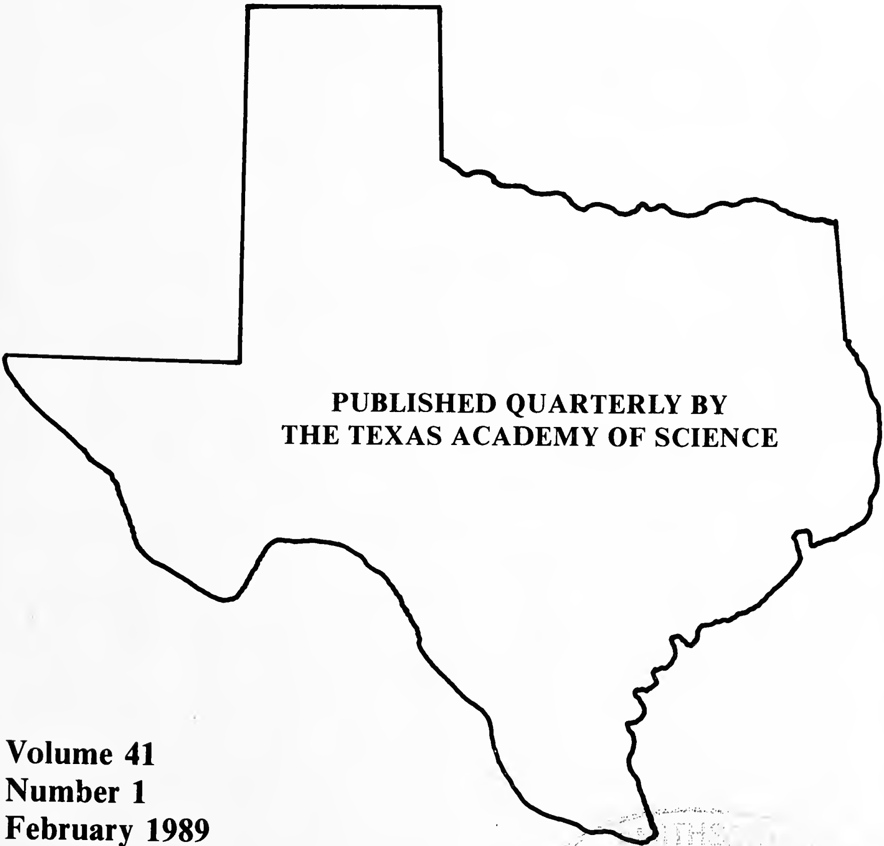
THE TEXAS JOURNAL OF SCIENCE



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General Notes

THE TEXAS JOURNAL OF SCIENCE
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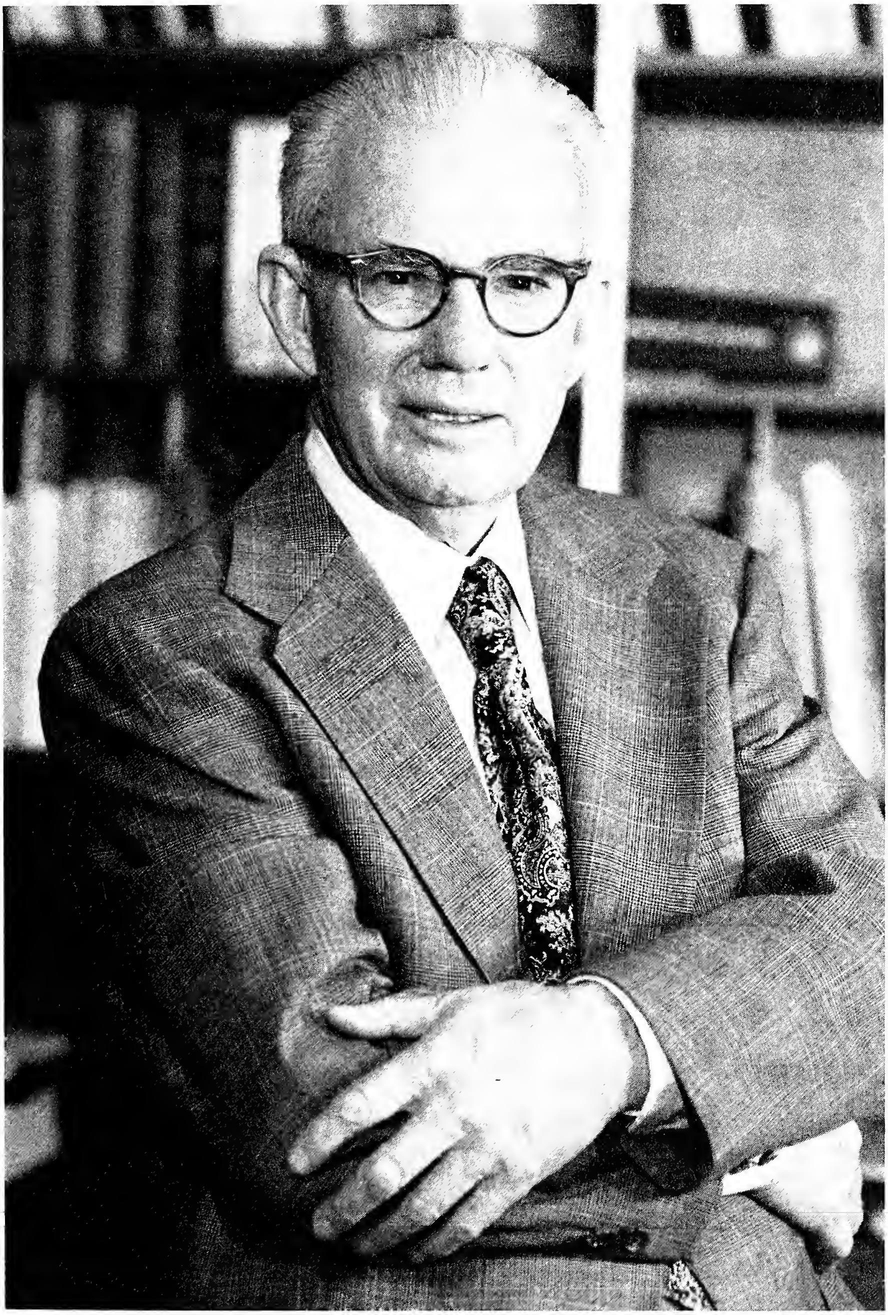

VIRGIL E. BARNES
Distinguished Texas Scientist, 1988

VIRGIL EVERETT BARNES was born in Chehalis, Washington, on 11 June 1903. He received his B.S. and M.S. degrees from Washington State College and his Ph.D. degree in 1930 from the University of Wisconsin.

Dr. Barnes was associated for most of his professional life with the Bureau of Economic Geology at The University of Texas at Austin and served as Associate Director of that organization from 1961 to 1968. In 1960 he was named Professor of Geology in the Department of Geological Sciences at Texas. The title of Professor Emeritus was conferred on Dr. Barnes in 1977.

In his 53 years at the Bureau, Dr. Barnes has published more than 200 articles, reports, maps, and monographs on the straigraphy of Paleozoic and Precambrian rocks, econimic geology, gravity and magnetic studies, earth temperatures, and tektites and meteorites. He is internationally known for his research on the origin of tektites.

Dr. Barnes was elected Fellow of the American Association for the Advancement of Science in 1987 and previously was elected Fellow of the Geological Society of America and Life Fellow of the Mineralogical Society of America. Since presenting the Plenary Address at the annual meeting of the Texas Academy of Science, he has been selected to receive the prestigeous Barringer Award for his tektite research at the 1989 Annual Meeting of the Meteoritical Society to be held in Vienna, Austria.

Following is the text of Dr. Barnes' Plenary Address at the 91st Annual Meeting of the Texas Academy of Science, Commerce, Texas, 4 March 1988.

ORIGIN OF TEKTITES

VIRGIL E. BARNES
Bureau of Economic Geology, The University of Texas at Austin, Austin, Texas 78713-7508

ABSTRACT.—Tektite research at the Bureau of Economic Geology, The University of Texas, is summarized, and new research includes analytical data for seven Muong Nong-type indochinites, two splash-form philippinites, and 16 samples of earth materials associated with, or in the vicinity of, tektite occurrences. Analytical data yield evidence that southeast Asian tektites in three of the seven localities sampled could have been derived from local earth materials. Localities from which positive results were obtained are Nong Sapong and Phang Daeng, Thailand, and near Kracheh, Kampuchea. If comet impact created the Austral-Asian tektites, then the shock metamorphism of minerals and melting of surficial materials to form Muong Nong-type tektites would have been produced by compression of the atmosphere against the Earth by the coma of the comet. The blast from the impact by the nucleus, in addition to creating splash-form indochinites, would have jetted melt through the hole in the atmosphere created by the incoming comet to produce the australites and the slightly ablated Indonesian tektites. *Key words:* tektites; Muong Nong-type tektites; indochinites; comet impact; rare earth elements.

The origin of small, curiously shaped (tear drops, dumbbells, buttons, plates, ovals, and irregular) glass objects named tektites has been a tantalizing scientific question for nearly 200 years. However, the earliest known record of tektites comes from the T'ang Dynasty in China during the tenth century (Da-ming, 1963). It was reported that black stones with a lovely brilliant luster were found and collected on the Luichow Peninsula. The Chinese believed that these stones fell from the sky and called them lei-gong-mo (inkstones of the Thunder God) or lei-gong-shih (the stool of the Thunder God).

The first mention of tektites in western scientific literature was made in 1787 by Joseph Mayer, who described glass objects found along the Moldau River in Bohemia that were being sold as chysolite, a gem mineral. Because these objects were unrelated to the rocks and pebbles with which they were associated, many scientists considered them to be meteorites.

Tektites are found worldwide in areas referred to as strewn-fields (Fig. 1) and occur in a variety of forms. Those from Czechoslovakia, named moldavites (about 14-15 Ma [million years] old), are mostly etched and green. Others, except for the straw-yellow Libyan Desert glass (about 28-29 Ma old), are black. The Ivory Coast tektites (about 1.1-1.3 Ma old) are rounded and slightly etched. North American tektites (about 32-34 Ma old), named for the former Indian tribe that occupied the area of their occurrence in Texas, appear to be mostly water-worn pebbles, some of which are deeply etched. The Georgia tektites and the lone Martha's Vineyard tektite belong to the bediasite (North American) strewn-field, as do microtektites and tektite fragments found in Barbados and in a

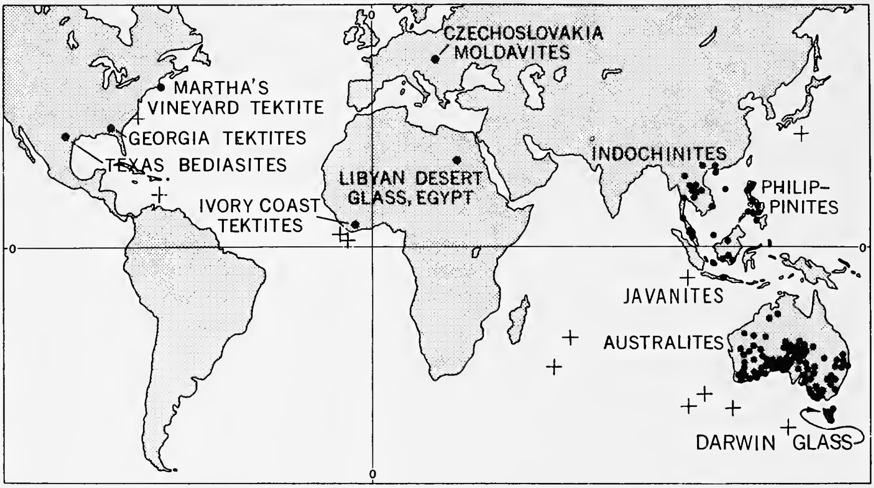

FIGURE 1. Map showing areas of tektite occurrence (strewn-fields). Symbols (+) show a few of the localities in which microtektites have been found in ocean sediment cores.

sediment core off the coast of New Jersey, and microtektites found in sediment cores in the Caribbean. The great Austral-Asian area of tektite occurrence (about 0.7 Ma old) is subdivided into the indochinite, australite, philippinite, and javanite (Indonesian) strewn-fields. The Darwin glass (Fig. 1) is a local impact glass from Tasmania of about the same age as the australites.

Tektites are now regarded as solidified melt of earth materials produced by impact of comets or possibly asteroids or meteorites. Some of the melt was spurted as columns of liquid that collapsed to produce the splash-form tektites and a spray of microtektites. Other tektites are layered and appear to have formed locally at the Earth's surface. The distinctive button-shaped australites were produced by ablation as solid tektites plunged into the atmosphere with melt formed on the anterior side flowing back to form a flange. The indochinites are noted 1) for their large number of splash-form types (tear drops, dumbbells, and other splash forms) and 2) for the abundance of Muong Nong-type (layered) tektites that have the appearance of having formed from puddles of melt.

Various previously postulated origins for tektites include ancient attempts to manufacture glass; glass produced by burning coal seams and gas and oil seeps, and by forest fires; fulgurites produced by lightning; glass bombs shot to Earth from moon volcanoes; and splashes to Earth from impacts on the moon.

REVIEW OF PREVIOUS BUREAU TEKTITE RESEARCH

Tektites first came to the attention of the Bureau of Economic Geology at The University of Texas in 1936 when specimens erroneously thought to be obsidian were received from eastern Texas in connection with a Works Progress Administration Mineral Survey of Grimes County. Grimes County is hundreds of kilometers from the nearest igneous terrain from which obsidian is derived. Dr. H. B. Stenzel, a Bureau scientist who was familiar with the tektite occurrence in Czechoslovakia, suggested that the specimens might be tektites. Search of world scientific literature confirmed that the Grimes County occurrence was not only the first discovery of tektites in North America but, as is now known, the first in the Western Hemisphere as well. Some South American glass pebbles, which had been postulated to be tektites on the basis of similar surface sculpture, are instead pebbles of a unique high-lithium volcanic glass derived from ash flows (Barnes et al., 1970).

Because of the paucity of information on tektites in North American scientific literature at the time of the Grimes County discovery, the tektite problem was reviewed, analyzed, and evaluated in the publication *North American Tektites* (Barnes, 1940). In this publication, a strong case was made for the origin of tektites from sedimentary rocks on the basis of chemical composition. Sand-size glassy particles within tektites were identified as fused quartz sand grains. Although the 1935 publication by Alfred LaCroix entitled “Les tectites sans formes figures de l’Indochine” (The unshaped tektites of Indochina) was cited in the 1940 publication, the importance of layered (unshaped) tektites in formulating an origin for tektites was not recognized at that time. Following publication of *North American Tektites*, tektite research generally slowed until the advent of the space age, at which time the theory in vogue was that tektites were splashes from impacts on the moon.

I published a general review of the tektite problem in 1957, which was followed by an article on the “Properties of tektites pertinent to their origin” in 1958, and a joint paper with Kopal and Urey on the “Origin of tektites” in 1958.

In view of the disregard of evidence supporting the origin of tektites from earth materials and the vast effort being made to prove that tektites were from the moon, I applied for and received support in the period 1960-1972 from the National Science Foundation (NSF) for “Research on composition and origin of tektites,” which included a study of the worldwide geologic occurrence of tektites.

Of high priority in this worldwide investigation of tektites was a visit to LaCroix’s original site of layered tektites near Muong Nong, Laos. By the time the project was under way, Laos was closed to travel, but fortunately, Dr. Kaset Pitakpaivan of the Geological Survey Division, Royal Department of Mines, Thailand, knew of both splash-form and Muong Nong-type tektite localities in northeastern Thailand and was amenable to a cooperative project to study their field relations. The results of this investigation, which included a study of the internal features of the Muong Nong-type indochinites and their bulk composition as compared with the lateritic material with which they are associated, furnished strong evidence that the Muong Nong-type indochinites are the result of the fusion of the ground before laterization (Barnes and Pitakpaivan, 1962).

Publications on tektites during the period of NSF support include "Significance of inhomogeneity in tektites" (Barnes, 1960); "A world-wide geological investigation of tektites" (Barnes, 1961*a*), reprinted with additional illustrations (Barnes, 1962*a*); "Tektites" (Barnes, 1961), reprinted with additional illustrations (Barnes, 1962*b*); "Tektites" (Barnes, 1962*c*); "Temperature of tektite formation" (Barnes, 1962*d*); "Origin of indochinite tektites" (Barnes and Pitakpaivan, 1962); "Detrital mineral grains in tektites" (Barnes, 1963*a*); "Tektite strewn-fields" (Barnes, 1963*b*); "Variation of petrographic and chemical characteristics of indochinite tektites within their strewn-field" (Barnes, 1964*a*); "Terrestrial implication of layering, bubble shape and minerals along faults in tektite origin" (Barnes, 1964*b*); "Rayed bubbles in tektites" (Barnes, 1964*c*); "Devitrification of glass around collapsed bubbles in tektites" (Barnes and Russell, 1966); "Tektites" (Barnes, 1967*a* and 1967*b*); "Petrography of new tektite localities in Thailand and the Philippines" (Barnes, 1968); "Petrology of moldavites" (Barnes, 1969*a*); "Progress of tektite studies in China" (Barnes, 1969*b*); "Macusanite occurrence, age, and composition" (Barnes et al., 1970); "Age of Asian tektites" (Barnes, 1971*a*); "Description and origin of large tektite from Thailand" (Barnes, 1971*b*); "Tektites" (Barnes and Barnes, 1972*a*); "World-wide investigation of tektites continued" (Barnes and Barnes, 1972*b*); and "New investigations of the strewn-field of Libyan Desert glass and its petrography" (Barnes and Underwood, 1976).

Discoveries pertinent to the tektite problem made during the NSF-supported research are enumerated as follows:

(1) Muong Nong-type (layered) tektites were formed locally as puddles of melt as supported by the following evidence:

(a) Sr^{87}/Sr^{86} ratios for layered indochinites and associated soils are identical (Hedge et al., 1965).

(b) Quartz grains found in layered tektites are identical in size and shape to those found in the associated soil and underlying sedimentary rock.

(c) Quartz-bearing layered tektites submitted to L. S. Walter (1965) were found to contain coesite, a mineral indicative of shock metamorphism.

(d) Layered tektites are faulted, with sand grains drawn into some of the fractures; the melt closed around the sand grains, and the fractures became perfectly welded. Faulting while the melt was still plastic suggests that sharp earth movements continued for some time after the initial shock or that there was more than one impacting body arriving at different times.

(e) Pointed and branching bubbles in layered tektites are interpreted as pore space trapped at the time the source material was melted.

(f) Chemically, layered indochinites and splash-form indochinites are identical.

(g) Specimens of layered tektites also are found among moldavites, bediasites, and philippinites, and Libyan Desert glass is a layered glass.

(2) All tektites have lost some surficial material by etching, as determined by petrographic studies. The only original surfaces preserved are beneath flanges on australite buttons where the surface is sealed from chemical attack.

(3) During solar furnace experiments, in which sunlight reflected from a bank of mirrors was focused by a parabolic mirror, all common rock-forming minerals except quartz immediately diffused into the melt when mixed with synthetic glass and subjected to the sudden intense heat at the focal point. Quartz changed to lechatelierite (silica glass).

(a) As quartz changed to lechatelierite it became frothy, then bubbly, then free of bubbles as the temperature rose. The degree of bubble concentration in lechatelierite furnishes a scale for judging the relative temperature of tektite formation.

(b) Lechatelierite in layered tektites is mostly frothy, indicating that layered tektites formed at a lower temperature than that at which splash-form tektites were produced.

(c) That layered tektites cooled more slowly than splash-form tektites is indicated by the presence of devitrification along some layers and along a few faults.

(d) Rays developed, extending outward from bubbles, when a mixture of muscovite and synthetic tektite glass was melted in the solar furnace. Rayed bubbles are also present in tektites. The rays in tektites, as well as those in solar furnace melts, were probably the result of explosive disintegration of hydrated minerals or of carbonate nodules in soils caused by sudden expansion of the contained water or carbon dioxide. Hydrated minerals and nodules of carbonate are not found on the moon but are common constituents of soils and rocks on Earth.

(e) Rocks in the range of tektite composition when melted in the solar furnace form green to brown glass having characteristics of tektite glass, including the presence of lechatelierite when quartz is present.

(4) The presence of almost perfect vacuums in tektite bubbles formerly was used as an argument for the formation of tektites on the moon, where conditions are similar to those in a vacuum. Devitrification was found around bubbles in philippinites that were in the Manila fire at the end of World War II, and similar devitrification was duplicated by means of heating experiments. These experiments indicate that water vapor

probably formed the bubbles and then was absorbed into the surrounding glass causing the bubbles to become vacuums and the surrounding glass to become reactive. This finding nullifies the chief argument for the origin of tektites on the moon.

(5) Iron-poor siliceous "fingers" identified in the outer portion of some tektites may indicate that tektites reached temperatures above the boiling point of iron (3000°C) or possibly that silica-rich material was accreted shortly after the melt was propelled from its source.

(6) Macusanite (an anomalous Peruvian obsidian) was found not to be a tektite, although it displays sculpture common to tektites. This high-alumina and otherwise unusual glass is associated with a Pliocene ignimbrite locally known as sillar.

The main purpose of the present analytical work is to expand the study started by Barnes and Pitakpaivan (1962) to all tektites and their associated earth materials collected in southeastern Asia during the NSF-supported investigation.

PRESENT TEKTITE RESEARCH

Field Relations

Samples of earth materials associated with southeastern Asian tektites were collected from three localities in Thailand, one in Kampuchea (Cambodia), one in Vietnam, and two in the Philippines. Earth materials physically associated with Muong Nong-type tektites were collected at only three localities, all in Nakhon Phenom Province, northeastern Thailand. The Thai localities are within 50 kilometers of each other.

The Muong Nong-type tektite locality at Nong Sapong, Thailand (104° 39.8′ E and 17° 5.3′ N), is near the southeastern corner of the village on the road leading west to Nong He and is about 150 meters west of the main north-south road through Nong Sapong. At this locality the road, one-vehicle-wide, had cut down through about 0.7 meter of soil to laterite in which the Muong Nong-type tektites are embedded. The laterite is exposed for about 100 meters along the road, and in this area, tektites were found in only one place. In a nearby well, the top of the laterite is irregular, ranging from 1.0 to 1.3 meters below the surface, and the laterite base is gradational to clay at a depth of 1.7 to 2.0 meters. A sample of the clay was collected at a depth of 2.0 meters, being limited by the water level in the well. A sample of the laterite associated with the tektites also was collected.

The Muong Nong-type tektite locality at Phang Daeng. Thailand (104° 23.5′ E and 16° 48.3′ N), discovered while a post hole was being dug, is to the left of a trail leading westward, about one kilometer from the village. To investigate this occurence, a fence was dismantled so that excavation could proceed outward from the original find. The area of tektite-bearing laterite was found to be about two meters across. A trench across the deposit exposed 28 centimeters of sandy soil, eight centimeters of laterite with abundant tektites, 18 centimeters of laterite in which tektites were scarce, and 23 centimeters of laterite free of tektites. The soil between 10 and 15 centimeters was sampled, as well as the laterite with abundant tektites and the laterite from depths of 46 and 76 centimeters.

The Muong Nong-type tektite locality near Kan Luang Dong, Thailand (104° 32.3′ E and 16° 45.2′ N), is at the south side of a rice paddy one kilometer west of the village in a well half-full of water and mud. Permission was not received to clean out the well. Numerous tektite fragments were collected from the well dump, and larger pieces were bought from the owners of the well, who had apparently stored the specimens with cotton bolls. The earth adhering to the tektites was removed in the laboratory and the organic material floated off.

In Kampuchea (Cambodia), seven tektites, one of which is of the Muong Nong-type, were collected 26.3 kilometers north of Kracheh (Kratiê) (115° 13′ E and 14° 6.7′ N) along route 13 at a point 2.4 kilometers northeast of where route 13 leaves the Mekong River. The tektites, found in a large area exposed by the removal of 20 to 25 centimeters of road material, were associated with buckshot laterite, which contained pebbles of sandstone and a few other lithologic types. That Muong Nong-type tektites also occur in this part of Kampuchea is demonstrated by the one specimen found. Although no *in situ* relationship has been shown between this specimen and the country rock, specimens of soil, yellow sandstone, and brown sandstone were collected for analysis from an exposure in a nearby gully.

In Da-lat, Vietnam, soil was collected in a road cut from around a teardrop tektite at a depth of 25 centimeters, and another sample was collected at a depth of one meter. One small deposit of Muong Nong-type tektites was found a few kilometers away in a shallow excavation near a school, but associated earth material was not collected.

Tektites resembling the Muong Nong-type are extremely scarce in the Philippines. Of the 123 philippines sectioned, only one tiny deeply etched fragment, Santa Mesa no. SMG, had some properties characteristic of Muong Nong-type tektites, including strong flow structure, almost no overall strain, and the presence of some bubbly to frothy lechatelierite. At Pugad Babuy, Bulacan Province, about 10 kilometers north of Santa Mesa, which is in the northeastern part of Manila, Beyer (1960-61) noted tektite specimens that appeared to have been soft and that sagged when they landed. This evidence of flattening while still plastic, if true, indicates a local origin for these splash-form philippinites. Three samples were collected from an excavation near the edge of Pugad Babuy: buckshot laterite at a depth of 34 centimeters, clay beneath the buckshot laterite at a depth of 75 centimeters, and tuff 15 centimeters beneath the clay at a depth of 1.8 meter.

A second area sampled in the Philippines is on Cabarruyan Island, Pangasinan Province, from where the uniquely etched Anda-type tektites originate. The sample that was collected about 100 meters west of the school at Aoila is an oyster-bearing clay that is too calcareous to be the direct source of philippinites. However, by leaching of carbonate during weathering, a soil of the correct composition to produce tektites might result.

Analytical Procedures

Tektite samples were washed with water to remove adhered earthen material. Tektite and earth-associated materials were ground in a tungsten carbide Shatterbox, resulting in a powdered sample of nominally -325 mesh. All samples were dried at 105° C prior to analyses.

Major elements (Si, Na, K, Mg, Ca, Al, Fe, Ti, Mn, and P) were determined using inductively coupled plasma optical emission spectrometry (ICP-OES) after fusion of the samples using a 2:1 $LiBO_4/LiBO_2$ fusion flux mixture and dissolution of the fusion button in dilute HNO_3. Trace elements (Cu, Ni, V, Zn, Mn, Li, Be, Sr, Ba, Zr, and Y) were determined by ICP-OES after acid digestion using a $HF/HClO_4/HNO_3$ mixed-acid digestion procedure. Rare-earth elements plus Y were determined by inductively coupled plasma mass spectrometry (ICP/MS) using the acid digest obtained for the trace element determinations.

Data for certain trace elements (for example, Zr, Ba, Sr) may be low because of the inability of the acid digestion procedure to quantitatively extract or dissolve refractory oxides or minerals containing these elements. Residual undigested material from the acid dissolution procedure was found for some samples.

Analytical Data

The analytical data in Table 1 cover a diversity of associated materials, including seven Muong Nong-type indochinites, two splash-form philippinites, five samples of laterite, three samples of clay, five samples of soil, and one each of tuff, brown sandstone, and yellow sandstone. The purpose of these analyses was to determine if any of the associated earth materials could have been the parent material for tektites and secondarily to expand the data base for Muong Nong-type indochinites.

These samples were analyzed for major and trace elements, including rare earth elements (REE), and for weight loss on ignition (LOI) (Table 1). In addition to the trace elements shown in Table 1, As, Cd, Mo, Pb, Sb, Se, Sn, U, and Th are present in quantities either below or near the detection limit.

Table 1. Analytical data. The oxide data and loss on ignition (LOI) are given in weight percent and the rest of the data in parts per million. Analysts: major elements, S. W. Tweedy; other elements, S. W. Tweedy, T. L. Pinkson, and K. Buchanan.

	Nong Sapong, Thailand			Phang Daeng, Thailand					
						Laterite			
	Tektite	Clay	Laterite	Tektites		With tektite	-20 cm	-50 cm	Soil
Analysis no.	86-289	86-286	86-292	86-290	86-285	86-291	86-309	86-287	86-288
Sample no.	158176	158173	158179	158177	158172	158178	PD-18	158174	158175
SiO_2	69.84	65.22	37.13	76.67	80.00	46.89	47.84	50.72	84.39
Al_2O_3	13.71	14.99	12.38	10.30	8.95	11.98	14.18	12.38	5.24
Fe_2O_3		11.36	42.97			30.96	27.30	25.51	5.13
FeO	5.08			3.88	3.45				
MgO	2.29	0.33	0.26	1.76	1.36	0.61	0.73	0.65	0.36
CaO	2.14	0.04	0.08	1.83	1.35	0.18	0.07	0.11	0.11
Na_2O	1.56	0.14	0.21	1.45	1.26	0.22	0.06	0.09	0.06
K_2O	3.11	1.37	0.95	2.65	2.37	1.23	1.18	1.30	0.70
TiO_2	0.90	0.86	0.63	0.73	0.65	0.58	0.64	0.59	0.47
LOI	0.0	5.4	7.1	n.d.	n.d.	7.6	6.8	7.3	2.7
Total	98.73	99.71	101.71	99.27	98.39	100.25	98.80	98.65	99.16
Mn	840	140	470	720	680	5500	340	470	120
P	590	80	310	430	310	440	260	220	140
Cu	24	35	43	15	43	46	31	36	17
Ni	43	22	46	30	27	53	46	45	15
V	110	170	390	73	61	540	340	330	94
Zn	55	29	44	65	64	85	65	61	32
Li	59	23	17	38	32	18	29	29	16
Be	3.6	3.4	10	2.7	2.5	9.8	8.7	7.5	1.4
Sr	160	43	25	140	130	30	35	39	21
Ba	490	230	120	430	410	920	220	220	110
Zr	300	120	56	350	370	110	110	90	63

TABLE 1. Continued.

Y	24	18	9.1	26	24	14	17	19	7.0
La	41	43	19	38	36	26	34	35	16
Ce	85	97	46	74	71	180	86	95	35
Pr	9.7	10	4.3	8.8	8.4	5.9	7.8	8.3	3.7
Nd	28	29	13	31	29	17	23	25	11
Sm	5.9	6.1	2.6	6.6	6.3	4.2	4.6	5.3	2.0
Eu	1.3	1.0	0.5	1.3	1.2	1.0	0.9	1.0	0.4
Gd	5.6	4.9	2.4	6.7	6.3	4.8	4.3	5.0	1.9
Tb	0.8	0.6	0.3	0.9	0.9	0.6	0.5	0.6	0.2
Dy	3.9	2.8	1.6	5.5	5.1	2.7	2.7	3.0	1.1
Ho	0.8	0.5	0.3	1.0	0.9	0.5	0.5	0.5	0.2
Er	2.2	1.5	0.9	3.0	2.7	1.4	1.3	1.5	0.6
Tm	0.3	0.2	0.1	0.4	0.3	0.2	0.2	0.2	0.1
Yb	2.4	1.4	0.8	3.0	2.8	1.4	1.4	1.5	0.7
Lu	0.3	0.2	0.1	0.4	0.4	0.2	0.2	0.2	0.1

	Kan Luang Dong, Thailand			Kracheh, Kampuchea				Da-lat, Vietman		
									Soil	
	Tektites		Soil	Tektite	Br.SS	Soil	Yel. SS	Tektite	With tektite	−75 cm
Analysis no.	86-302	86-303	86-304	86-298	86-299	86-300	86-301	86-295	86-296	86-297
Sample no.	KLD-6	KLD-8A	KLD-SO	K-F	K-SB	K-SO	K-SY	DA-A	DA-S10	DA-S40
SiO_2	82.08	79.33	89.14	75.49	63.44	62.21	63.75	75.85	39.71	45.92
Al_2O_3	8.05	9.76	5.33	11.89	15.13	18.02	15.84	11.85	27.84	29.83
Fe_2O_3			0.72		6.28	7.23	6.07		12.45	9.55
FeO	3.24	3.78		5.13				4.57		
MgO	1.21	1.35	0.22	2.13	4.19	1.05	3.36	1.99	0.14	0.24
CaO	1.12	1.09	0.18	1.86	2.34	0.61	1.28	1.96	0.06	0.04
Na_2O	1.07	1.30	<0.03	1.12	3.23	2.05	3.73	1.50	0.15	0.17

TABLE 1. Continued.

K_2O	2.18	2.68	0.17	2.36	1.99	1.42	1.73	2.87	0.41	0.73
TiO_2	0.52	0.68	0.48	0.78	0.60	0.70	0.64	0.82	1.92	1.17
LOI	n.d.	n.d.	3.3	n.d.	2.8	5.8	3.6	n.d.	17.1	12.9
Total	99.47	99.97	99.54	100.76	100.00	99.09	100.00	101.41	99.78	100.55
Mn	920	860	51	780	760	420	720	720	420	170
P	270	370	160	220	440	<50	90	360	140	<69
Cu	10	13	44	7	37	33	32	13	21	19
Ni	27	31	10	84	130	45	96	42	19	14
V	56	70	43	90	160	160	150	86	170	120
Zn	290	510	58	20	79	81	92	46	40	48
Li	27	36	16	46	29	40	32	46	10	4.1*
Be	2.1	2.6	<0.3	3.2	2.5	3.5	2.9	3.0	3.2	3.2
Sr	110	110	18	140	500	230	450	150	8.7	6.1
Ba	390	410	77	410	790	730	890	430	26	30
Zr	220	270	68	270	61	65	55	330	72	69
Y	20	23	3.4	27	27	24	39	28	2.3	2.5
La	29	35	12	38	39	38	110	40	8.1	4.6
Ce	57	68	24	74	38	41	49	77	14	19
Pr	6.6	8.0	2.2	9.0	8.9	8.6	25	9.1	1.5	0.8
Nd	23	28	6.0	32	28	27	73	32	3.6	2.2
Sm	5.0	5.8	1.2	6.7	6.6	5.9	14	6.9	0.7	0.5
Eu	1.0	1.1	0.2	1.3	1.7	1.4	3.5	1.3	0.2	0.1
Gd	5.1	5.9	0.9	6.9	5.4	4.8	12	7.0	0.6	0.5
Tb	0.7	0.8	0.1	1.0	0.8	0.7	1.5	1.0	0.1	0.1
Dy	4.2	4.6	0.6	5.7	4.5	3.7	7.2	5.5	0.4	0.3
Ho	0.8	0.9	0.1	1.1	0.9	0.8	1.3	1.1	0.1	0.2
Er	2.3	2.6	0.4	3.3	2.5	2.2	3.5	3.2	0.2	0.3
Tm	0.3	0.4	0.06	0.4	0.4	0.3	0.5	0.4	0.05	0.04
Yb	2.3	2.6	0.4	3.1	2.5	2.2	3.0	3.1	0.4	0.4
Lu	0.3	0.4	0.06	0.4	0.3	0.3	0.4	0.4	0.1	0.06

TABLE 1. Continued

	Pugad Babuy, Philippines				Anda, Philippines	
	Tektite	Clay	Laterite	Tuff	Tektite	Clay
Analysis no.	86-308	86-307	86-306	86-305	86-294	86-293
Sample no.	PBR-G	PB-30	PB-18	PB-6	A-P	A-CL
SiO_2	72.61	44.47	39.59	60.03	73.50	47.47
Al_2O_3	13.03	29.07	12.81	16.64	12.82	16.95
Fe_2O_3		11.73	35.27	6.80		9.70
FeO	5.15				5.01	
MgO	2.91	0.54	0.14	1.19	2.42	2.68
CaO	3.26	0.26	0.13	2.08	2.89	9.53
Na_2O	0.93	<0.03	<0.03	1.06	1.50	0.83
K_2O	2.10	<0.05	<0.05	1.36	2.87	0.58
TiO_2	0.86	1.47	0.93	0.90	0.88	0.72
LOI	n.d.	12.1	9.4	7.4	n.d.	12.4
Total	100.85	99.64	98.27	97.46	101.89	100.86
Mn	780	210	9800	1200	770	1000
P	209	370	880	590	350	<60
Cu	1.7*	59	180	33	5.2	55
Ni	47	13*	36	8.1*	53	120
V	74	190	980	73	90	180
Zn	15	64	46	110	24	77
Li	48	4.9*	7.3*	4.1*	51	71
Be	3.3	3.6	11	5.2	3.3	2.0
Sr	180	230	17	430	170	94
Ba	440	200	1600	1300	430	77
Zr	310	300	86	240	300	55
Y	29	16	8.6	66	30	14
La	43	89	8.6	48	43	4.8
Ce	82	140	100	87	84	14

TABLE 1. Continued.

Pr	9.8	15	2.1	13	10	1.6
Nd	34	37	6.7	46	36	5.8
Sm	7.1	6.8	2.3	11	7.5	1.9
Eu	1.3	1.7	0.8	3.3	1.5	0.7
Gd	7.4	6.0	2.3	11	7.5	2.0
Tb	1.1	0.7	0.3	1.5	1.1	0.3
Dy	5.8	3.4	1.6	8.7	6.2	2.3
Ho	1.1	0.6	0.3	1.9	1.2	0.5
Er	3.3	1.6	1.1	5.5	3.5	1.3
Tm	0.4	0.2	0.2	0.8	0.5	0.2
Yb	3.2	1.4	1.2	5.7	3.3	1.4
Lu	0.5	0.2	0.2	0.8	0.5	0.2

*near detection limit.

Koeberl (1986) compiled averages for 19 Muong Nong-type specimens, which are compared with the averages of the present seven analyses in Table 2. Of the constituents common to the two sets (SiO_2, Ni, Li, Be, and Lu), averages are lower in the present seven analyses, and all other constiuents are higher. Most of the averages compare favorably except for Ni and Zn. The Ni value of 84 parts per million for the Kracheh specimen is considerably higher than the 33 ppm average for the other six specimens and the average shown by Koeberl. The Zn values of 290 and 510 ppm for the Kan Luang Dong specimens are much higher than the 50 ppm average for the other five specimens and the 67 ppm listed by Koeberl. As mentioned previously, these two specimens had been stored with organic material, and other contaminants may have been present. In selecting material for analyses the outer part of the specimens were broken away, but because these tektites are porous, some contaminated material may have remained. The high values for Cu, V, and a few other elements in the laterite and clay samples at Pugad Babuy may represent contamination by leachates from junk discarded in and around the quarry from which the samples were obtained.

Discussion

Stability of Elements during Weathering

If Muong Nong-type tektites formed in puddles as the result of local fusion of the ground, then the chemical composition of the tektites should be similar to that of the material in which they are embedded, providing that no change in the host material has taken place since the tektites formed. However, laterization, which involves significant chemical change, has taken place. Barnes and Pitakpaivan (1962) assumed that alumina is stable during the weathering cycle and that it can be used as a standard for judging changes in other constituents. That alumina is stable is supported by Mason (1966:166), who found that Al_2O_3 is virtually insoluable between pH 5 and 9 but becomes even more soluble than silica below pH 4. According to Ollier (1969:28), environments in this lower pH range are rare and mostly confined to peat bogs and certain acid mine waters and hot springs.

Assuming a constant mass of alumina and a starting material of the composition of the tektites, the calculated percentage changes in masses of other constituents during clay formation and laterite development are listed in Table 3 for the Nong Sapong and Phang Daeng localities, Thailand. Because the Fe in tektites is dominantly ferrous and, in the clay and laterite, dominantly ferric, the iron is shown as total Fe.

In the clay (Table 3) Fe, Cu, V, and Ce have been enriched (the latter slightly), and all other constituents have been depleted by various

TABLE 2. Major and trace element data for Muong Nong-type indochinites of present analyses compared with Koeberl (1986) compilation (average from 19 samples), which breaks out Chapman and Scheiber average for seven samples separately.

	Koeberl compilation		Present analyses	
	Average of 19 analyses	Chapman and Scheiber, average of seven analyses	Average of seven analyses	Range
SiO_2	78.30		77.04	69.84-82.08
Al_2O_3	10.18		10.64	8.05-13.71
FeO	3.75		4.16	3.24-5.13
MgO	1.43		1.73	1.21-2.29
CaO	1.21		1.62	1.09-2.14
Na_2O	0.92		1.32	1.07-1.56
K_2O	2.41		2.60	2.18-3.11
TiO_2	0.63		0.73	0.52-0.90
Mn	675	770	790	680-920
Cu	13.5	16.4	18	7.3-43
Ni	50	33	40	27-84
V		72	78	56-110
Zn	67		150	20-510
Li	42		41	27-59
Be	3.7		2.8	2.1-3.6
Sr	106		130	110-160
Ba	340		430	390-490
Zr	290	270	300	220-370
Y		27	25	20-29
La	24.4		37	27-48
Ce	60		72	57-85
Nd	21.7		30	23-35
Sm	4.82		6.3	5.0-7.0
Eu	0.84		1.2	1.0-1.5
Tb	0.69		0.9	0.7-1.0
Dy	4.40		5.2	3.9-5.7
Yb	2.31		2.8	2.3-3.1
Lu	0.44		0.39	0.3-0.4

amounts except for the light rare earth elements (LREE, La, Pr, Nd, and Sm), which show little change.

That REE are also stable during the weathering cycle is suggested by Fleet (1984:345), who stated: "The overwhelming concentration of the REE in the detrital fraction of transported material, rather than in the dissolved portion, must mean that the REE pass from weathering to deposition almost exclusively without taking part, en route, in any significant chemical processes."

So far as the clay at Nong Sapong is concerned (Table 3), the LREE in relation to constant Al_2O_3 show a slight depletion, whereas the HREE are depleted by about 19 to 45 percent. Concerning the tektite-bearing

TABLE 3. Chemical changes (+ = gains; − = losses) involved in producing associated clay and laterite from material with original composition of Muong Nong-type indochinites, assuming no change in mass of Al during clay formation or during laterite development. Percentage change in mass relative to Muong Nong-type indochinites.

	Nong Sapong		Phang Daeng Laterite		
	Clay	Laterite	With tektite	−20 cm	−50 cm
SiO_2	−15	−41	−59	−52	−50
Al_2O_3	0	0	0	0	0
Fe	+84	+740	+355	+510	+390
MgO	−87	−87	−68	−69	−70
CaO	−98	−96	−97	−91	−95
Na_2O	−92	−85	−97	−87	−95
K_2O	−60	−67	−68	−60	−63
TiO_2	−13	−23	−37	−33	−39
P	−82	−42	−53	−4	−55
Mn	−85	−38	−67	+530	−48
Cu	+35	+100	−28	+30	−3
Ni	−51	+19	+9	+48	+20
V	+43	+300	+250	+550	+280
Zn	−51	−9	−31	+6	−36
Li	−64	−68	−43	−59	−36
Be	−13	+220	+120	+200	+120
Y	−31	−56	−54	−55	−41
La	−2	−48	−37	−43	−27
Ce	+3	−39	−21	+98	+2
Pr	−4	−51	−38	−45	−25
Nd	−3	−47	−50	−54	−35
Sm	−4	−51	−52	−48	−36
Eu	−26	−59	−52	−35	−39
Gd	−19	−53	−55	−41	−40
Tb	−34	−60	−61	−47	−49
Dy	−33	−54	−66	−59	−55
Ho	−45	−60	−66	−59	−61
Er	−36	−57	−70	−62	−60
Tm	−42	−65	−66	−58	−61
Yb	−45	−65	−67	−62	−87
Lu	−42	−65	−66	−58	−61

laterite, the LREE in relation to constant Al_2O_3 are depleted by 39 to 59 percent and the HREE are depleted from 53 to 65 percent. These data do not indicate which of the two, Al_2O_3 or LREE, is more stable during the weathering cycle. Also, during laterization the REE depletion must be by solution rather than by removal of detrital particles, which is contrary to Fleet's (1984) conclusion.

TiO_2 may be more stable than either Al_2O_3 or LREE. In the clay at Nong Sapong, in relation to constant Al_2O_3, 13 percent of the TiO_2 is lost, and in the laterite associated with the tektites, 23 percent of the TiO_2 is lost. In the three laterite samples from Phang Daeng, in relation to constant Al_2O_3, similar calculations show that 37, 33, and 39 percent TiO_2 is lost. If TiO_2 is constant, then Al_2O_3 should show some gain and LREE should show mostly some loss.

That Al_2O_3 may be enriched to some extent is indicated by Nahon (1986), who stated: "Iron hydroxide precipitates in places where quartz and kaolinite dissolve due to epigenetic replacement. Progressively more indurated ferruginous layers will consist of Al-rich oxyhydroxides due to a relative accumulation of Fe and partially of Al."

Kang et al. (1983:409), using rates of weathering cited in the literature, calculated that the 10- to 15-meters-thick weathering crust on Hai Nan Island, which is within the area of the southeastern Asian tektite strewnfield, took about 0.5 to 0.75 Ma to form. The southeastern Asia tektites formed about 0.7 Ma ago; therefore, laterization mostly has taken place since that time.

Rare Earth Element Data

Because all of the samples (tektites, soil, laterite, clay, sandstone, and tuff) show somewhat similar LREE-enriched patterns when normalized to chondrites, each was normalized to the North American Shale Composite (NASC) for closer inspection of intersample variation. NASC values are taken from Haskin et al. (1968). All of the REE patterns and the discussions are made relative to NASC-normalized values.

REE data for tektites.—All of the tektites in this study exhibit remarkably similar REE characteristics. Compared with chondrites, tektites are about 100 times more enriched in LREE and about 10 times more enriched in HREE and have a slight negative Eu anomaly. This pattern is similar to average crust, as proposed by Taylor (1966) and is nearly identical to NASC. Compared with NASC, all of the tektites in this study have normalized values of 1 (within analytical error) and thus produce extremely flat REE distribution patterns (Fig. 2). For most practical purposes, these values are equivalent to average Phanerozoic continental crust.

These patterns indicate that the source of the tektites is either average crust, average shale (which is essentially the same thing), or some other material of similar composition such as loess. It is clear from the REE patterns and abundances that tektites in this study are not meteorites. The tektites are derived from a source that has undergone significant LREE enrichment relative to chondrites, probably through crustal differentiation processes.

REE data by localities.—The following discussion presents chemical data for the various localities in roughly the order of decreasing possibility that the associated earth materials are the parent material for the particular Muong Nong-type tektite or splash-form tektite analyzed from a given locality.

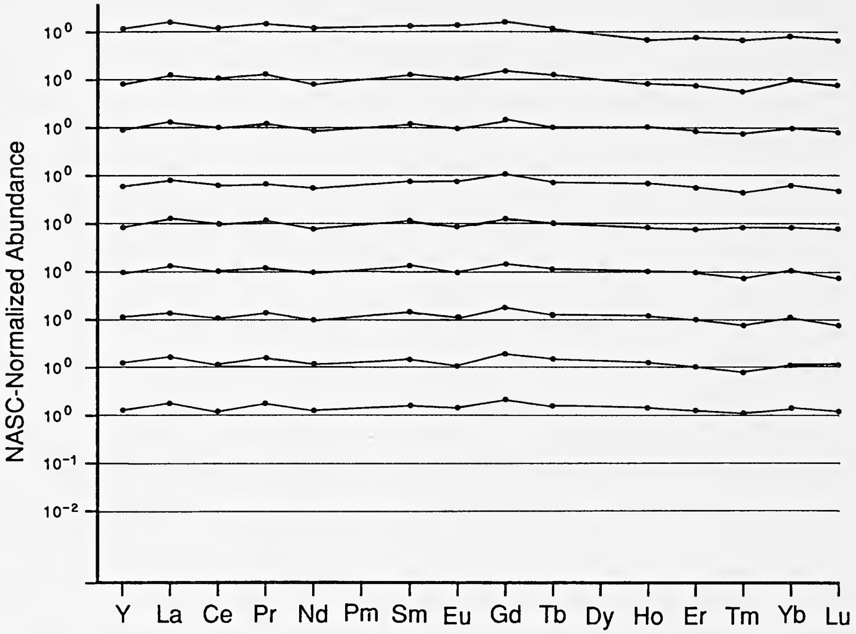

FIGURE 2. Masuda-Coryell diagrams using North American Shale Composite for comparing rare earth element (REE) content of nine southeast Asian tektites. Localities of Muong Nong-type are (1) Nong Sapong, (2) Phang Daeng (high silica), (3) Phang Daeng (low silica), (4) Kan Luang Dong (high silica), (5) Kan Luang Dong (low silica), Thailand, (6) Kracheh, Kampuchea, (7) Da-lat, Vietnam; localities of splash-forms are (8) Pugad Babuy and (9) Anda, Philippines.

In its unweathered or slightly weathered condition, the clay from which the laterite is forming at Nong Sapong appears to be the best candidate as the source material for the associated tektites. That the original material from which the tektites were derived may have been slightly weathered is indicated by the slight depletion of HREE in the Nong Sapong tektite (Fig. 3). The LREE patterns for the tektite and for the clay in the nearby well an Nong Sapong are similar but not identical (Fig. 3). Both show slight enrichment in most of the LREE relative to shale, the clay slightly more so. The HREE are depleted in both the tektite and clay, being considerably more so in the clay. The LREE are strongly depleted in the laterite, and the HREE are even more depleted. However, the graphic pattern for the laterite mimics the pattern for the tektite.

If the unweathered material from which the clay formed is the parent material for the tektites at Nong Sapong and it is assumed that Al_2O_3 is neither gained nor lost during weathering, then the LREE, except for a slight enrichment of Ce and depletion of Eu, are only slightly depleted during this stage of the weathering cycle (Table 3). Except for a

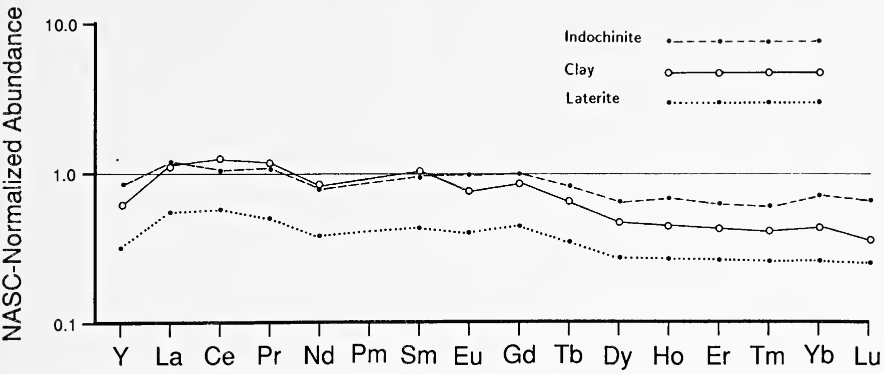

FIGURE 3. Masuda-Coryell diagram using North American Shale Composite for comparing REE content of Muong Nong-type indochinite, associated laterite, and clay from which the laterite formed, Nong Sapong, Thailand.

substantial gain in Fe, Cr, Cu, and V, most other constiuents show a loss, with CaO and Na_2O being the most severely depleted. The stability of the LREE as shown in Figure 2 and Table 3 furnishes compelling evidence that the unweathered material from which the clay developed is the source material for the Muong Nong-type tektites at Nong Sapong. When the same treatment is applied to the laterite at Nong Sapong (Table 3), the relationship is not as clear. The LREE are depleted by about 50 percent and the HREE by about 60 percent. Fe is enriched by about 740 percent; V, 300 percent; Be, 220 percent; and Cu, 100 percent. These two analyses (clay and laterite at Nong Sapong) are also important in showing the chemical change that takes place between an early stage of weathering and the present laterite.

For the Phang Daeng locality (Fig. 4), the REE patterns for the high- and low-silica tektites are almost identical. Except for the depletion of HREE, the REE patterns for the laterite 50 and 20 centimeters below the tektite level compare fairly closely with the tektite patterns. Except for strong enrichment of Ce and some depletion of Nd, the laterite with the tektites is similar to the other two laterite samples. These data also support the premise that the tektites could have been derived from material that weathered to form the laterite in which they now reside. Because of its younger age relative to the underlying laterite, the present soil cannot be the source of the tektites. Also, it seems unlikely that soil of this composition could weather to form laterite of the kind found at Phang Daeng.

The three samples analyzed from Kan Luang Dong include two tektites chosen on the basis of refractive index as representing extremes in composition. The third sample is adhering earth material removed from the tektites after they reached the laboratory. The pattern for the low-silica tektite (Fig. 5), except for a slight saw-tooth variation, is almost a

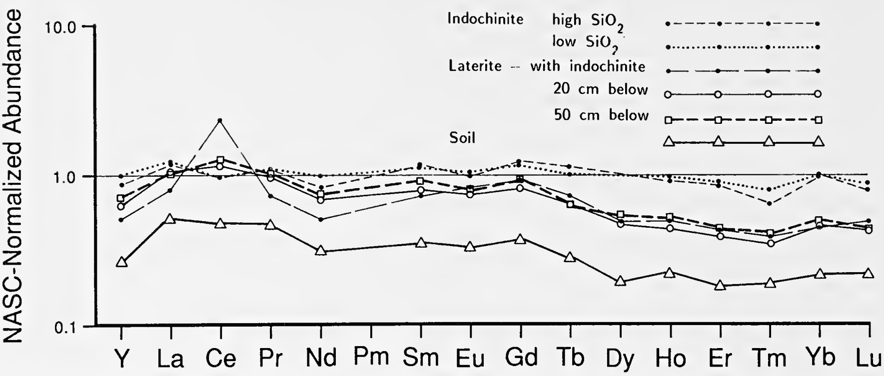

FIGURE 4. Masuda-Coryell diagram using North American Shale Composite for comparing REE content of two Muong Nong-type indochinites, associated laterite, laterite 20 centimeters and 50 centimeters below the indochinites, and the present soil above the laterite, Phang Daeng, Thailand.

straight line showing little enrichment or depletion for the LREE relative to shale. The pattern for the high-silica tektite shows some depletion for all of the REE, and a similar saw-tooth variation is seen for the pattern as in the low-silica specimen. The pattern for the adhering soil shows strong depletion of the REE, becoming progressively more depleted the heavier the REE. It is quite unlikely that this soil could have been the source material for the tektites. It is unknown if the material analyzed is actually the kind of material in which the tektites were embedded or if it is modern soil that adhered to the tektites when the well was dug. Laterite is not present in the dump nor on the tektites, indicating that this deposit and associated materials escaped lateritic weathering—in which case the associated earth materials should be little changed.

The four analyzed samples from near Kracheh, Kampuchea, include a Muong Nong-type indochinite not found *in situ*, soil, brown sandstone, and yellow sandstone. The pattern for the tektite (Fig. 6) shows a slight enrichment of the LREE; the HREE, except for Gd, exhibit only slight enrichment or depletion relative to shale. The pattern for the soil is similar to the pattern for the tektite except for a strong depletion of Ce and some depletion of the HREE. The pattern for the soil is similar to that of the brown sandstone except that the HREE are slightly more depleted. The pattern for the yellow sandstone shows a strong enrichment for all REE except Ce and Dy to Lu. This sandstone is an unlikely source material for the tektites. However, except for a strong depletion of Ce, both the brown sandstone and the soil appear to be of compositions suitable for the production of the tektites.

The Muong Nong-type tektite analyzed from Da-lat, Vietnam, was not from the vicinity of the two soils analyzed. One of the soils occurs at the level that a splash-form tektite was found, and the other, 75 centimeters

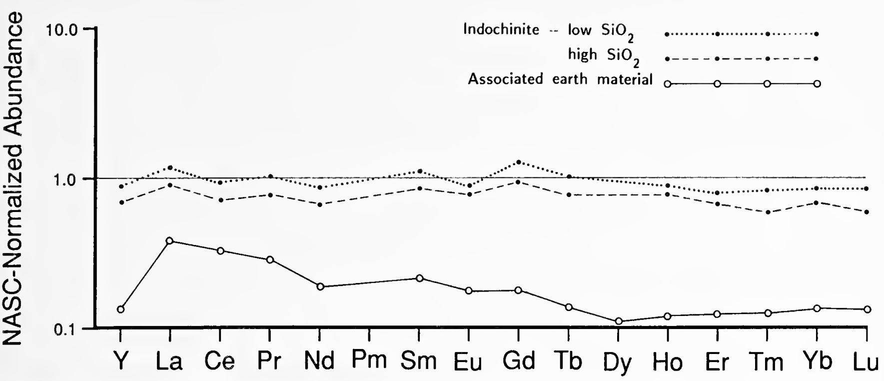

FIGURE 5. Masuda-Coryell diagram using North American Shale Composite for comparing REE content of two Muong Nong-type indochinites with earth material removed from them in the laboratory, Kan Luang Dong, Thailand.

beneath. The pattern for the tektite (Fig. 7) is flat except for a slight enrichment of Gd. The patterns for both of the soil samples show strong depletion of REE relative to shale and to the tektite. Neither appears to be a suitable source material for tektites.

The four samples analyzed from Pugad Babuy, Philippines, include one splash-form tektite, laterite, clay, and tuff. The pattern for the tektite (Fig. 8) shows a slight enrichment of the LREE relative to shale, somewhat greater enrichment of Gd and Tb, and neither enrichment nor depletion for the rest of the REE. The pattern for the laterite, except for enrichment of Ce, shows a strong depletion of the rest of the REE except for Eu. The pattern for the clay ranges from a strong enrichment of La and a lesser enrichment of the rest of the LREE and Gd to a strong depletion of Lu and a lesser depletion of the rest of the HREE. The

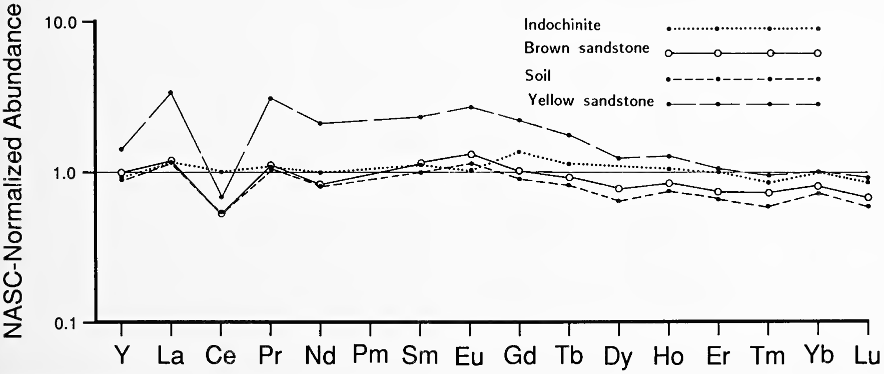

FIGURE 6. Masuda-Coryell diagram using North American Shale Composite for comparing REE content of Muong Nong-type indochinite, brown sandstone, soil, and yellow sandstone, 26.3 kilometers north of Kracheh, Kampuchea.

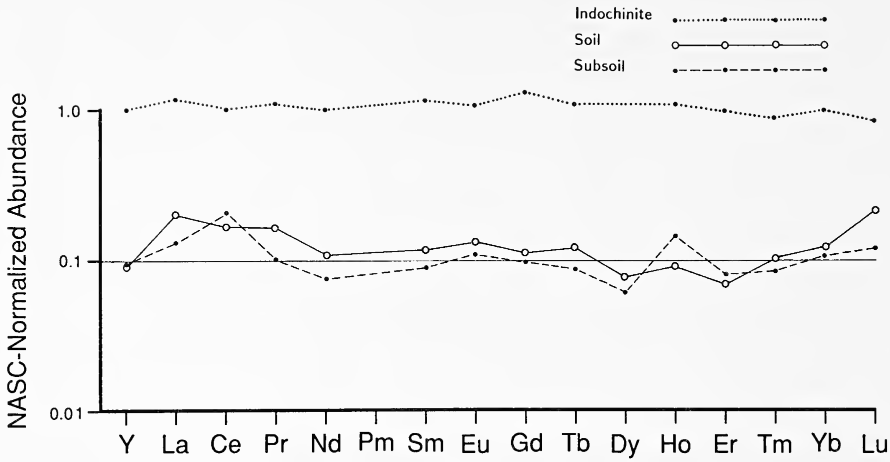

FIGURE 7. Masuda-Coryell diagram using North American Shale Composite for comparing REE content of Muong Nong-type indochinite, soil associated with a splash-form indochinite, and subsoil 75 centimeters beneath the splash-form indochinite, Da-lat, Vietnam.

pattern for the tuff shows strong enrichment of all the REE except for a slight enrichment of Ce. None of these materials appears suitable as a source for tektites.

The two samples analyzed from near Aolie, Cabarruyan Island, Philippines, consist of a splash-form tektite and calcareous clay. The pattern for the tektite (Fig. 9) shows some enrichment for all of the REE. The pattern for the clay shows strong depletion of the HREE and even greater depletion of most of the LREE. Assuming that weathering would have produced HREE depletions relative to LREE, this clay or its parent material could not have been the source material for tektites.

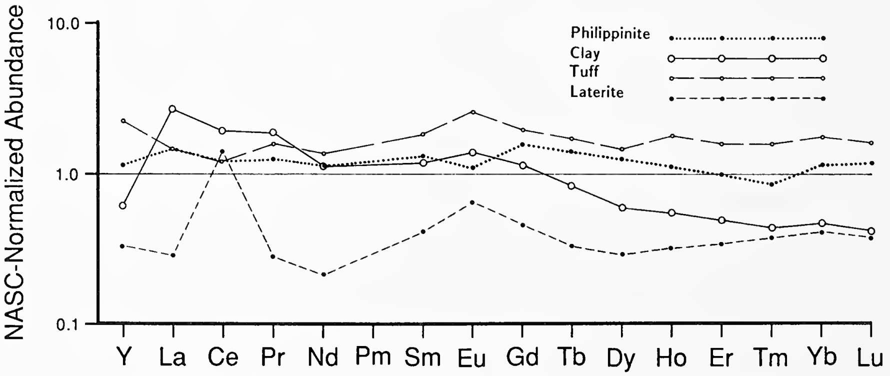

FIGURE 8. Masuda-Coryell diagram using North American Shale Composite for comparing REE content of splash-form philippinite, clay, tuff, and laterite, Pugad Babuy, Philippines.

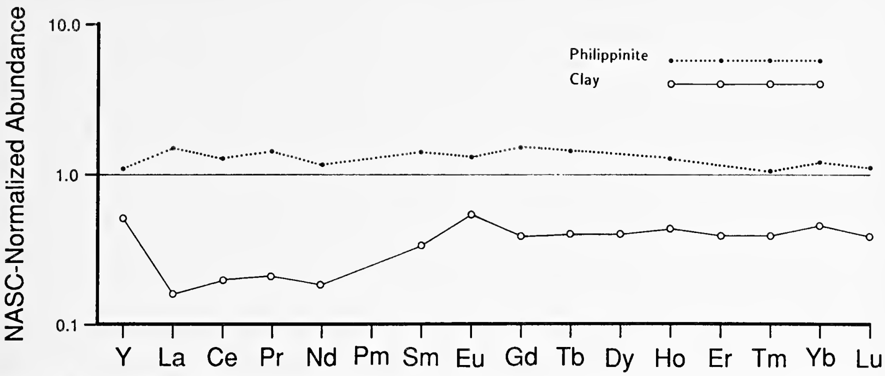

FIGURE 9. Masuda-Coryell diagram using North American Shale Composite for comparing REE content of splash-form philippinite and clay, Anda, Pangasinan Province, Philippines.

REE data by rock type.—None of the associated laterite or other materials in the vicinity have REE patterns identical to those of tektites. Although soils and laterites in the Philippines, Kampuchea, and Thailand each appear similar to shale (for example, tektite) patterns, the trends shown by the sampling do not represent material of a tektite source. However, deeper sampling in the three Thailand localities may uncover such unweathered parent material.

Regardless of the age of the tektites and associated materials it is clear that all tektites of this study are from a similar source (Fig. 2). The tektite source is a homogeneous material with a composition nearly identical to that of crustal rocks. Parent materials could be shale, loess, or other materials with bulk rock compositions that average close to that of shale. Shallow soils of the kind analyzed could not have contributed significantly to the bulk tektite composition because the tektite patterns do not look like those of soils.

Positive Ce anomalies are most pronounced in shallow laterite. This is probably due to oxidation of Ce^{+3} to Ce^{+4} during weathering and formation of laterite and soil. Ce, presumably in the more immobile oxidized state, appears to have been preferentially sequestered and conserved *in situ*, whereas all other REE were dissolved and removed by ground water. A single sample from Phang Daeng (Fig. 4), which is enriched relative to NASC (for example, tektite), indicates that Ce actually may undergo enrichment during weathering or laterization. Ce anomalies in sandstone are due either to incorporation of limestone (or some other marine component with a strong negative Ce anomaly) or to the preferential loss of Ce by mass transport away from the sample collected.

Overall, it appears that during weathering that yields soil, REE are depleted and carried away by ground water. This can be seen in several profiles of this study where REE are depleted in shallow soils or laterites relative to their deeper counterparts. Because of the manner in which processes of soil formation and laterization work, the shallower materials are older, more mature, and have been exposed to more oxidizing ground water than have the younger, deeper samples.

Understanding local weathering relationships by evaluating REE patterns may be a way of determining several parameters, such as weathering rates, oxygen potential in soils, water-rock ratios, and time-integrated redox potential. From the analyses in this study, we have been able to determine that tektites are derived from an extremely homogeneous, strongly fractionated source such as shale. If the source materials for the tektites are local, than they are either from materials deeper than those sampled, or the soil-laterite REE profiles developed after formation of the tektites.

The soils have generally similar characteristics but are differentiated into two endmember groups based on REE patterns. Samples in the first group (Kracheh, Fig. 6) have relatively flat REE patterns showing slight HREE depletion relative to NASC, whereas the second group (Phang Daeng—Fig. 4; Kan Luang Dong—Fig. 5; Da-lat—Fig. 7) has generally more depleted concentrations with even higher LREE/HREE ratios.

The extent of REE depletion appears to depend on stratigraphic position (Da-lat). The deeper sample is less depleted than the shallower one. In addition, soil samples showing the greatest REE depletion have the most perturbed patterns (Da-lat, Kan Luang Dong), some showing positive slopes (Da-lat) among the HREE.

Da-lat subsoil has a positive Ce anomaly even though the overlying soil has no Ce anomaly. Apparently these soils show differential Ce mobility relative to the other REE during soil development. The Kracheh soil has a strong negative Ce anomaly, but this characteristic appears to be related to the rock protolith; both of the sandstone samples in the vicinity of the soil show significant Ce depletion.

The older, more mature, upper-horizon laterite at Phang Daeng (Fig. 4) shows a greater degree of LREE depletion than the deeper, less mature samples. Two laterite samples (one with tektites at Phang Daeng and the other at Pugad Babuy—Fig. 8) have strong positive Ce anomalies. Both are enriched relative to both the laterite and the NASC. Ce enrichment is indicative of Ce mobility in the weathering environment and indicates preferential enrichment due to Ce oxidation (see Goldberg et al., 1963; Moller, 1983; and deBaar et al., 1985).

The clay samples in this study have REE patterns indicative of quite different sources. The Anda clay (Fig. 9) is strongly depleted in REE and has a positive LREE/HREE slope and a slight positive Eu anomaly. On the other hand, the samples from Nong Sapong (Fig. 3) and Pugad Babuy (Fig. 8) have negative slopes, the former being shallower than the latter, and thus indicative of a less differentiated, intermediate parent rock. The Nong Sapong clay is more like the tektite samples than any other material examined, although it demonstrates greater HREE depletion than do tektites.

The two sandstone samples (Kracheh, Fig. 6) have strong negative Ce anomalies indicating either of two possible features. Seawater, and materials precipitated from it, have strong negative Ce anomalies owing to the preferential incorporation of Ce^{+4} by Fe-Mn oxides. Thus both sandstone samples may contain marine calcite cement or marine-generated grains that cause a negative Ce anomaly. On the other hand, the sample may have lost Ce during weathering.

CONCLUSIONS

That the Muong Nong-type tektites of southeastern Asia were produced from local surficial material as suggested by Barnes and Pitakpaivan (1962) is supported by the present analytical data. Schwarcz (1962) stated that tektites may have been formed by the melting of soil at impact sites. The following year Sun (1963) noted that loess is compositionally suited for tektite production. Glass (1970, 1972), on the basis of size and sorting of mineral inclusions, and Glass and Barlow (1979), on the basis of shock metamorphism of these minerals, suggested that the Muong Nong-type indochinites were formed by shock melting of a well-sorted, silt-size sedimentary material.

Loess is this sort of material. The great loess deposits of China may have extended much farther south during the Pleistocene, covering the area where Muong Nong-type tektites now are found. Although loess has not been recognized in this area, its presence may be masked by weathering. It is possible that the clay in the well at Nong Sapong is weathered loess.

Additional evidence that Muong Nong-type tektites formed where they now are found is furnished by the natural remanent magnetism of Muong Nong-type tektites. De Gasparis et al. (1975) stated: "The mechanism of magnetization proposed here is compatible with the model of origin of the Muong Nong tektites suggested by Barnes and Pitakpaivan (1962), which is that these tektites cooled as puddles of molten glass. Some flow of glass ensued (Barnes, 1963a), causing a foliation plane parallel to an existing horizontal surface."

If the original conclusion (Barnes and Pitakpaivan, 1962) that the deposits of Muong Nong-type indochinites formed as puddles of melt in topographic lows is valid, then the heat source would have been intense enough to melt surficial materials from southeastern China through Thailand. The coma of a comet could embrace this much area. The proposal that comet collisions with the earth produced the tektite strewn-fields is not new (Urey, 1955, 1957, 1963; Urey and O'Keefe, 1971). In a typescript note to me attached to the 1971 reprint Urey stated: "This is not [*is not* underlined in red] a joint publication. I did not see O'Keefe's contribution until it appeared in print. If I had, I would have emphasized that only comet collisions and not meteorite collisions could have produced the tektite fields. Also, we should, and for ten years should have tried to account for the difficulties of earth origin instead of trying to prove the impossible lunar origin."

I propose that the Austral-Asian strewn-field is the result of the impact of a comet arriving from the southeast and that the nucleus came to Earth near the middle of the area of Muong Nong-type indochinite occurrence. The delta of the Mekong is near this center, but no crater is known here. However, the Mekong, which carries a heavy load of sediment, has built a great delta in the area of Cambodia and southern Vietnam. Furthermore, the Mekong overflows into the Tonle Sap in western Cambodia during the rainy season. This basin has been mentioned as a possible site for a buried impact crater, as has the Mekong delta area and the adjacent area of the South China Sea (Walter et al., 1986).

If a comet impact produced the Austral-Asian tektite strewn-field, one possible deduction is that the coma surrounding the nucleus compressed the atmosphere against the Earth, shock-metamorphosed minerals, produced melt, and temporarily left a great hole in the atmosphere. The nucleus hit the Earth simultaneously, and melt created by the impact was jetted through the hole in the atmosphere produced by the incoming comet. Once above the atmosphere, the tektites were free to travel at their initial speed until gravity pulled them into the atmosphere.

The presence of slightly ablated tektites in Indonesia, midway between the indochinite and australite strewn-field, supports this conclusion. The Indonesian tektites, traveling more slowly, would have been pulled to Earth sooner. As they were descending at a slower speed, they would have been ablated less than the australites. Additional support for this conclusion is furnished by de Gasparis et al. (1975), who noted that the more perfect flanged shapes, those ablated most, occur in the extreme southeastern part of the australite strewn-field.

That similar origins apply to all strewn-fields is indicated by the presence of Muong Nong-type tektites in the indochinite, Libyan Desert, moldavite, and bediasite strewn-fields; of microtektites in the australite, bediasite, and Ivory Coast strewn-fields; and of impact craters related to the moldavite and Ivory Coast strewn-fields.

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LITERATURE CITED

Barnes, V. E. 1940. North American tektites, Univ. Texas Publ., 3945:477-582.

———. 1957. Tektites. Geotimes, 1(12):6-7, 16-17.

———. 1958. Properties of tektites pertinent to their origin. Geochim. Cosmochim. Acta, 14:267-278.

———. 1960. Significance of inhomogeneity in tektites. Proc. XXI Internat. Geol. Cong., Copenhagen, 8:328-332.

———. 1961*a*. A world-wide geological investigation of tektites. Geotimes, 6(2):8-12, 38.

———. 1961*b*. Tektites. Sci. Amer., 205(5):58-65.

———. 1962*a*. A world-wide geological investigation of tektites (reprint of 1961 Geotimes article with two additional pages of photographs). Lapidary J., 16(1):132-138.

———. 1962*b*. On the origin of tektites [reprint of 1961 Scientific American article with additional tektite photographs]. Gems & Minerals, 299:16-21.

———. 1962*c*. Tektites. Internat. Council Sci. Unions (ICSU) Rev., 4:75-81.

———. 1962*d*. Temperature of tektite formation. J. Amer. Geophys. Union, 67:35-40.

———. 1963*a*. Detrital mineral grains in tektites. Science, 142:1651-1652.

———. 1963*b*. Tektite strewn-fields. Pp. 25-50, *in* Tektites, (J. A. O'Keefe, ed.), University of Chicago Press, Chicago, 25:xii+1-228.

———. 1964*a*. Variation of petrographic and chemical characteristics of indochinite tektites within their strewn-field. Geochim. Cosmochim. Acta, 28:893-913.

———. 1964*b*. Terrestrial implication of layering, bubble shape and minerals along faults in tektite origin. Geochim. Cosmochim. Acta, 28:1267-1271.

———. 1964*c*. Rayed bubbles in tektites. Geochim. Cosmochim. Acta, 28:1373-1375.

———. 1967*a*. Tektites, Encyclopedia Britannica, 21:763.

———. 1967*b*. Tektites, Internat. Dictionary Geophysics, S. K. Runcorn (ed.), Pergamon Press, 2:1507-1518.

———. 1968. Petrography of new tektite localities in Thailand and the Philippines. Proc. XXIII Internat. Geol. Cong., Prague, 13:27-36.

———. 1969*a*. Petrology of moldavites. Geochim. Cosmochim. Acta, 33:1121-1134.

———. 1969*b*. Progress of tektite studies in China. Trans. Amer. Geophys. Union, 50:704-709.

———. 1971*a*. Age of Asian tektites. Bull. Geol. Soc. Amer., 82:1995-1996.

———. 1971*b*. Description and origin of large tektite from Thailand. Chemie der Erde, 30:13-19.

Barnes, V. E., and M. A. Barnes (eds.). 1973. Tektites. Dowden, Hutchinson & Ross, Inc., Stroudsburg, Pennsylvania, xv+445 pp.

Barnes, V. E., and M. L. Barnes, 1972. World-wide investigation of tektites continued. Lapidary J., 26(1):18-48.

Barnes, V. E., G. Edwards, W. A. McLaughlin, I. Friedman, and O. Joensuu. 1970. Macusanite occurrence, age, and composition, Macusani, Peru. Bull. Geol. Soc. Amer., 81:1539-1546.

Barnes, V. E., C. E. Hedge, and Z. E. Peterman. 1965. Soil: source material for tektites (abs.). Trans. Amer. Geophys. Union, Fifth Western Natl. Meeting, 46(3):545.

Barnes, V. E., Z. Kopal, and H. C. Urey. 1958. Origin of tektites. Nature, 181:1457-1458.

Barnes, V. E., and K. Pitakpaivan. 1962. Origin of indochinite tektites. Proc. Natl. Acad. Sci., 48:947-955.

Barnes, V. E., and R. V. Russell. 1966. Devitrification of glass around collapsed bubbles in tektites. Geochim. Cosmochim. Acta, 30:143-152.

Barnes, V. E., and J. R. Underwood, Jr. 1976. New investigations of the strewn field of Libyan Desert glass and its petrography. Earth Planet. Sci. Lett., 30:117-122.

Beyer, H. O. 1960-1961. Philippine tektites. Univ. Philippines Publ. Nat. Hist. Space Sci., Quezon City and Manila, 1(1):125.

Da-ming, L. 1963. A preliminary survey and study of the tektites lei-gong-mo—from Leichow Peninsula and Hainan Island, China. Sci. Geol. Sinica [see Barnes, 1969*b*, for translation by C. J. Peng].

deBaar, H. J. W., M. P. Bacon, and P. C. Brewer. 1985. Rare earth elements in the Pacific and Atlantic Oceans. Geochim. Cosmochim. Acta, 49:1943-1959.

de Gasparis, A. A., M. Fuller and W. A. Cassidy. 1975. Natural remanent magnetism of tektites of the Muong Nong-type and its bearing on models of their origin. Geology, 3:605-607.

Fleet, A. J. 1984. Aqueous and sedimentary geochemistry of the rare earth elements. Pp. 343-373, *in* Developments in Geochemistry 2, Rare Earth Element Geochemistry (P. Henderson, ed.), Elsevier, Amsterdam, 343:xii+1-510.

Glass, B. P. 1970. Zircon and chromite crystals in a Muong Nong-type tektite. Science, 169:766-769.

———. 1972. Crystalline inclusions in a Muong Nong-type indochinite. Earth Planet Sci. Lett., 16:23-26.

Glass, B. P., and R. A. Barlow. 1979. Mineral inclusions in Muong Nong-type indochinites: Implications concerning parent material and process of formation. Meteoritics, 14:55-67.

Goldberg, E. D., M. Koide, R. A. Schmitt, and R. H. Smith. 1963. Rare-earth distributions in the marine environment. J. Geophys. Res., 68:4209-4217.

Haskin, L. A., M. A. Haskin, F. A. Frey, and T. R. Wilderman. 1968. Relative and absolute terrestrial abundances of the rare earths. Pp. 889-912, *in* Origin and distribution of the elements (L. H. Ahrens, ed.), Pergamon Press, Oxford, 889:xvii+1-1178.

Hedge, C. E., V. E. Barnes, and Z. E. Peterman. 1965. Soil: source material for tektites. Trans. Amer., Geophys. Union, 46:545.

Kang, L., W. Shousong, H. Xiuling, and Z. Rufan. 1983. Quarternary laterization in Hainan Island. Pp. 377-411, *in* Leaching and diffusion in rocks and their weathering products, (S. S. Augustithis, ed.), Theophrastus Publ., Athens, 377:x+1-562.

Koeberl, C. 1986. Geochemistry of tektites and impact glasses. Ann. Rev. Earth Planet. Sci., 14:323-350.

LaCroix, A. 1935. Les tectites sans formes figurees de l'Indochine. Acad. Sci. Paris Comptes rendus, 200:2129-2132.

Mason, B. 1966. Principles of geochemistry. John Wiley and Sons, 3rd ed., New York, vii+329 pp.

Mayer, J. 1788. Ueber die bohmischen Gallmeyarten, die grune Erde der Mineralogen, die Chrysolithen von Thein und die Steinart von Kuchel: Bohmischen Gesell. Wiss. Abh., Jahr 1787, Prague and Dresden, pp. 265-268.

Möller, P. 1983. Lanthanoids as a geochemical probe and problems in lanthanoid geochemistry, distribution and behavior of lanthanoids in non-magmatic-phases. Pp.

561-616, *in* Systematics and the properties of the lanthanides, (S. P. Sinha, ed.), D. Reidel Publ. Co., Dordrecht, Holland, 561:viii+1-648.

Nahon, D. B. 1986. Evolution of iron crusts in tropical landscapes. Pp. 169-191, *in* Rates of chemical weathering of rocks and minerals, (S. M. Colman and D. P. Dethier, eds.), Academic Press, Orlando, Florida, 169:xviii+1-603.

Ollier, C. D. 1969. Weathering. Oliver and Boyd, Edinburgh, vii+304 pp.

Schwarcz, H. P. 1962. A possible origin of tektites by soil fusion at impact sites. Nature, 194(4823):8-10.

Sun, M.S. 1963. The origin of Asia-Australia tektites. Trans. Amer. Geophys. Union, 44:93-94.

Taylor, S. R. 1966. Australites, Henbury impact glass and subgreywacke: a comparison of the abundance of 51 elements. Geochim. Cosmochim. Acta, 30:1121-1136.

Urey, H. C. 1955. On the origin of tektites. Proc. Natl. Acad. Sci., 41:27-31.

———. 1957. Origin of tektites. Nature, 179:556-557.

———. 1963. Cometary collisions and tektites. Nature, 197:228-230.

Urey, H. C., and J. A. O'Keefe. 1971. Tektites from the Earth. Science, 171:312-314.

Walter, L. S. 1965. Coesite discovered in tektites. Science, 147:1029-1032.

Walter, L. S., C. C. Schnetzler, and J. G. Marsh, 1986. Search for the Australasian tektite source crater. Meteoritics, 21:529-530.

LATE PLEISTOCENE MAMMALS FROM THE NORTHWESTERN CORNER OF THE OKLAHOMA PANHANDLE

Walter W. Dalquest and Frederick B. Stangl, Jr.
Department of Biology, Midwestern State University, Wichita Falls, Texas 76308

Abstract.—An early, late Wisconsin mammalian local fauna, radiocarbon dated at *ca.* 31,000 years before present, was obtained from a cutbank in Tesequite Canyon in the northwestern corner of Cimarron County, Oklahoma. The fauna includes 14 taxa: proboscidian and extinct horse; cottontail and woodrat not identified to species; and 10 mammals identified at least tentatively to species. Nine of these occur today less than 220 kilometers from Tesequite Canyon, mostly at similar elevations and in similar habitats. The water shrew, *Sorex palustris*, seems out of place in the fauna, occurring today in alpine habitat at higher elevations. Otherwise, with the exception of the extinct species, the Tesequite local fauna might have lived in Tesequite Canyon in late Holocene, pre-Columbian times and does not suggest a glacial maximum climate. *Key words:* Tesequite Canyon, Oklahoma; Pleistocene mammals.

In the autumn of 1986, Jack Wiggins of Kenton, Oklahoma, Midwestern State University graduate student Larry Choate, and the senior author discovered most of the bones of the foot of an extinct horse near the base of a cutbank in Tesequite Canyon, 6 km. SSE Kenton, Cimarron Co., Oklahoma. A subsequent field party removed approximately 1300 kilograms of sandy matrix from the site, which was screen-washed to yield the Tesequite local fauna described herein.

Tesequite Creek, a tributary of the Cimarron River, originates in rough and broken land 13 km. S Kenton, and flows 16 kilometers northeastward to its junction with the Cimarron. The southeastern edge of Black Mesa lies 10 kilometers to the northwest of the collecting site. Black Mesa is a basalt-capped butte, and at almost 5000 feet in elevation, is the highest point in Oklahoma. Black Mesa and the dissected Cretaceous sandstones immediately to the south and east are cloaked with piñon pine and juniper trees. This piñon-juniper zone extends northward into Colorado and westward into New Mexico. The relatively level short-grass prairies of the Great Plains extend to the east of Tesequite Creek.

Tesequite Canyon is about 230 kilometers west of Meade County, Kansas, where the numerous studies of Hibbard (for bibliography, see Smith and Friedland, 1975) established a basis for the study of Pleistocene vertebrate microfaunas of North America. The Meade County local faunas come from sites at relatively low elevation that are now prairie environment. The early, late-Wisconsin fauna of Tesequite Canyon, situated at the boundary between the southern Rocky Mountains to the west and the Great Plains, adds information to our understanding of mammalian distribution during the Pleistocene.

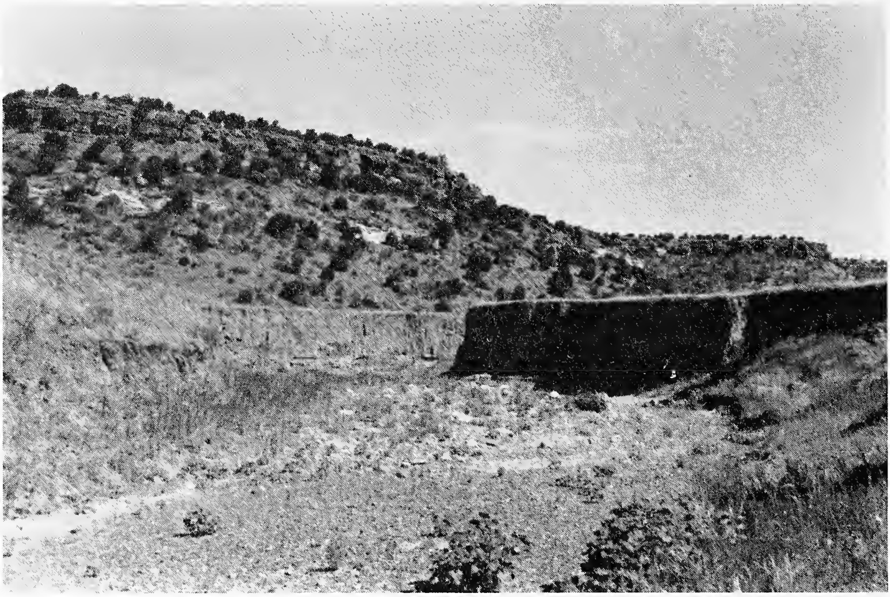

FIGURE 1.—View of Tesequite Arroyo from near collecting site, facing south. Canyon slopes are clothed in juniper.

DESCRIPTION OF COLLECTION SITE

The ditchlike arroyo of Tesequite Creek is a relatively recent occurrence. Schoff and Stovall (1943) noted that in historic times Tesequite Creek had no channel but flowed over a well-sodded valley bottom. They stated that the present arroyo developed as a result of floods in 1914 and 1924. Mr. Bud Davis, manager of the 101 Ranch on which the collecting site is located, remembers when the canyon bottom was a level grassland with the creek winding its way across the surface. He stated that the arroyo appeared after the dust bowl days of the 1930s. Prickly pear and cholla cacti, once minor elements of the vegetation, have increased in recent years and are of serious concern. Rothrock (1925) provided a photograph of the grassland of the floor of Tesequite Canyon before the arroyo developed.

Tesequite Canyon is approximately one kilometer wide at the collecting site, bordered by steep walls of sandstone and shales. The canyon floor is level alluvium approximately 500 meters wide. Tesequite Creek, now an intermittent stream, has entrenched through the sands and silts of the valley fill in an arroyo 10 to 25 meters wide and up to six meters deep (Fig. 1).

At the collecting site and elsewhere nearby, the base of the exposed section seen in the cutbank wall consists of a thick bed of coarse gravel, cobbles, and boulders more than one meter thick. The bottom is not exposed. This we take to be the original stream load before the valley bottom filled with finer materials, mostly sand and clay. The fossiliferous stratum immediately above the basal conglomerate is 1.5 meters of brownish sand and clay with abundant mollusk shells. The Tesequite local fauna was recovered from this stratum (Fig. 2). Shells from the fossiliferous zone gave a radiocarbon date of 31,360 ± 570 years bp (#Beta-22875). This is the age of the fossils and the time when the filling of the canyon bottom, above the basal conglomerate, began. Above the mollusk-rich layer lie more than two meters of brown sandy silts, stratified and more or less calcareous in places, forming the vertical banks of the arroyo.

FIGURE 2.—View of wall of Tesequite Arroyo. Basal conglomerate covered with slump. Man's hand rests on top of fossiliferous layer.

ACCOUNTS OF SPECIES

Following is a synoptic treatment of the Tesequite local fauna. Numbers in parentheses correspond to catalog entries in the Midwestern State University Collection of Fossil Vertebrates.

Sorex palustris Richardson

The single jaw of a water shrew (12410) was recovered. At present this species occurs no nearer Tesequite Canyon than the crest of the Sangre de Christo Mountains, more than 150 kilometers to the west. Usual habitat is small, cold-water streams and marshy margins of ponds and wet meadows, mostly at elevations above 8000 feet (Findley et al., 1975).

Late Pleistocene faunas from prairie habitats east of Tesequite Canyon, such as Meade County, Kansas (Schultz, 1969) and Hardeman County, Texas (Dalquest, 1965) included *Sorex palustris*, together with such montane associates as *Sorex vagrans, S. cinereus, Microtus longicaudus*, and *Zapus hudsonius*. None of these taxa are represented in the Tesequite local fauna.

Notiosorex crawfordi (Coues)

The fragmentary lower jaw (12411) of a shrew was identified for us by C. A. Repenning, U.S. Geological Survey, as *Notiosorex crawfordi*. This species lives today in Tesequite Canyon (Hall, 1981). The desert shrew occurs in a wide variety of habitats, and is of little assistance in reconstructing paleoenvironments.

Sylvilagus sp.

Three isolated upper molars of a cottontail rabbit were recovered (12412), but without a diagnostic lower p3, identification of species is not possible. *Sylvilagus audubonii* presently occurs in Tesequite Canyon, and both *S. nuttallii* and *S. floridanus* are found less than 100 kilometers distant.

Tamias quadrivitattus (Say)

A lower molar (12414) matches that of the Colorado chipmunk. Although we found no sign of this sciurid in Tesequite Canyon, it has been collected on the slope of Black Mesa, about 10 kilometers to the northwest.

Tamias minimus has been recorded in nearby Colfax County, New Mexico, less than 150 kilometers from Tesequite Canyon, but at elevations above 7000 feet. We could not differentiate isolated lower molars of the two species, but presence of *T. minimus* in the Tesequite local fauna seems unlikely.

Spermophilus franklinii (Sabine)

Three lower molars, m1, m2, m3 (12415), all from the left side and in the same stage of wear, appear to be from one individual. Franklin's ground squirrel occurs no nearer Tesequite Canyon today than the grasslands of Trego County, Kansas, 220 kilometers to the northeast.

Late Pleistocene fossils of *Spermophilus franklinii* and *S. richardsonii* may be confused. Upper molars of *S. franklinii* are broad and rectangular as compared to those of *S. richardsonii* but lower molars are less distinctive. The lower molars of *S. franklinii* are smaller, and the m3 relatively broader, than those of *S. richardsonii.* In these features, the Tesequite specimens resemble *S. franklinii.*

Cynomys ludovicianus (Ord)

The palate of a prairie dog (12417) contains both M2's and M3's. The teeth are large, larger than the teeth of white-tailed prairie dogs with which they were compared. A lower third molar is required for positive identification but reference of the fossil to *Cynomys ludovicianus* seems probable.

No prairie dogs live in Tesequite Canyon today, but they do occur less than 50 kilometers to the south and southwest. *Cynomys ludovicianus* is a species typical of the Great Plains. The level bottom of Tesequite Canyon, a grassland in historic times, doubtless supported prairie dogs in the recent past.

Thomomys bottae (Eydoux and Gervais)

Remains of pocket gophers are second in numerical representation only to those of voles in the Tesequite local fauna. Collectively catalogued specimens (12418) include edentulous fragments of skulls and jaws, and isolated teeth. Of major value in identification are three p4's.

Thomomys does not occur at Tesequite Canyon today. *Cratogeomys castanops*, the yellow-faced pocket gopher, is abundant there, its earthen mounds littering the canyon floor. Another species, *Geomys bursarius*, was taken 40 kilometers to the southeast but doubtless occurs even nearer the canyon. *Thomomys* has abandoned Tesequite Canyon since the late Pleistocene and has been replaced by *Cratogeomys.*

Thomomys bottae occurs today just west of Rabbit Ear Mountain, Union Co., New Mexico, 50 kilometers southwest of Tesequite Canyon (Best, 1973), and in what may be a relict population. *Thomomys bottae* is common at higher elevations 80 kilometers west of Tesequite Canyon. *T. talpoides* is found in the still higher elevations of the Sangre de Christos, western Colfax Co., New Mexico, 200 kilometers west of Tesequite Canyon.

Thomomys bottae is readily separated from *T. talpoides* by the enamel pattern of the p4 (Fig. 3). In *T. talpoides* the enamel plate of the anteriolingual side of the trigonid of p4, anterior to the small anteriolingual dentine tract, is concave in occlusal view. The concavity may be short and U-shaped or shallower, but is always present. The trigonid is thus asymmetrical. In *T. bottae*, the enamel plate is usually across the front of the trigonid, not the lingual side, and is straight or convex. The trigonid is usually symmetrical. This characteristic holds in more than 100 specimens of each species examined by us from across their geographic ranges.

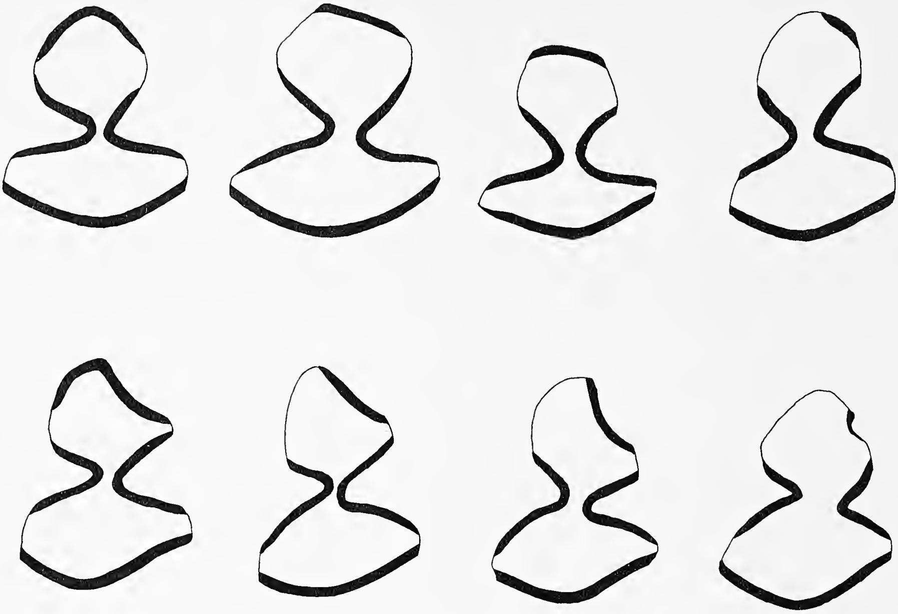

FIGURE 3.—Occlusal view of lower p4 of species of *Thomomys* in New Mexico. Upper row are representative specimens of *T. bottae*, exhibiting straight to convex nature of anterior enamel plate of trigonid. Lower row are representative specimens of *T. talpoides*, exhibiting concavity of anterior enamel plate of trigonid.

The trigonid of p4 in occasional specimens is so greatly worn that it is difficult to characterize. If even a small arc of concave enamel of *Thomomys talpoides* is present, identification is simple. Extreme wear may distort the normal shape of the p3 of *T. bottae*, destroy most of the enamel, and give the trigonid an asymmetrical appearance more typical of *T. talpoides*. If the tooth is isolated from the jaw or can be removed from the jaw, the basal enamel pattern at the tooth base can be examined. Details not readily apparent at the occlusal surface then can be detected and identification is simple.

We have found the p4 character useful in identification of specimens of modern *Thomomys* (see also Hoffmeister, 1986). The character is more readily apparent than the presence or absence of the sphenoidal fissure (Hall, 1981).

Perognathus flavus Baird

The edentulous lower jaw (12419) of a tiny pocket mouse may belong to *Perognathus flavus, P. flavescens*, or even *P. fasciatus. P. flavus* and *P. flavescens* occur in the Tesequite area today and *P. fasciatus* lives in south-central Colorado 200 kilometers to the west. Inasmuch as *P. fasciatus* occurs today so far away from Tesequite Canyon, and *P.*

flavescens is a species rather restricted to sandy sagebrush habitat, the specimen is more likely to be *P. flavus.* None of the other mammals from the Tesequite local fauna suggests presence of sage, and no sage grew at Tesequite Canyon in historic times. *Perognathus flavus* has a broad range of tolerance to environmental conditions and today lives even in the piñon-juniper habitat, sometimes up almost to the margin of the yellow pine forest.

The small species of pocket mice are almost impossible to differentiate on the basis of dentitions. Even with a jaw and complete dentition, identification of the species would be tentative.

Peromyscus maniculatus (Wagner)

A lower jaw with ml (12420) is of a small deer mouse. Five species of *Peromyscus* live in Tesequite Canyon today—*P. maniculatus, P. leucopus, P. boylii, P. truei*, and *P. difficilis*. Jaws and teeth of the three latter species are too large for the fossil. The local subspecies of *P. maniculatus*, probably *P. m. luteus*, is small, whereas the local race of the white-footed mouse, *P. l. tornillo*, is large. First lower molars of these two species can be separated with some confidence (Fig. 4).

Peromyscus maniculatus is rare at Tesequite Canyon, as well as over the northwestern part of Cimarron County, Oklahoma, and much of adjacent eastern Union County, New Mexico. Habitat that elsewhere would be occupied by *P. maniculatus* is instead inhabited by *P. leucopus.* Farther east, in shortgrass prairie habitat, *P. maniculatus* is sometimes common. It seems odd that the only *Peromyscus* taken at the Tesequite Creek fossil deposit should be *P. maniculatus*, and may reflect sampling error.

Neotoma sp.

The single woodrat fossil (12423) is an upper third molar. The fossil is too poor for certain identification, but it is the general size of *Neotoma micropus.* It is much worn and a bit of the crown has been chipped away. Three species of woodrats live near the fossil deposit today. *Neotoma micropus* occurs in the vegetation on the floor of Tesequite Canyon, *N. albigula* in the cliffs and talus of the canyon walls, and *N. mexicana* on the slopes of Black Mesa, 10 kilometers to the northwest. The Mexican woodrat also may live in Tesequite Canyon but we took no specimens there.

Microtus (Pedomys) ochrogaster (Wagner)

Forty relatively complete molars and numerous cheektooth fragments were recovered at Tesequite Creek. Voles are often important indicators of environmental conditions. None live today at Tesequite Canyon; the

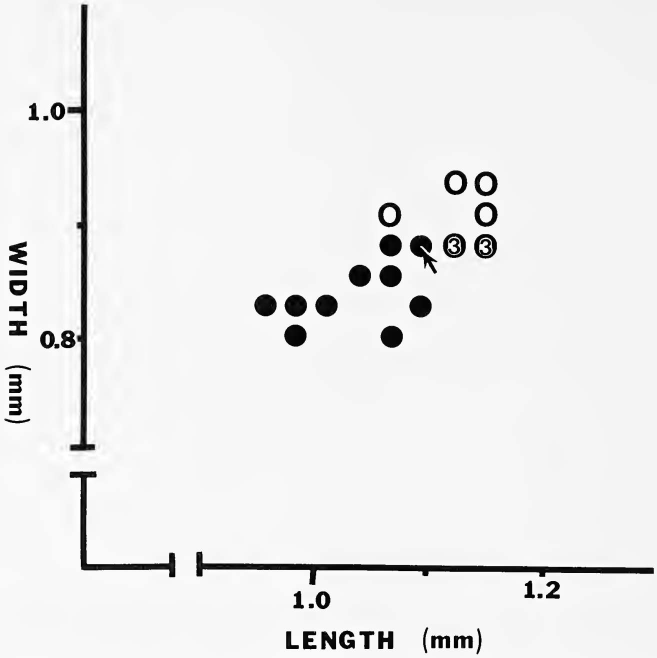

FIGURE 4.—Comparative size of m1 of two species of *Peromyscus* from New Mexico. Closed circles represent teeth of *P. maniculatus*, open circles represent teeth of *P. leucopus*. Numbers within circles represent number of individuals with same measurements. Arrow indicates fossil specimen from Tesequite collecting site.

nearest occurrence being 100 kilometers to the west (Capulin Mountain area, New Mexico). However, five species do occur within a radius of 200 kilometers of Tesequite Canyon, and some of these have restricted habitat requirements. Four of these species (*Microtus pennsylvanicus, M. montanus, M. longicaudus, M. mexicanus*) occur in mountain habitats west of Tesequite Canyon. It seems probable that some species presently living at higher elevations might have occurred at lower elevations, including Tesequite Canyon, in the later Pleistocene, 30,000 years ago.

Over much of the Great Plains, later Pleistocene local faunas usually include only two kinds of voles—*Microtus pennsylvanicus* and *Microtus (Pedomys) ochrogaster* or *Microtus (Pitymys)* sp. *Microtus (Microtus) pennsylvanicus* is readily separated from *Pedomys* and *Pitymys* by possession of five closed triangles on the m1 and one rather than two salient angles on the lingual side, between anterior and posterior loops, of M3. *Pitymys* and *Pedomys* cannot always be separated on tooth morphology (Graham and Semken, 1987), but *Pitymys* is typically a vole of the deciduous eastern woodlands, ranging westward onto the Great Plains as far as central Kansas and Oklahoma only where ecological conditions are suitable. *Pedomys* is a prairie species, preferring well-drained, short-grass prairie. Presence of *Pitymys* at Tesequite Canyon in the late Pleistocene seems improbable.

Five of the fossil teeth, two m1's and three M3's, belong to *Microtus (Pedomys) ochrogaster.* The species has been recorded from near Cimarron, Colfax Co., New Mexico (175 kilometers west of Tesequite Canyon), and Meade County, Kansas (150 kilometers east of Tesequite Canyon; Hall, 1981). There are numerous records from the prairies of central Oklahoma and Kansas. The fossils indicate presence of short-grass prairie at Tesequite Canyon in later Wisconsin times.

Microtus (Microtus) pennsylvanicus (Ord)

A lower jaw with m1 and m2 and three M2's definitely belong to the meadow vole. This is a common species on the prairies from Kansas northward, but at the latitude of Tesequite Canyon, it occurs only at higher elevations. Preferred habitat is tall, grassy meadows, preferably where the soil is humid.

Understanding of the taxonomy and morphology of voles has increased greatly in late years (see Chaline and Graf, 1988, and references therein). Chaline and Graf showed that the distinctive features of the m1 and M3 that link *Pitymys* and *Pedomys* are primitive, and separate them as subgenera of *Microtus. Microtus (Microtus)* has distinctive enamel patterns of m1 and M3, and the number and position of mammae and plantar tubercules of the hind feet differ in the three subgenera.

In all specimens of Recent *Microtus pennsylvanicus* that we have examined, including material from Raton Pass and from Walsenberg, Huerfano Co., Colorado (165 kilometers west of Tesequite Canyon and the nearest record stations as far as we are aware) have the small posterior loop on M2 that is absent in *M. ochrogaster, M. longicaudus, M. montanus*, and *M. mexicanus.*

There are seven other m1's that are not *Microtus ochrogaster.* It is probable that all belong to *M. pennsylvanicus.* However, Davis (1987) noted that *M. montanus* may have occurred as far east as Kansas in the Pleistocene and that the Jones local fauna of Meade County, Kansas, almost equivalent in age to the Tesequite local fauna and only 150 kilometers farther east, contains a species of *Microtus (Microtus)* other than the meadow vole. We are unable to separate the isolated vole teeth beyond the identification of *M. ochrogaster* and *M. pennsylvanicus,* although a few small teeth do resemble *M. mexicanus* in size and structure.

Undetermined proboscidean

A chip of ivory from a tusk (12412) is from an extinct proboscidean that might be either mammoth or mastodon.

Equus cf. *conversidens* Owen

A hind foot, lacking astragalus and calcaneus, was found in place in the brown silts. The bones are slightly etched by humic acid. The ungual phalanx is partly destroyed, but otherwise the specimen is well preserved. Several fragments of horse limb bones showing evidence of destruction by carnivores or scavengers also were noted.

The fossils are of a small species of horse. The animal was mature for there are no traces of sutures remaining on the metatarsal. Direct comparisons with foot bones of *Equus conversidens* from localities in Texas and México reveal no appreciable differences. The Tesequite metatarsal can be matched almost perfectly with *E. conversidens* metatarsals from the Cedazo local fauna of Aguascalientes, México, and from the Slaton local fauna of Texas. The metapodial is too small to be that of *E. niobrarensis* and too stout and relatively short for *Asinus tau* or *A. francisci.* Certain identification must await the discovery of dentitions.

Equus conversidens seems to have been a common small horse of the mid- to late-Pleistocene with a known range from central México to northern Canada.

Greatest length, proximal breadth, midshaft breadth, and distal articular breadth, respectively, of some bones are:
metatarsal—252, 42.4, 28.4, 42.3; proximal phalanx—74.7, 45.5, 27.5, 33.1; medial phalanx—39.0, 40.9, 39.1, 39.3.

Discussion

The only large mammals, horse and proboscidean, in the Tesequite local fauna are extinct, whereas all small mammals of the fauna are extant. The specimens of cottontail rabbit and woodrat cannot be identified to species and do not help in faunal or environmental interpretations. *Notiosorex crawfordi* and *Peromyscus maniculatus* are too generalized to be of help. Of the remaining eight mammals, only *Sorex palustris* is today a montane species at the latitude of Tesequite Creek. *Spermophilus franklinii, Cynomys ludovicianus, Perognathus flavus, Microtus pennsylvanicus*, and *Microtus ochrogaster* suggest a prairie environment. *Cynomys* and *Perognathus* probably occurred at Tesequite Creek in the recent past. *Spermophilus franklinii, Microtus pennsylvanicus*, and *Microtus ochrogaster* are not local residents but do exist today relatively near Tesequite Canyon.

Tamias quadrivittatus and *Thomomys umbrinus* are mammals of higher elevations and often rougher lands west of the Great Plains. *Tamias* occurs at or near Tesequite Canyon today, and *Thomomys* but a short distance away.

Other than the water shrew, a seeming anomaly in the fauna, the Tesequite local fauna differs little (exclusive of the extinct species) from what we would have expected at Tesequite Canyon in immediate pre-Columbian time, before alteration of the habitat by the drought of the dust bowl, erosion, and environmental changes resulting from European occupation, especially grazing of cattle. Tesequite Canyon, in the late Pleistocene, was probably a grassland among hills clothed in piñon and juniper, as it was in early historic times. The climate may have been slightly cooler and more humid than it is today, but minimally so. The fauna is not the type expected during full glaciation.

Schoff and Stovall (1943) reported poorly preserved fragments of Pleistocene fossils, including mammoth, horse and camel, in desposits from caves in the Cheyenne Sandstone in Tesequite Canyon. These caves lie approximately 20 meters higher than the base of Tesequite Arroyo and may or may not be of the same age as the Tesequite local fauna. One large cave is only a few hundred meters from the locality that furnished our fossils. We did not excavate in it, although the caves deserve future investigation.

Hager (1974) has reported two superimposed local faunas from about 55 kilometers east-northeast of Tesequite Creek, in southeastern Colorado. The older, the Donnelly Ranch local fauna, is of Blancan age; the younger, the Mesa de Maya local fauna, is Sangamonian in age. Both are too old for meaningful comparisons with the Tesequite local fauna.

The Bar M local fauna of Harper County, Oklahoma (Hibbard, 1970) is from 260 kilometers east of Tesequite Creek and dates from 21, 360 ± 1250 years bp, but is limited in mammalian species. The Jones local fauna of Meade County, Kansas (Hibbard and Taylor, 1960) comes from 150 kilometers east of Tesequite Creek. The *Ambystoma* faunule of the Jones local fauna dates from 26,700 ± 1500 to 29,000 ± 1300 years bp (Davis, 1987), or quite close to the age of the Tesequite local fauna. The Robert local fauna of Meade County, Kansas (Schultz, 1969) dates only 11,100 ± 390 years bp. This locality is also some 150 kilometers east of Tesequite Creek. If the given date is correct, the Robert local fauna is much younger than the Tesequite local fauna but the two faunas are somewhat similar in species composition (Table 1).

At 31,000 years, the Tesequite local fauna is a bit older than the more numerous local faunas dating from 10,000 to 20,000 years bp. Nevertheless, we still consider it to be a late Wisconsin fauna. Its importance lies in its location west of, and at a higher elevation than, the well-studied Pleistocene local faunas from immediately to the east.

ACKNOWLEDGMENTS

We are indebted to Jack Wiggins and Bud Davis of Kenton, Oklahoma, for permission to work on their lands, and for numerous other favors. Jon Baskin, Larry Choate, Kyle Wells,

TABLE 1. Comparative faunal composition of Tesequite Canyon site with the Jones (Hibbard and Taylor, 1960) and Robert (Schultz, 1969) local faunas.

	Local Faunas		
Taxa	Tesequite	Jones	Robert
Sorex cinereus	—	x	x
Sorex palustris	x	—	x
Sorex arcticus	—	—	x
Notiosorex crawfordi	x	—	—
Blarina brevicauda	—	—	x
Sylvilagus sp.	x	—	—
Tamias quadrivitattus	x	—	—
Spermophilus richardsonii	—	x	x
Spermophilus franklinii	x	x	—
Spermophilus tridecemlineatus	—	x	x
Cynomys ludovicianus	x	x	x
Thomomys talpoides	—	—	x
Thomomys bottae	x	—	—
Thomomys sp.	—	x	—
Geomys sp.	—	—	x
Perognathus flavus	x	—	—
Perognathus sp.	x	x	—
Reithrodontomys sp.	—	—	x
Peromyscus maniculatus	x	—	x
Peromyscus leucopus	—	—	x
Peromyscus sp.	—	x	—
Onychomys leucogaster	—	x	—
Neotoma sp.	x	—	—
Microtus pennsylvanicus	x	x	x
Microtus ochrogaster	x	x	x
Synaptomys cooperi	—	—	x
Zapus hudsonius	—	—	x
Taxidea taxus	—	x	—
Mammuthus sp.	—	x	—
Undetermined proboscidean	x	—	—
Platygonus compressus	—	x	—
Equus conversidens	x	—	—
Equus sp.	—	x	—

and Tracy Schafer aided in the field. Photos were made by Norman Horner. Our work was supported by a research grant from Midwestern State University.

LITERATURE CITED

Best, T. L. 1973. Ecological separation of three genera of pocket gophers (Geomyidae). Ecology, 54:1311-1319.

Chaline, J., and J. D. Graf. 1988. Phylogeny of the Arvicolidae (Rodentia): biochemical and paleontological evidence. J. Mamm., 69:22-33.

Dalquest, W. W. 1965. New Pleistocene formation and local fauna from Hardeman County, Texas. J. Paleo., 39:63-79.

Davis, L. C. 1987. Late Pleistocene/Holocene environmental changes in the central plains of the United States: the mammalian record. Pp. 88-143, *in* Late Quaternary mammalian biogeography and environments of the Great Plains and prairies (R. W. Graham, H. A. Semken, Jr., and M. A. Graham, eds.), Illinois State Mus. Sci. Papers, 22:xiv+1-491.

Findley, J. S., A. H. Harris, D. E. Wilson and C. Jones. 1975. Mammals of New Mexico. Univ. New Mexico Press, xxii+360 pp.

Graham, R. W., and H. A. Semken. 1987. Philosophy and procedures for paleoenvironmental studies of Quaternary mammalian faunas. Pp. 1-17, *in* Late Quaternary mammalian biogeography and environments of the Great Plains and prairies (R. W. Graham, H. A. Semken, Jr., and M. A. Graham, eds.), Illinois State Mus. Sci. Papers, 22:xiv+1-491.

Hager, M. W. 1974. Late Pliocene and Pleistocene history of the Donnelly Ranch vertebrate site, southeastern Colorado. Contrib. Geol. Univ. Wyoming, Paper, 1:1-62.

Hall, E. R. 1981. The mammals of North America. John Wiley and Sons, New York, 2nd ed., 1:xv+1-600 + *90* and 2:vi + 601-1181 + *90*.

Hibbard, C. W. 1970. Pleistocene local faunas from the Great Plains and Central Lowland provinces of the United States. Pp. 395-433, *in* Pleistocene and Recent environment of the central Great Plains, (W. Dort, Jr., and J. K. Jones, Jr., eds.), Univ. Kansas Dept. Geol., Spec. Publ., 3:1-433.

Hibbard, C. W., and D. W. Taylor. 1960. Two late Pleistocene faunas from southwestern Kansas. Contrib. Mus. Paleo., Univ. Michigan, 16:1-223.

Hoffmeister, D. F. 1986. Mammals of Arizona. Univ. Arizona Press, Tucson, xix + 602 pp.

Rothrock, E. P. 1925. Geology of Cimarron County, Oklahoma. Bull. Oklahoma Geol. Surv., 34:1-110.

Schoff, S. L., and J. W. Stovall. 1943. Geology and ground water resources of Cimarron County, Oklahoma. Bull. Oklahoma Geol. Surv., 64:1-133.

Schultz, G. E. 1969. Geology and paleontology of a late Pleistocene basin in southwest Kansas. Spec. Paper Geol. Soc. Amer., 105:1-85.

Smith, G. R., and N. E. Friedland. (eds.). 1975. Studies on Cenozoic paleontology and stratigraphy in honor of Claude W. Hibbard. Mus. Paleo., Univ. Michigan, 3:1-143.

PHYSIOLOGICAL AND RENAL MICROSTRUCTURAL EFFECTS OF DIMETHYLSULFOXIDE INGESTION IN THE LABORATORY RAT

James R. Arnold, John V. Grimes, and Rodney L. Cate
Department of Biology, Midwestern State University,
Wichita Falls, Texas 76308

Abstract.—Rats were allowed to ingest five percent dimethylsulfoxide in drinking water for a period of 20 days. Fluid intake and urine output volumes were 1.4 and 2.0 times greater, respectively, in treated animals than in controls. The number of lysosomelike cytoplasmic bodies increased 2.4-fold in the proximal convoluted tubule cells of kidneys of treated animals. The average body weight increased 36.4 percent in controls and 7.2 percent in treated animals. Microscopic examination of the proximal convoluted tubule and the glomerular filtration systems disclosed no discernible damage; however, the cytoplasmic body response indirectly indicates that alteration of the filtration system occurred. Both weight change and cytoplasmic body abundance of the treated animals exhibited a weight-dependent relationship. Animals with the largest initial body weight showed the greatest response. *Key words*: dimethylsulfoxide; ultrastructure; renal; rat.

Dimethylsulfoxide (DMSO) is a colorless liquid that has unique properties as an organic solvent. DMSO dissolves most aromatic hydrocarbons, almost all nitro compounds, and forms hydrogen bonds with polar compounds (Alsup and DeBowes, 1984; Trice and Pinals, 1985). Recently, DMSO has been utilized in the treatment of cerebral edema, kidney failure, a variety of musculoskeletal disorders, and as a cryoprotectant in organ transplantation (Alsup and DeBowes, 1984; Yoshimitsu et al., 1984; Trice and Pinals, 1985).

The effects of DMSO on biological membrane permeability have been widely studied (for example, Kligman, 1965; Hellman et al., 1967; Ellison et al., 1984), and alteration of the neuronal membrane has been investigated in association with the use of DMSO as an analgesic (Sawada and Sato, 1975). The introduction of DMSO as a therapeutic agent led to studies on its toxicological properties. Monkeys were injected intravenously with DMSO by de la Torre et al. (1981), who performed tests on cardiovascular, neuronal, ocular, hematologic, and urinary functions. The only significant effect reported was an increase in urine volume. Bennett and Muther (1981) reported no short-term nephrotoxicity, but noted hemoglobin in urine resulting from hemolysis and an increase in urine volume. Our investigation was designed to determine physiological and structural effects of a short-term concentrated exposure of DMSO on rat kidney.

Materials and Methods

Twelve male Sprague-Dawley rats (*Rattus norvegicus*), all born within a two-week timespan and aged seven to eight months, were selected at random from the colony maintained at Midwestern State University. Weights of the rats ranged from 200 to 350 grams. The animals were placed in pairs in six standard metabolic cages, and maintained with food and water *ad libitum* for a period of three days to acclimatize them to their surroundings. Fluid intake and urine output volumes for each cage, measured daily during this period, never varied by more than 10 percent. The light-dark cycle was maintained at 12 hour-12 hour intervals throughout the experimental period.

Animals were reweighed when the experimental treatment was initiated. Six rats (three cages) were given food and five percent DMSO in water *ad libitum*. The six remaining rats (three cages) were used for controls and received food and water *ad libitum*. Urine was collected in glass bottles and the volume recorded daily. The tips of collecting funnels were loosely packed with cotton to prevent contamination of the urine by food and fecal matter. Fluid intake also was recorded daily. Rats were removed from their cages daily for cleaning. Treatment conditions were continued for 20 days, at which time the animals were sacrificed for analysis.

DMSO content of urine was determined using high performance liquid chromatography (HPLC). Urine samples were prepared immediately after collection. Methanol-water and acetonitrile-water were used with equal effectiveness as solvent systems. The samples were diluted 20-fold with a 50 percent mixture of the respective solvent system. Each diluted sample (5.0 milliliters) was added to 0.5 gram of Amberlite MB-1 ion exchange resin in order to remove salts that reduce resolution of DMSO. This mixture was then agitated for 15 minutes and filtered through a 0.2 micron prefilter (Millipore Corporation) to eliminate bacteria and other particulates. Following filtration, 10 μl of the sample was injected into the HPLC for analysis.

A Beckman Model 344 HPLC system equipped with an Altex 5.0 micron, 4.6 by 150 millimeter ultrasphere ODS column was utilized for DMSO detection. A 4.6 by 75 millimeter guard column containing Whatman Pell ODS preceded and protected the analytical column. Following sample injection, the column was developed isocratically at 1.0 milliliters per minute with 15 percent acetonitrile or methanol in water, and analyzed at a wavelength of 235 nanometers. The peak representing the DMSO was identified by retention time. DMSO concentration was determined by comparison with a standard curve prepared by adding known concentrations of DMSO to untreated urine and preparing the sample in the manner previously described.

Following the 20-day exposure period, the animals were anesthetized by intraperitoneal injection of sodium pentabarbitol. Animals were weighed and the body cavities were opened by midventral incision. The right renal artery and vein were clamped with a hemostat to prevent blood loss. The kidney was immediately excised, placed in a solution of four percent glutaraldehyde in 0.1 M phosphate buffer and 0.2 M sucrose (pH 7.4). One millimeter cubes of cortical tissue were cut from thin slices of kidney. Fixation continued in the glutaraldehyde solution for one hour. Tissue cubes were rinsed in buffer, post-fixed in one percent osmium tetroxide (0.1 M buffered) for one hour, and then rinsed thoroughly in the buffer alone. After dehydration in a graded series of alcohol, tissue blocks were embedded in Spurr resin.

Kidney tissue from six animals representing each group was analyzed by both light and electron microscopy. A series of semithin sections, approximately one micrometer thick, was taken before and after each series of ultrathin sections and stained with methylene blue. The semithin sections were photographed on an American Optical Microstar microscope using a Nikon automatic camera system.

Tissue sections for the electron microscope were poststained with three percent aqueous uranyl acetate and lead citrate (Reynolds, 1963). Sections were analyzed on an AEI EM6B or a Philips 400 electron microscope. Measurements of basal lamina thickness and spaces between both podocyte feet and capillary endothelial fenestrations were taken in all electron micrographs.

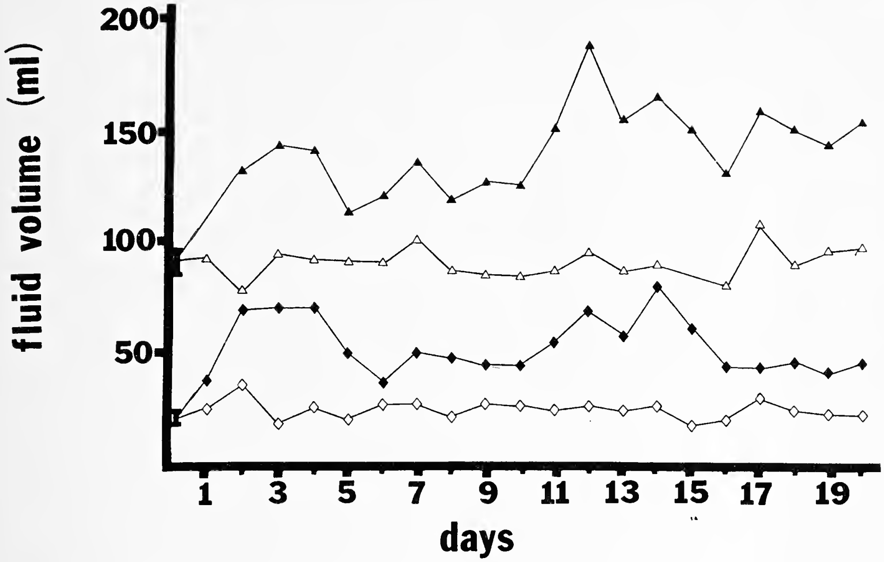

FIGURE 1. Daily fluctuations in fluid volumes. Values are mean pooled amounts for two animals. Fluid intake in control (△) and DMSO-treated (▲) rats; urine output for control (◇) and DMSO-treated (◆) rats.

Semithin sections of 16 proximal convoluted tubule cells were analyzed on each of the treated and control animals, and the number of basophilic granules was counted and recorded for each cell. Granule counts were made only on semithin sections immediately preceding and following the ultrathin sections used for electron microscopy. Only cells with distinct limits or borders were utilized.

The significance of differences between groups was evaluated using t-tests (Gilbert, 1976) and correlations were determined by the methods of Sokal and Rohlf (1969).

RESULTS

An increase in fluid turnover occurred within the first day of DMSO treatment and continued to the third or fourth day (Fig. 1). Fluid volumes of treated animals fluctuated after the fourth day, but were consistently greater than in the controls. Mean daily rate of fluid intake and urine output per unit of initial body weight (Table 1) were 1.40 and 2.04 times greater, respectively, for treated animals than for controls ($P < 0.05$). As determined by HPLC analysis, concentration of DMSO in the urine averaged 3.2 percent in the DMSO-treated animals and 0.26 percent in the untreated controls. The DMSO found in the controls was significantly less than for treated animals and is representative of background peaks in the urine samples (Table 1).

The weight changes that occurred over the course of the experiment were variable within the treated group. Three of the treated animals, but none of the controls, lost weight during the 20-day test period (Fig. 2). If

TABLE 1. Mean (± 1 S.E.) values for measurements of treated and control rats. All treatment (DMSO) means were significantly different from controls ($P < 0.05$, Student's two-tailed t-test).

Parameter	Controls	DMSO
Average fluid consumption - ml/d/g*	0.1944 ± 0.0215	0.2719 ± 0.0166
Average urine production - ml/d/g	0.0504 ± 0.0148	0.1028 ± 0.0050
Relative weight change (percent increase)	36.40 ± 5.01	7.20 ±11.5
Urine DMSO concentration (percent)	0.26 ± 0.0015	3.2 ± 0.153
Number of dense cytoplasmic bodies per cell section	3.68 ± 0.084	8.66 ± 0.6322

*All values based on initial animal weights

the initial weights of treated animals are taken into account, a trend in change of body weight is observed. The higher the initial body weight of the treated animal, the greater the weight loss during the course of the experiment. The controls all exhibited an increase in body weight regardless of their initial weight.

On the eleventh day it was noted that urine in the collecting bottle of two DMSO-treated rats was slightly reddish-brown in color, an indication of hemolysis. The coloration appeared to intensify through the remainder of the experiment.

Light microscopic analysis of kidney tissue revealed no unusual features except an increase in basophilic granules in cells of the proximal convoluted tubule of the treated animals (Fig. 3). For treated animals,

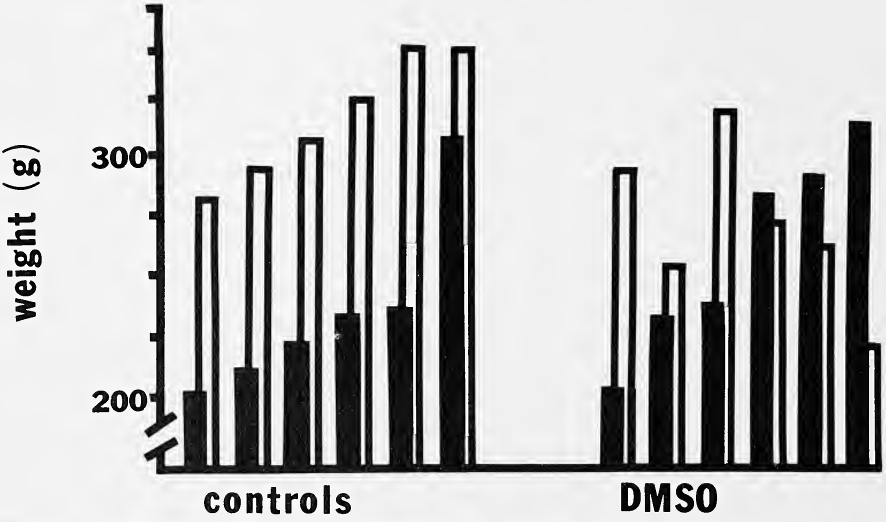

FIGURE 2. Weight-related response to DMSO in rat. Initial (solid bars) and final (open bars) weights for control and DMSO-treated animals for a 20-day test period.

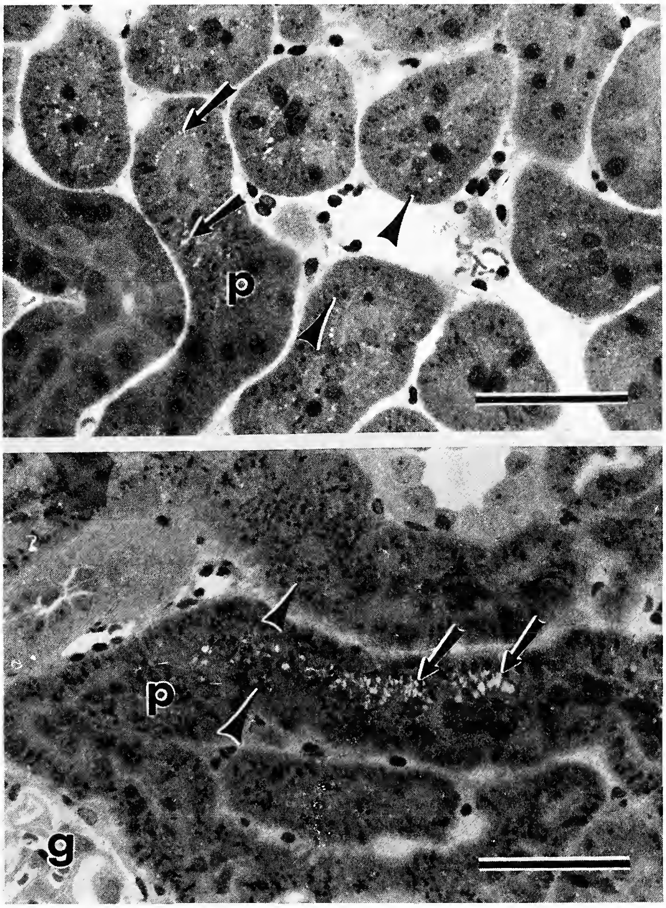

FIGURE 3. Light micrographs of rat kidney. Methylene blue. Upper, control showing proximal convoluted tubules (p) with dense basophilic granules (arrowheads) and slight vacuolization (arrows). Lower, treated with five percent DMSO for 20 days; glomerulus (g); vacuoles (arrows) are somewhat larger than in controls. Note the abundance of basophilic granules (arrowheads) compared to controls. Scale bars represent 30 μM.

the mean (± 1 S.E.) number of granules per cell was 8.66 ± 0.63, and for the controls, 3.68 ± 0.08. This represents a 2.4-fold increase in the number of granules present in the cells of the treated animals. For the treated animal group, the number of granules was positively correlated ($r = 0.9977$; $P < 0.05$) to initial animal weight. The higher the initial weight, the greater the number of granules present. No significant correlation was found between granule number and initial weight in the controls. As seen in electron micrographs the basophilic granules correspond to type II cytoplasmic bodies in the classification scheme of Maunsbach (1969), and are characterized as lysosomes (Fig. 4). They are dense osmiophilic

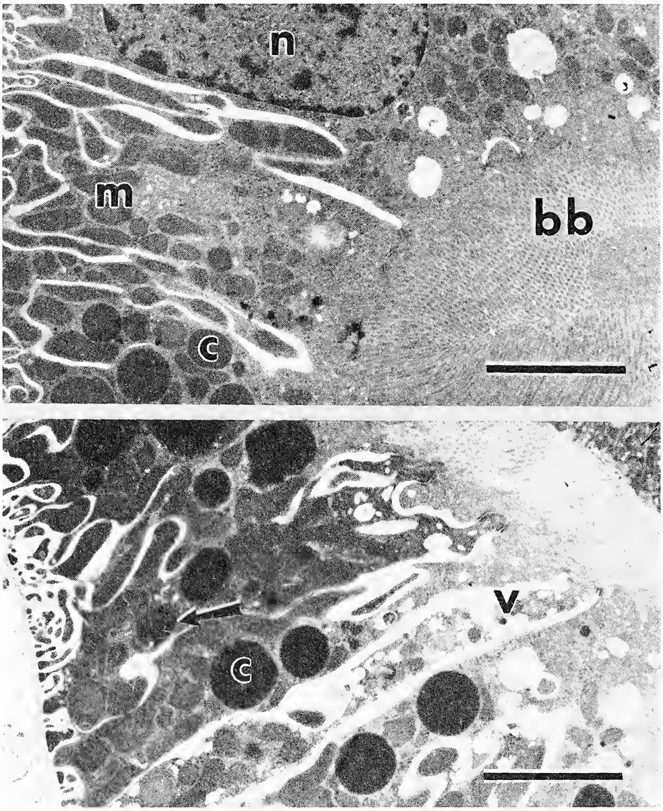

FIGURE 4. Electron micrographs of rat kidney proximal convoluted tubule cells. Uranyl acetate/lead citrate. Upper, control includes dense osmiophilic cytoplasmic bodies (c), nucleus (n), brush border (bb), and mitochondria (m). Lower, treated for 20 days with five percent DMSO. Cytoplasmic bodies (c) and vacuoles (v) are more abundant. Note the presence of a crystalline granule in the dense body (arrow), an indication that the structure is a secondary lysosome. Scale bars represent 3 μM.

structures, spherical to ovoid, 0.5 to 2.0 μm in diameter, and enveloped in a single membrane approximately 90 Å in thickness. They commonly are associated with apical vacuoles and occasionally with residual bodies or secondary lysosomes (Fig. 4). Electron microscopic analysis of the proximal tubule filtration system showed no abnormalities. In all cell types, the intracellular organelles were intact. Spacing and elevation of the microvilli were normal as were the infoldings associated with the basal surface. Intracellular structure appeared unaffected. The spacing of the capillary endothelium was normal and contained adequate pores. The basal lamina was intact and of uniform thickness. Podocytes were correctly oriented and their interdigitations were abundant and properly spaced.

Discussion

The elevated fluid intake response of animals treated with DMSO probably resulted from two separate modes of action, one being a solvation effect of DMSO in water. DMSO absorbs more than 70 percent of its own weight of water from air at 20°C and 65 percent relative humidity (Willson et al., 1965). So hygroscopic a substance could render some of the water in the body physiologically unavailable, acting as a dehydration agent. The animals would require more water and thus imbibe more fluids than their control counterparts. A second mode of action could be a diuretic effect on the kidney or on the osmoregulatory center of the brain, or both. Support for this explanation is based on the observation that treated animals produced a volume of urine 2.04 times greater than controls while drinking only 1.40 times as much fluid (Table 1). The animals were thus experiencing a net water loss compared to the controls. This diuretic effect, as such, would require the animals to increase their fluid consumption. While this response would normally compensate for the diuresis, it cannot be ruled out that DMSO may have a more direct effect involving the thirst center, or perhaps production of antidiuretic hormone, angiotensin, or other regulator of fluid levels.

An increase in urine volume was observed when DMSO was administered intravenously in rhesus monkeys (de la Torre et al., 1981) and humans (Muther and Bennett, 1980). To our knowledge, diuresis induced by oral administration of DMSO has not been reported previously for any animal. However, its occurrence is not surprising, considering that ^{35}S-labeled DMSO is rapidly and widely dispersed in rat tissues regardless of the route of administration (Hucker et al., 1966; Denko et al., 1967). DMSO is known to be osmotically active (Jacob and Wood, 1967). Trice and Pinals (1985) believed urinary output increase following DMSO administration is an osmotic diuretic effect in both humans and animals. A full understanding of the diuretic mechanism of DMSO awaits study of blood and urine osmotic balance through a graded dosage series.

Analysis of weight data indicates that DMSO has a pronounced effect on weight-gaining capacity of rats. The average body weight increased 36.4 percent in controls and 7.2 percent in treated animals. Failure of the treated group to stay abreast of the control group in weight gain may be explained by inconstancy among treated individuals, half of which lost weight, perhaps for reasons unrelated to treatment. The difference also could be accounted for by a weight- or maturity-dependent effect; the lighter animals, presumably less mature, being less affected than the heavier, presumably more mature animals. All treated animals weighing more than 250 grams at the start of treatment exhibited a weight loss (Fig. 2). Brown et al. (1963) likewise noted weight loss in amounts up to 17 percent in rats dosed orally with DMSO on five consecutive days.

Weight was mostly regained during the sixth and seventh days when no dosing took place. Such readily reversible weight changes indicate that DMSO causes a shift in the water content more so than in the organic (for example, lipid) content of the body.

Concentration of DMSO in the urine (3.2 percent) was below that which the animals ingested (5.0 percent). This difference could be the result of elimination of DMSO through exhalation and perspiration, the evaporation of DMSO from the urine collecting apparatus, the metabolism of some of the DMSO to products like dimethyl sulfone and dimethyl sulfide (Layman, 1987), or the accumulation of DMSO in the body (or some combination thereof). Because DMSO was dispersed in an aqueous solution, urine, we think that whatever amount may have evaporated during the 24-hour collection periods did so at a uniform rate. The other possible means of DMSO loss were not explored and their relative importance is speculative.

The cause of the proliferation of the dense cytoplasmic bodies in the proximal convoluted tubules of DMSO-treated rats is not known. The identification of these organelles as lysosomes must be confirmed by cytochemical and biochemical techniques (Holtzman and Novikoff, 1984) and for now must be regarded as tentative. Microscopic analysis indicates that, while alteration of the normal kidney does occur (an increase in cytoplasmic bodies), it was not extensive at the DMSO concentration and exposure period in this study. The number of cytoplasmic bodies was, however, significantly higher than for controls (Table 1) and was strongly and positively correlated to the initial weight of the treated animals. No such correlation was found in controls. The increase in cytoplasmic bodies also is related to the initial weight of the animals; the heavier the animals initially, the greater the increase in these organelles when treated with DMSO. Increase in lysosomes has been related to the reabsorption of carbohydrates, proteins, and lipoproteins by the proximal convoluted tubule (Latta et al., 1967). Evidence of hemolysis was found in two of the treated animals. Alsup and DeBowes (1984) believed that renal toxicosis, consisting primarily of mild tubular nephrosis in DMSO-treated animals, is caused by the breakdown products of hemolysis. Inasmuch as only two of our six rats were determined to be hemolytic, we feel this explanation, while contributory, does not fully explain the cause of our observed nephrotoxicity.

DMSO toxicity has been demonstrated in this study. The high concentration, short-term exposure elicited both the physiological and ultrastructural responses of the kidney.

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We are grateful to O. W. Van Auken for advice and discussions that aided in the preparation of the manuscript and Frederick Stangl, Jr., who kindly produced Figures 1 and 2 and provided helpful suggestions for each draft. For critical reviews we are also thankful to Walter W. Dalquest, Robert Cox, and two anonymous reviewers.

LITERATURE CITED

Alsup, E. M., and R. M. DeBowes. 1984. Dimethyl sulfoxide. J. Amer. Vet. Med. Assoc., 185:1011-1014.

Bennett, W. M., and R. S. Muther. 1981. Lack of nephrotoxicity of intravenous dimethyl sulfoxide. Clin. Toxicol., 18:615-618.

Brown, V. K., J. Robinson, and D. E. Stevenson. 1963. A note on the toxicity and solvent properties of dimethyl sulphoxide. J. Pharm. Pharmacol., 15:688-692.

de la Torre, J. C., J. W. Surgeon, T. Ernest, and R. Wollmann. 1981. Subacute toxicity of intravenous dimethyl sulfoxide in rhesus monkeys. J. Toxicol. Environ. Health, 1:49-57.

Denko, C. W., R. M. Goodman, R. Miller, and T. Donovan. 1967. Distribution of dimethyl sulfoxide-^{35}S in the rat. Ann. New York Acad. Sci., 141:77-84.

Ellison, D. H., H. E. Velazquez, and F. S. Wright. 1984. Osmotic activity of dimethyl sulfoxide in the renal distal tubule. Kidney Int., 26:471-475.

Gilbert, N. 1976. Statistics. W. B. Saunders Co., Philadelphia ix + 364 pp.

Hellman, A., J. G. Farrelly, and D. H. Martin. 1967. Some biological properties of dimethyl sulphoxide. Nature, 213:982-985.

Holzman, E., and A. B. Novikoff. 1984. Cells and organelles. Saunders College Publ., Philadelphia, x + 660 pp.

Hucker, H. B., P. M. Ahmad, and E. A. Miller, 1966. Absorption, distribution and metabolism of dimethylsulfoxide in the rat, rabbit and guinea pig. J. Pharmacol. Exp. Ther., 154:176-184.

Jacob, S. W., and D. C. Wood. 1967. Dimethylsulfoxide [DMSO]: toxicity, pharmacology and clinical experience. Amer. J. Surg., 114:414-426.

Kligman, A. M. 1965. Topical pharmacology and toxicology of dimethyl sulfoxide. Part I. J. Amer. Med. Assoc., 193:796-804.

Latta, H., A. B. Maunsbach, and L. Osvaldo. 1967. The fine structure of renal tubules in cortex and medulla. Pp. 1-56, *in* Ultrastructure in biological systems (A. J. Dalton and F. Haguenau, eds), Academic Press, New York, 2: x + 1-240.

Layman, D. L. 1987. Growth inhibitory effects of dimethyl sulfoxide and dimethyl sulfone on vascular smooth muscle and endothelial cells in vitro. In Vitro Cell. Dev. Biol., 23:422-428.

Maunsbach, A. B. 1969. Functions of lysosomes in kidney cells. Pp. 1-56, *in* Lysosomes in biology and pathology (J. T. Dingle and H. B. Fell, eds.), North Holland Publ. Co., Amsterdam, 1:xxiii + 1-543.

Muther, R. S., and W. M. Bennett. 1980. Effects of DMSO on renal function in man. J. Amer. Med. Assoc., 244:2081-2083.

Reynolds, E. S. 1963. The use of lead citrate at high pH as an electron-opaque stain in electron microscopy. J. Cell Biol., 17:208-212.

Sawada, M., and M. Sato. 1975. The effect of dimethyl sulfoxide on the neuronal excitability and cholinergic transmission in *Aplysia* ganglion cells. Ann. New York Acad. Sci., 243:337-357.

Sokal, R. R., and F. J. Rohlf. 1969. Biometry. W. H. Freeman and Co., San Francisco, 776 pp.

Trice, J. M., and R. S. Pinals. 1985. Dimethyl sulfoxide: A review of its use in the rheumatic disorders. Semin. Arthritis Rheum., 15:45-60.

Willson, J. E., D. E. Brown, and E. K. Timmens. 1965. A toxicological study of dimethyl sulfoxide. Toxicol. Appl. Pharmacol., 7:104-112.

Yoshimitsu, K., N. Koga, Y. Kitamura, K. Fukuda, E. Kittaka, N. Horino, N. Sakura, T. Tanaka, Y. Nishi, T. Sakano, Y. Kobayashi, and T. Usui. 1984. Favorable effect of dimethyl sulfoxide on secondary amyloidosis in juvenile rheumatoid arthritis. Pediatr. Pharmacol., 4:177-181.

Present address of Arnold: *Chemical Pathology Division, Department of Pathology, The University of Texas Medical Branch, Galveston, Texas 77550.*

SEASONAL HERBIVORY EFFECTS ON HERBACEOUS PLANT COMMUNITIES OF THE EDWARDS PLATEAU

Guy R. McPherson and G. Allen Rasmussen
Department of Range and Wildlife Management, Texas Tech University, Lubbock, Texas 79409

Abstract.—Reciprocal averaging ordination, t-tests, and diversity indices indicated that grazing history and soils affected herbaceous botanical composition on the Edwards Plateau of Texas. Several uncommon warm-season (C_4) species were restricted to winter-spring grazed or lightly grazed pastures. Winter-spring grazing reduced cool-season (C_3) grass composition. Three strategies were identified that allowed species to tolerate herbivory: (1) critical growth periods not coincident with period of exposure to ungulate herbivory, (2) relatively low palatability, and (3) morphological features. Diversity generally was higher on hillsides than on plateau tops or low-lying sites, probably a result of increased environmental heterogeneity associated with gravelly slopes. *Key words*: diversity; grazing effects; ordination; plant communities.

Alteration of rangeland plant communities by herbivory has been well documented. Early studies of effects of herbivory on community patterns (for example, Weaver and Clements, 1938; Dyksterhuis, 1946*a*, 1946*b*) led to the develoment of several grazing systems, most of which utilize seasonal grazing regimes. Grazing during a particular season may provide a competitive advantage to one or a few species over other species (Harper, 1977; McNaughton, 1979). Continued herbivory during the same season each year generally causes a shift in species composition.

Response of individual species to herbivory depends upon severity (Crider, 1955; Branson, 1956; Ellison, 1960) and season (Blaisdell and Pechanac, 1949; Jameson, 1963) of defoliation, morphological characteristics (Dahl and Hyder, 1977), associated species (Caldwell et al., 1981; Boryslawsky and Bentley, 1985; Belsky, 1986*a*; McNaughton, 1986), and environmental factors (Ahlgren, 1938). Plant defoliation alters carbohydrate storage patterns. Frequent, severe defoliation generally results in decreased herbage productivity and vigor (Menke, 1973; Stoddart et al., 1975; Trlica, 1977). Defoliation during periods of carbohydrate translocation to storage organs can be particularly damaging (Dahl and Hyder, 1977). However, allocation of plant resources to particular structures and ability to quickly replace photosynthetic tissue following a defoliation event may be more important than carbohydrate storage patterns (Caldwell et al., 1981; Richards and Caldwell, 1985). Morphological and phenological characteristics that affect a plant's ability to compete under different grazing regimes have been reviewed by Crawley (1983).

Diamond et al. (1987) stated "published quantitative data on plant communities are incomplete . . . especially [in the] south Texas Plains, lower Rio Grande Valley, Edwards Plateau, and Rolling Plains." This study attempts to partially fill this void with descriptive plant community

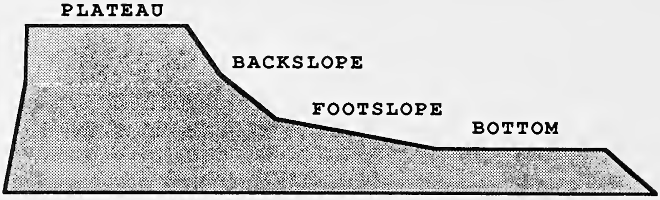

FIGURE 1. Relationship between topography and soil series on rangelands in Callahan County, Texas (adapted from Rasmussen, 1986).

data from the Edwards Plateau. Specific objectives were (1) to determine the effect of four grazing regimes on herbaceous community patterns, and (2) to identify strategies whereby dominant herbaceous plants adapt to repeated seasonal defoliation. Ordination was used to detect vegetation patterns related to grazing history and forage value of plants.

METHODS

The study was conducted in July 1985 on the Spring Gap Ranch, located on a northern outlier of the Edwards Plateau, Callahan County, Texas (99°17′00″ W, 36°16′00″ N). Average annual precipitation at the ranch is 630 millimeters. Four limestone-derived soil series dominate the study area (Fig. 1). The Speck series (clay, mixed, thermic Lithic Argiustoll) is a shallow (30 centimeters) noncalcareous soil located on plateaus (nomenclature follows Soil Survey Staff, 1975). The Oplin series (loamy skeletal, carbonatic, thermic Typic Calciustoll) is a shallow (35 centimeters) soil on plateau backslopes. Brackett soils (loamy, carbonatic, thermic Fluventic Calciustolls) typically occur downslope from Oplin soils. Mean soil depth of the Brackett series is 45 centimeters. Slopes of backslopes and footslopes varied from 10 to 40 percent. Deep (up to 200 centimeters) clay soils of the Nuvalde (fine silty, mixed, thermic Typic Calciustoll) and Mereta (fine silty, mixed, thermic Petrocalcic Calciustoll) series occur in low-lying areas between plateaus (collectively, bottomland soils) (Rasmussen, 1986).

Two winter-spring (December-May) grazed pastures, two summer-autumn (June-November) grazed pastures, and two continuously grazed (year long) pastures were sampled in the summer of 1985. Pasture size varied from 400 to 819 hectares. All pastures were continuously grazed at the same stocking rate and otherwise undisturbed before 1970. They were individually tree-dozed and prescribe burned from 1970-1976, and pastures have been subjected to the winter-spring or summer-autumn grazing regime since 1978. The winter-spring, summer-autumn, and one continuously grazed pasture were grazed by cattle at 0.6 hectare per 455-kilogram animal per month (moderate intensity). The other continuously grazed pasture was grazed at 1.2 hectares per 455-kilogram animal per month (light intensity). Animal density in seasonally grazed pastures was twice that in the moderately but continuously grazed pasture.

All soil series (Speck, Oplin, Brackett, and bottom soils) were sampled along four plateaus in each pasture. A 100-meter line transect was randomly located on each of the four soils associated with each plateau. An inclined 10-point sampling frame (Levy and Madden, 1933) was placed at two-meter intervals along transects; basal herbaceous cover was estimated by recording the species, bare ground, or mulch at each contact. Thus, 500 points characterized each sampling area. Compared to other measures of vegetation response (biomass production and foliar cover, for example), basal cover is less sensitive to seasonal effects or short-term climatic fluctuations. Therefore, it is the best measure of long-term effects of soil conditions and grazing (ASRM-AB, 1962). Species composition was estimated as the number of contacts of a species divided by the sum of contacts for all species. Percentage data were arcsine transformed before analyses (Bartlett, 1947).

Reciprocal averaging ordination (RA) was used to detect and display vegetation patterns; uncommon species (basal cover less than one percent on all transects) were removed from the data set (Gauch, 1982). Grazing effects on individual species were determined using within-plot variability as the source of error for t-tests; therefore, interpretations of results are inferences external to the analyses (see Belsky, 1986*b*). Diversity was estimated for each soil and grazing treatment with Simpson's (c) and Shannon's (H) indices (Greig-Smith, 1983). Diversity indices were highly correlated; therefore, only c, which decreases with increasing heterogeneity, is reported. Oplin and Brackett soils supported similar vegetation (botanical composition and diversity relations) and ordination diagrams were similar; for the sake of simplicity, most results from Brackett soils are excluded from discussion.

Botanical nomenclature follows Hitchcock (1950). Assessment of grazing values follows Gould (1978).

RESULTS

Basal cover of 22 species exceeded one percent on at least one transect; 37 other species (primarily forbs) were encountered but excluded from analyses. RA of all transects together produced an ordination with the first axis reflecting variation in soil depth and the second axis displaying grazing intensity effects (data not shown). Because RA can be used divisively (Gauch, 1982) and the different soils supported markedly different vegetation, data were ordinated by soil series.

The first axis differentiated continuously grazed transects from seasonally grazed transects on low-lying soils (Fig. 2). Yearlong moderately and lightly grazed transects were difficult to distinguish because cattle tend to concentrate in flat low-lying areas (Stoddart et al., 1975). Flat, productive bottomland sites receive more grazing pressure than other areas (especially steep slopes) in lightly grazed pastures. Therefore, grazing pressure was uniformly high on moderately and lightly grazed bottomlands. The second axis ordered seasonally grazed transects by grazing season. Summer-autumn grazed pastures were dominated by *Stipa leucotricha*, a cool-season (C_3) grass of fair forage value. Winter-spring grazing reduced *Stipa* by 75 percent (Table 1), favoring the warm-season (C_4) grass *Sporobolus clandestinus.*

Species scores provided insight into ordination of transects. The presence of *Hilaria belangeri*, a warm-season, stoloniferous short grass of fair forage value, in continuously grazed pastures and its absence elsewhere caused all continuously grazed transects except one (which lacked *Hilaria*) to be ordinated positively on Axis I. Separation of summer-autumn and winter-spring grazed transects was influenced by relatively uncommon species that were restricted to one of the two grazing treatments (for example, *Sorghastrum nutans*, *Sporobolus asper* var. *hookeri*, and *Leptochloa dubia*).

Transect ordination of Speck soils (Fig. 3) indicated a strong similarity between summer-autumn grazed and moderately continuously grazed

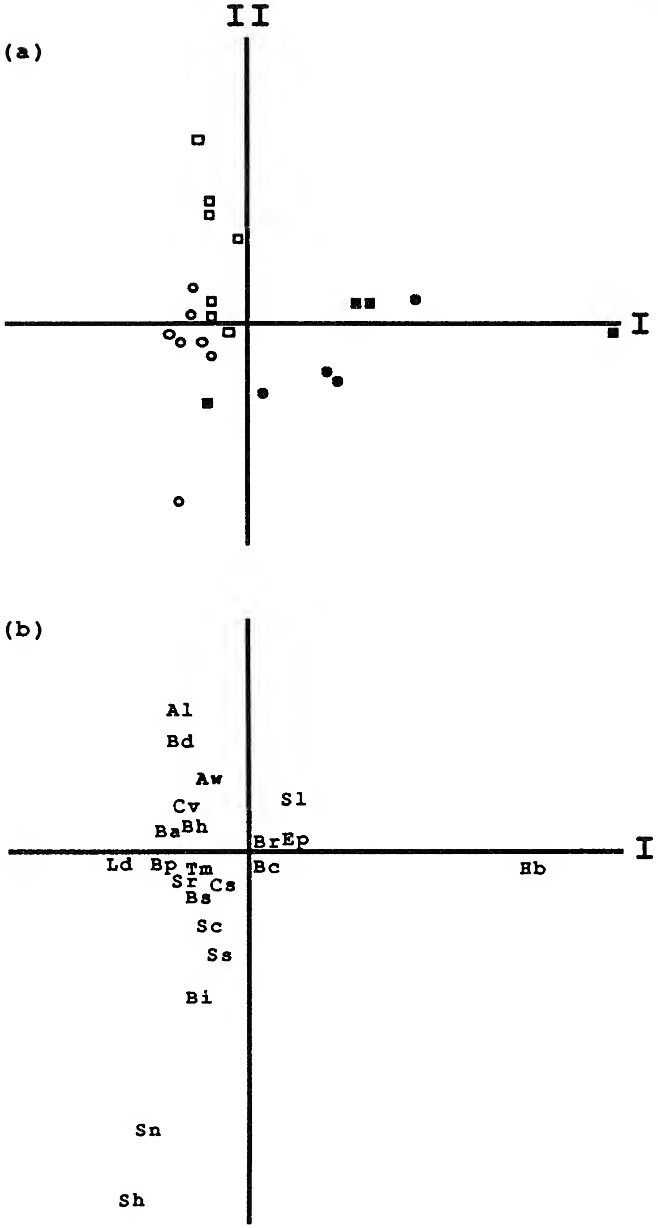

FIGURE 2. Ordination of stand (a) and species scores (b) on bottomland sites on the Texas Edwards Plateau. Four grazing regimes were sampled: moderate continuous (■), light continuous (●), summer-autumn (□), and winter-spring (○). Species codes are listed in Table 2.

TABLE 1. Botanical composition of common species and diversity of herbaceous plants under four grazing regimes on the northern Edwards Plateau, Texas.

	Bottom[1]				Speck				Oplin			
Species	CM[2]	CL	SA	WS	CM	CL	SA	WS	CM	CL	SA	WS
Stipa leucotricha	34	34	36	8	8	4	9	1	1	0	0	0
Carex sp.	1	2	5	2	4	4	2	1	1	2	16	1
Hilaria belangeri	32	19	0	0	0	0	0	0	0	0	0	0
Bouteloua hirsuta	4	6	11	14	8	16	8	6	6	0	10	7
Bouteloua pectinata	0	0	0	1	0	0	0	0	0	8	2	8
Bouteloua rigidiseta	7	6	11	4	0	0	0	2	0	0	2	1
Bouteloua curtipendula	2	5	2	5	10	5	1	13	8	0	4	10
Sporobolus clandestinus	8	19	2	27	1	17	1	3	15	39	13	37
Sporobolus cryptandrus	0	1	0	3	2	2	0	8	0	1	1	0
Aristida wrightii	1	0	2	1	10	4	11	4	20	4	15	5
Aristida longiseta	0	0	1	1	3	20	6	1	11	1	8	2
Buchloe dactyloides	0	0	16	10	5	7	18	8	0	0	2	1
Andropogon saccharoides	3	2	8	11	0	1	1	9	0	1	7	5
Erioneuron pilosum	1	1	1	1	44	11	36	19	13	0	5	1
Schizachyrium scoparium	2	7	1	5	0	0	0	0	4	35	6	8
Sorghastrum nutans	0	0	0	1	0	0	0	0	0	6	0	0
Diversity (c)	.40	.29	.27	.15	.29	.17	.26	.15	.18	.33	.13	.21

[1] Includes soils of the Nuvalde and Mereta series.

[2] Grazing regimes: CM, moderate continuous; CL, light continuous; SA, summer-autumn; WS, winter-spring grazing.

transects. These transects lacked several species that were common on, or restricted to, winter-spring grazed or lightly continuously grazed pastures (for example, *Sporobolus clandestinus*, *Andropogon saccharoides*, *Leptochloa dubia*, and *Chloris verticillata*) (Fig. 3, Table 1). Additionally, these transects were dominated by low-growing grasses (for example, *Erioneuron pilosum* and *Aristida* sp.). Winter-spring grazed pastures, which lacked *Stipa leucotricha*, were positioned positively on Axis I.

Ordination of transects on Oplin (Fig. 4) and Brackett (data not shown) soils failed to differentiate between summer-autumn grazed and moderately continuously grazed transects. As with Speck soils, low-growing grasses characterized summer-autumn grazed and moderately continuously grazed transects. *Sorghastrum nutans* composed 24 percent of the species of one lightly grazed transect, strongly influencing the transect ordination. Winter-spring grazed transects were ordinated positively on Axis II; *Leptochloa dubia* and *Andropogon ischaemum* were restricted to these pastures on all soils. The absence of these species on a few winter-spring grazed transects resulted in stand ordinations with overlapping boundaries between winter-spring grazed and other regimes (Figs. 2-4).

TABLE 2. Species codes for RA diagrams.

Code	Species
Al	*Aristida longiseta* Steud.
Aw	*A. wrightii* Nash.
Ba	*Bouteloua parryi* (Fourn.) Griffiths.
Bc	*B. curtipendula* (Michx.) Torr.
Bd	*Buchloe dactyloides* (Nutt.) Engelm.
Bh	*Bouteloua hirsuta* Lag.
Bi	*Andropogon ischaemum* L.
Bp	*Bouteloua pectinata* Featherly.
Br	*B. rigidiseta* (Steud.) Hitchc.
Bs	*Andropogon saccharoides* Swartz.
Cs	*Carex* sp.
Cv	*Chloris verticillata* Nutt.
Ep	*Erioneuron pilosum* Nash.
Hb	*Hilaria belangeri* (Steud.) Nash.
Ld	*Leptochloa dubia* (H.B.K.) Nees.
Sc	*Sporobolus clandestinus* (Bieler.) Hitchc.
Sh	*S. asper* var. *hookeri* (Trin.) Vasey
Sl	*Stipa leucotricha* Trin and Rupr.
Sn	*Sorghastrum nutans* (L.) Nash.
Sr	*Sporobolus cryptandrus* (Torr.) A. Gray.
Ss	*Schizachyrium scoparium* Nash.
Tm	*Tridens muticus* (Torr.) Nash.

Composition of 12 species, as indicated by t-tests, differed ($P < 0.05$) between soil series. Grazing regime affected composition ($P < 0.05$) of 13 species. Furthermore, interactions between grazing history and soil series were exhibited ($P < 0.05$) by nine species.

Stipa leucotricha dominated low-lying areas except in winter-spring grazed pastures (Table 1). *Stipa* comprised more than one-third of the botanical composition in summer-autumn grazed and both continuously grazed pastures, but only 8.2 percent of the composition under the winter-spring grazing regime. A similar trend occurred on Speck soils, where *Stipa* composition was lower ($P <0.05$) in winter-spring grazed pastures (mean, 0.7 percent) than in other pastures (mean, 6.6 percent). Winter-spring grazing reduced ($P < 0.01$) *Stipa* composition on plateau tops and in low-lying areas between plateaus. However, *Stipa* composition did not differ ($P > 0.10$) on Brackett or Oplin soils where *Stipa* was rare (composition $\leq$2.7 percent on all transects).

Carex sp., cool-season grass-like plants of fair forage value, exhibited a response to grazing on slopes similar to that of *Stipa* in flat areas. *Carex* was relatively abundant on Oplin soils in summer-autumn grazed pastures (mean composition, 16.0 percent), but less abundant ($P < 0.05$) under other grazing regimes (mean composition, 1.2 percent). *Carex* composition on Brackett soils was higher ($P < 0.05$) in summer-autumn

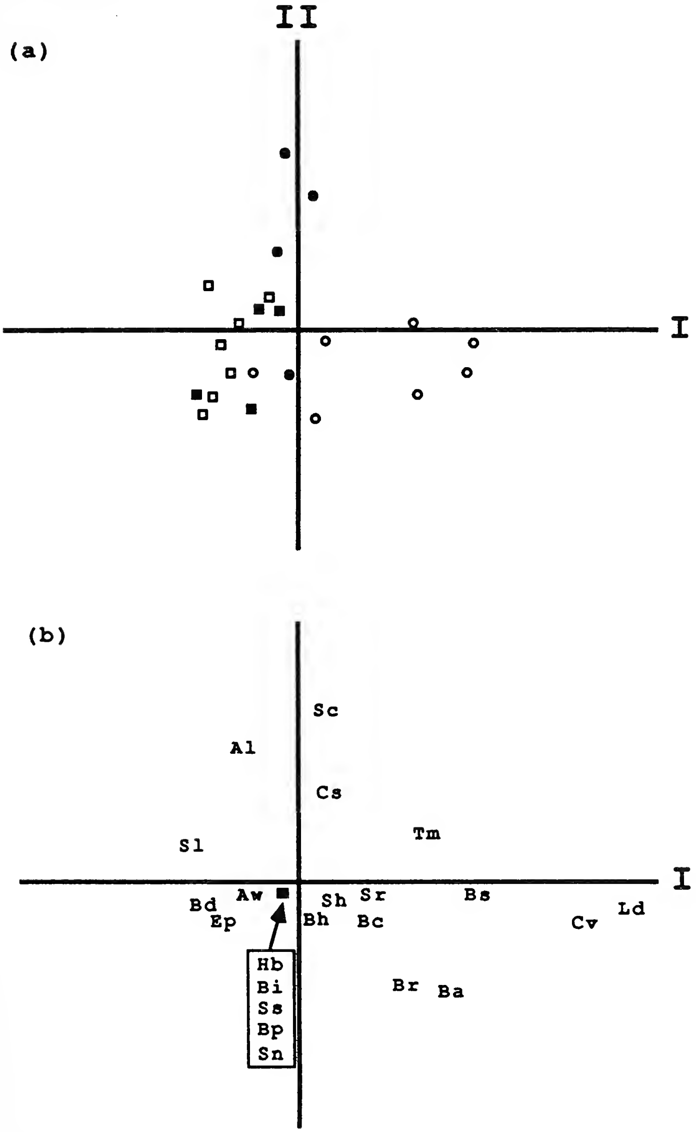

FIGURE 3. Ordination of stand (a) and species scores (b) on Speck soils on the Texas Edwards Plateau. Four grazing regimes were sampled: moderate continuous (■), light continuous (●), summer-autumn (□), and winter-spring (○). Species codes are listed in Table 2.

grazed and lightly continuously grazed pastures (mean composition, 6.0 percent) than in winter-spring grazed and moderately continuously grazed pastures (mean composition, 1.7 percent). *Carex* composition did not differ ($P > 0.05$) on other soils.

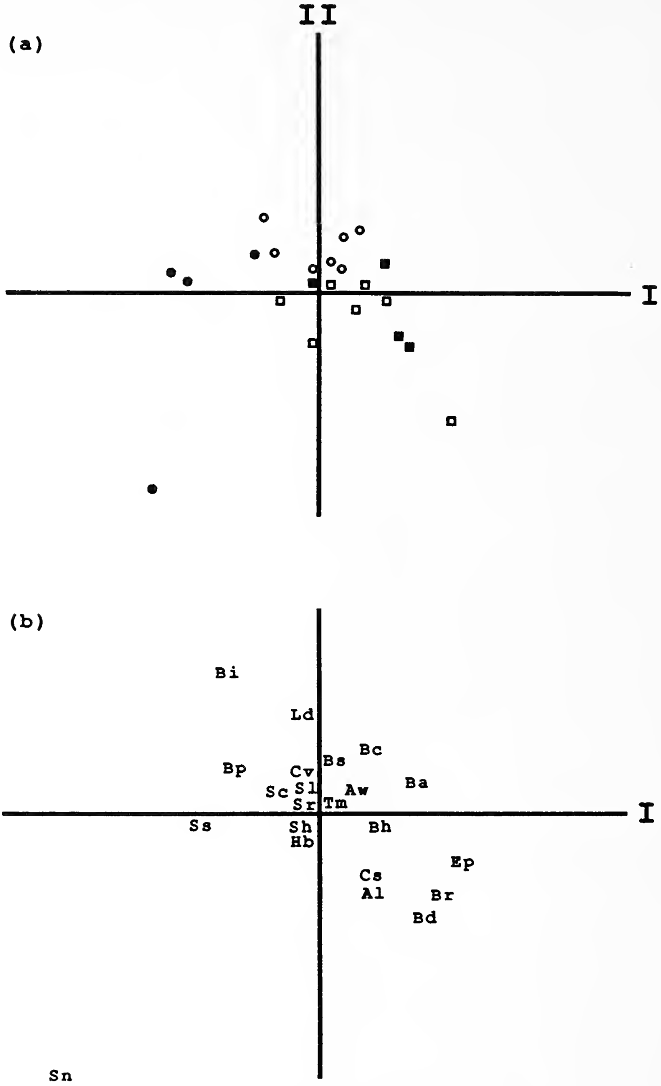

FIGURE 4. Ordination of stand (a) and species scores (b) on Oplin soils on the Texas Edwards Plateau. Four grazing regimes were sampled: moderate continuous (■), light continuous (●), summer-autumn (□), and winter-spring (○). Species codes are listed in Table 2.

Cool-season plants are characterized by high carbohydrate storage patterns during the winter and spring. Defoliation prior to summer dormancy stimulates regrowth, reducing stored carbohydrates critical for summer survival. Therefore, decreased composition of *Stipa leucotricha* and *Carex* sp. following frequent winter-spring defoliation events is to be expected. By contrast, warm-season (C_4) grasses have their highest level of stored carbohydrates during the autumn. Regrowth following defoliation during this period depletes stored carbohydrates; these carbohydrates usually can not be restored before frost (Stoddart et al., 1975; Dahl and Hyder, 1977). As a result, competitive advantage was conferred to cool-season grasses by defoliating warm-season species during the autumn. This advantage was manifested by dominance of cool-season grasses following repeated summer-autumn defoliation events.

Hilaria belangeri was prevalent on continuously grazed soils in low-lying areas (mean composition, 32.0 percent on moderately grazed sites, 19.4 percent in lightly grazed areas) and was absent elsewhere. *Hilaria* apparently replaced species of higher forage value (*Buchloe dactyloides* and *Andropogon saccharoides*, for example) that were prevalent on low-lying areas in pastures that were not grazed for part of each year. Similar trends were evident on all soils: species with higher forage value were more conspicuous in lightly grazed or seasonally grazed pastures than in continuously moderately grazed pastures.

Heterogeneity was a complex function of soil type and season of herbivory (Table 1). Diversity was greatest under the summer-autumn grazing regime, and lowest under light continuous grazing, on Brackett (data not shown) and Oplin soils. Diversity on plateau tops and bottomland sites was greatest in winter-spring grazed pastures; moderate continuous grazing reduced heterogeneity by a factor of two. Diversity generally was greater on backslope (Oplin) and footslope (Brackett) soils than on plateau tops or low-lying sites. Increased environmental heterogeneity associated with gravelly slopes was reflected in increased heterogeneity of vegetation. The notable exception in lightly grazed pastures resulted from the lack of grazing on slopes. Oplin and Brackett soils in lightly grazed pastures supported dense stands of two large bunchgrasses (*Schizachyrium scoparium*, *Sporobolus clandestinus*). Few other species were present, and none exceeded 10 percent composition (Table 1). These soils supported late-successional vegetation, which often is less diverse than early- to mid-successional vegetation (Bazzaz, 1975; Whittaker, 1975; Barbour et al., 1987). Late-successional herbaceous vegetation displayed relatively little tolerance to grazing, and was restricted to winter-spring pastures and slopes of lightly continuously grazed sites.

Discussion

Grazing regimes strongly affected herbaceous botanical composition in this study. Common species had characteristics that could be related to seasonal herbivory effects. Plant strategies to avoid defoliation or minimize its effects enhanced the competitive ability of selected species.

These avoidance strategies may be classified into three categories; several species exhibited more than one strategy.

Rapid growth and carbohydrate translocation to storage organs, noncoincident with the defoliation period, is one strategy whereby dominant plants minimized the impact of defoliation. Cool season plants (*Stipa leucotricha*, *Carex* sp.) dominated summer-autumn grazed areas, and warm season plants dominated winter-spring grazed areas. Dominant plants in both regimes exhibited the competitive advantage of being in a relatively dormant state during the grazing period. Herbivory coincident with rapid growth apparently reduced competitive ability.

Relatively low grazing preference is another strategy contributing to the competitive ability of a species. Unpreferred species increased with increasing grazing pressures, replacing more preferred species (for example, *Hilaria belangeri* for *Buchloe dactyloides* in low-lying areas, *Aristida* sp. for *Sporobolus clandestinus* and *Schizachyrium scoparium* on slopes). Harper (1977) discussed the competitive advantage resulting from selective defoliation (for example, grasses of different palatabilities).

Morphological adaptations that minimize impacts of defoliation included short shoots (compressed internodes that reduce the probability of removing the apical meristem; for example, *Stipa leucotricha* has short shoots, *Sorghastrum nutans* has long shoots) and short leaves (for example, *Erioneuron pilosum* and *Aristida* sp.) (Dahl and Hyder 1977). Species with these morphologies allocated fewer resources to structures that could be lost to herbivores than their less competitive neighbors. Hence, defoliation shifts the competitive advantage from tall grasses to grazing-tolerant short grasses, as discussed by Boryslawsky and Bentley (1985) and Belsky (1986*a*).

Results from this study indicate that timing of herbivory, along with differences in soils, can significantly influence dominance-diversity relationships in grasslands. For example, continuous grazing favored low-growing grass species at the expense of tall grasses, and seasonal herbivory conferred a competitive advantage to species or groups of species that were dormant during the grazing season. These results do not imply that herbivory benefits plants by increasing their fitness. Rather, a competitive advantage was accrued to some species because they possessed characteristics for avoiding herbivory to a greater degree than their neighbors.

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LITERATURE CITED

Ahlgren, H. L. 1938. Effect of fertilization, cutting treatments, and irrigation on yield of forage and chemical composition of the rhizomes of Kentucky bluegrass (*Poa pratensis* L.). J. Amer. Soc. Agron., 30:683-691.

American Society of Range Management-Agricultural Board. 1962. Basic problems and techniques in range research. Nat. Acad. Sci.-Nat. Res. Council Publ., 890:1-341.

Bartlett, M. S. 1947. The use of transformations. Biometrics, 3:39-52.

Barbour, M. G., J. H. Burk, and W. D. Pitts. 1987. Terrestrial plant ecology. The Benjamin/Cummings Publ. Co., Inc., Menlo Park, California, 2nd ed., 634 pp.

Bazzaz, F. A. 1975. Plant species diversity in old-field successional ecosystems in southern Illinois. Ecology, 56:485-488.

Belsky, A. J. 1986*a*. Does herbivory benefit plants? A review of the evidence. Amer. Nat., 127:870-892.

———. 1986*b*. Revegetation of artificial disturbances in grasslands of the Serengeti National Park, Tanzania. I. Colonization of grazed and ungrazed plots. J. Ecol., 74:419-437.

Blaisdell, J. P., and J. F. Pechanec. 1949. Effects of herbage removal at various dates on vigor of bluebunch wheatgrass and arrowleaf balsam root. J. Range Manag., 6:298-305.

Boryslawsky, Z., and B. L. Bentley. 1985. The effect of nitrogen and clipping on interference between C_3 and C_4 grasses. J. Ecol., 73:113-121.

Branson, F. A. 1956. Quantitative effects of clipping treatments on five range grasses. J. Range Manag., 9:86-88.

Caldwell, M. M., R. H. Richards, D. A. Johnson, R. S. Nowak, and R. S. Dzurec. 1981. Coping with herbivory: photosynthetic capacity and resource allocation in two semiarid *Agropyron* bunchgrass. Oecologia, 50:14-24.

Crawley, M. J. 1983. Herbivory, the dynamics of animal-plant interactions. Univ. California Press, Berkeley, 437 pp.

Crider, F. J. 1955. Root-growth stoppage resulting from defoliation of grass. U.S. Dept. Agric., Tech. Bull., 1102:1-23.

Dahl, B. E., and D. N. Hyder. 1977. Developmental morphology and management implications. Pp. 257-290, *in* Rangeland plant physiology (R. E. Sosebee, ed.), Soc. Range Manag., Denver, Colorado, 290 pp.

Diamond, D. D., D. H. Riskind, and S. L. Orzell. 1987. A framework for plant community classification and conservation in Texas. Texas J. Sci., 39:203-221.

Dyksterhuis, E. J. 1946*a*. The vegetation of the Fort Worth Prairie. Ecol. Monogr., 16:1-29.

———. 1946*b*. The vegetation of the western Cross Timbers. Ecol. Monogr., 18:325-376.

Ellison, L. 1960. Influence of grazing on plant succession of rangelands. Bot. Rev., 26:1-78.

Gauch, H. G. 1982. Multivariate analysis in community ecology. Cambridge Univ. Press, New York, 298 pp.

Gould, F. W. 1978. Common Texas grasses. Texas A&M Univ. Press, College Station, 267 pp.

Greig-Smith, P. 1983. Quantitative plant ecology. Univ. California, Berkeley, 3rd ed., 359 pp.

Harper, J. L. 1977. Population biology of plants. Academic Press, London, England, 892 pp.

Hitchcock, A. S. 1950. Manual of the grasses of the United States. U.S. Gov. Print. Off., Washington, D. C., 2nd ed., 1051 pp.

Jameson, D. A. 1963. Responses of individual plants to harvesting. Bot. Rev., 29:532-594.

Levy, E. B., and E. A. Madden. 1933. The point method of pasture analysis. New Zealand J. Agric., 46:267-279.

McNaughton, S. J. 1979. Grazing as an optimization process: grassland-ungulate relationships in the Serengeti. Amer. Nat., 113:691-703.

———. 1986. On plants and herbivores. Amer. Nat., 128:765-770.

Menke, J. W. 1973. Effects of defoliation on carbohydrate reserve, vigor and herbage yield for several important Colorado range species. Unpublished Ph.D. dissertation, Colorado State Univ., Ft. Collins, 311 pp.

Rasmussen, G. A. 1986. Long-term effects of prescribed fire on ashe juniper communities. Unpublished Ph.D. dissertation, Texas Tech Univ., Lubbock, 123 pp.

Richards, J. H., and M. M. Caldwell. 1985. Soluble carbohydrates, concurrent photosynthesis and efficiency in regrowth following defoliation: a field study with *Agropyron* species. J. Appl. Ecol., 22:907-920.

Soil Survey Staff. 1975. Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. U.S. Dept. Agric., Soil Conser. Serv., Agric. Handbook, 436:1-754.

Stoddart, L. A., A. D. Smith, and T. W. Box. 1975. Range management. McGraw-Hill Book Co., New York, 3rd edition, 532 pp.

Trlica, M. J. 1977. Distribution and utilization of carbohydrate reserves in range plants. Pp. 73-96, *in* Rangeland plant physiology (R. E. Sosebee, ed.), Soc. Range Manag., Denver, Colorado, 290 pp.

Weaver, J. E., and F. E. Clements. 1938. Plant ecology. McGraw-Hill Book Co., New York, 2nd ed., 601 pp.

Whittaker, R. H. 1975. Communities and ecosystems. Macmillan Publ. Co., New York, 2nd ed., 385 pp.

Present address of McPherson: Department of Range Science, Texas A&M University, College Station, Texas 77843.

CHROMOSOMAL BANDING STUDY OF THE HISPID POCKET MOUSE, *CHAETODIPUS HISPIDUS* (RODENTIA: HETEROMYIDAE)

Frederick B. Stangl, Jr., Eileen Barberides, and Judi K. Speights
Department of Biology, Midwestern State University, Wichita Falls, Texas 76308

Abstract.—The G- and C-banded karyotype of *Chaetodipus hispidus* is presented, and represents the first such complete karyotypic characterization of a pocket mouse. Of particular interest is the Y chromosome, which is completely euchromatic to include the centric region. A second class of mitotic cell is described, which comprised about 30 percent of the observed mitotic metaphase cells in each examined individual. These cells may represent polyploid cells (megakaryocytes or osteoclasts), but appear to be comprised of individual, rather than paired, chromatids (chromosomes). *Key words: Chaetodipus hispidus*; pocket mouse chromosomes; karyology.

Standard (nondifferentially stained) chromosomal data have been presented for several species of pocket mice of the genera *Perognathus* (Patton, 1967*a*; Williams, 1978) and *Chaetodipus* (Patton, 1967*b*; 1969, 1977). Similar data are also available for the heteromyid rodent genera *Liomys* and *Heteromys* (Engstrom et al., 1987; Genoways, 1973), *Dipodomys* (Stock, 1974), and *Microdipodops* (Hafner et al., 1979).

Baker et al. (1987) discussed the utility of chromosomal banding data in systematic mammalogy, and summarized the available studies. Hafner and Hafner (1983) pointed out the need of such data for the Heteromyidae, but examples in the literature are few. C-banding studies are available for *Dipodomys ordii* (Bostock et al., 1972), *D. microps* and *D. merriami* (Stock, 1974), and *Chaetodipus baileyi* (Patton, 1977). The G-banded karyotype of *D. merriami* was presented by Mascarello et al. (1974). The only comprehensive banding information (G- and C-banded chromosomes) is from *Liomys salvini* and two species of *Heteromys* (Mascarello and Rogers, 1988).

This study details the G- and C-banded karyotypes of *Chaetodipus hispidus*. To our knowledge, this is the first example of a G-banded karyotype of a pocket mouse (*Perognathus* or *Chaetodipus*) in the literature.

Materials and Methods

All animals were collected from natural populations, and karyotyped by the *in vivo* bone marrow method of Lee and Elder (1980) as modified by Baker et al. (1982). Slide preparations were G-banded following Seabright (1971) as modified by Baker et al. (1982), and C-banded as outlined by Baker et al., (1982). Voucher specimens were prepared as standard museum skins with skulls, and are deposited in the Collection of Recent Mammals, Midwestern State University.

Specimens examined.—Texas: *Montague Co.*, 4 mi. E Bellevue (2 ♂, 3 ♀); *Wichita Co.*, 1.5 mi. NE Burkburnett (1 ♀), Wichita Falls (1 ♂, 3 ♀).

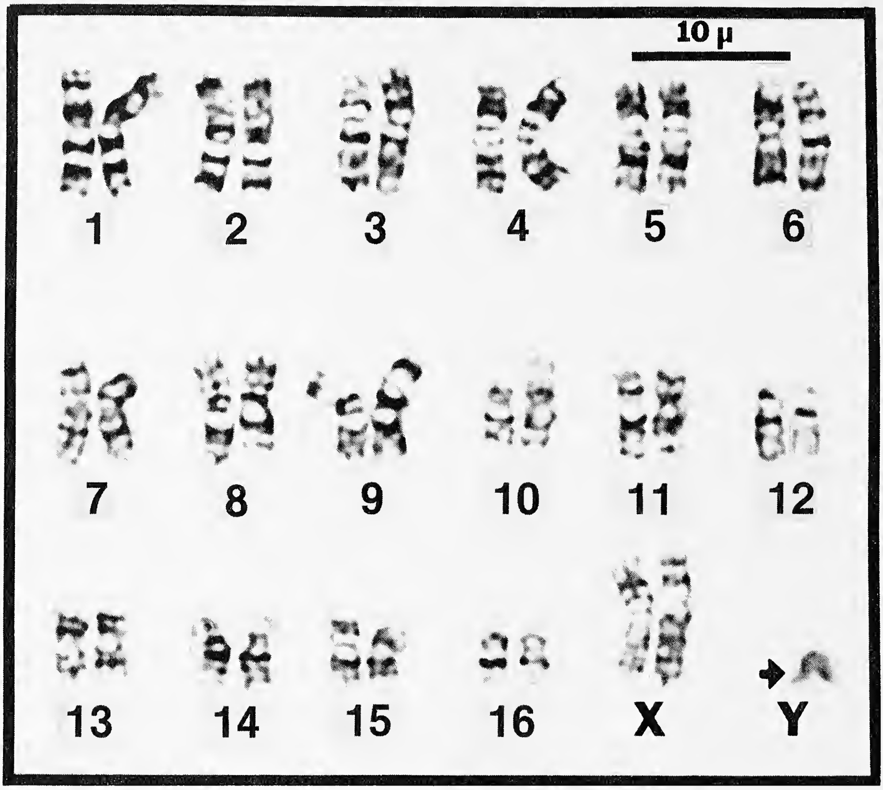

FIGURE 1. G-banded chromosomal complement of a female *Chaetodipus hispidus*. Numbered pairs infer homologous pairs of chromosomes. Arrow indicates acrocentric Y chromosome from a male.

RESULTS

Standard (nondifferentially stained) preparations from each of the 10 specimens examined substantiate Patton's (1967*b*) description of the karyotype of *Chaetodipus hispidus*. The somatic cell complements (2N = 34) are comprised of biarmed chromosomes, with the exception of the small, acrocentric Y chromosome. The X chromosome is a large metacentric (or nearly so) element, described by Patton (1967*b*) as a submetacentric.

Chromosome banding analyses.—Karyotypic preparations of *Chaetodipus hispidus* cannot be banded readily by available techniques. C-bands of suitable quality were obtained for six of the 10 specimens, and five G-banded preparations were judged of sufficient quality for analysis.

G-banding permitted accurate determination of homologous chromosomes, which were numbered in descending order by size (Fig. 1). G-banding analysis revealed that constitutive heterochromatin in *Chaetodi-*

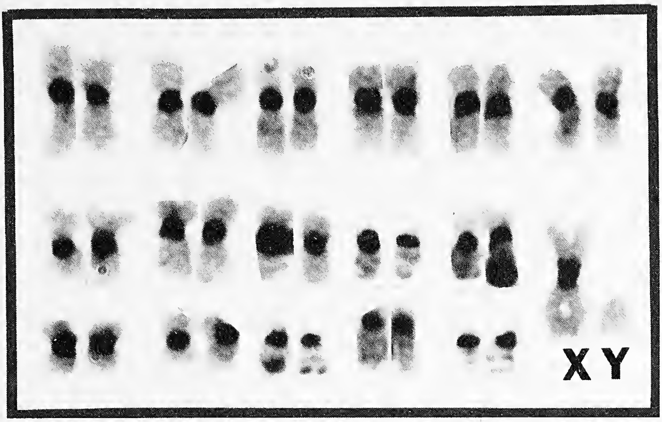

FIGURE 2. C-banded chromosomal complement of a male *Chaetodipus hispidus*. Pairing indicates presumed homologous chromosome pairs.

pus hispidus is restricted to centric regions, and that euchromatic regions exhibited differential staining qualities (Fig. 2). Homologies between G- and C-banded chromosomes could not be determined with certainty, with the exception of the completely euchromatic (to include centric region) Y chromosomes of males.

Mitotic spreads.—Mitotic metaphase spreads were of two recognizable classes: those comprised of "normal," paired chromatids, or chromosomes, and those containing smaller elements (Fig. 3). Spreads from two slides of each of the 10 specimens examined were counted. Of a total of 1145 spreads, 435 (30 percent) were of the latter category. Proportions of the two classes of spreads varied little between specimens, but did not appear to be correlated with the mitotic index of individual specimens.

DISCUSSION

Pocket mice of the family Heteromyidae have traditionally been placed within the genus *Perognathus*, consisting of the subgenera *Perognathus* and *Chaetodipus* (Hall, 1981; Merriam, 1889). Hafner and Hafner (1983) recently proposed the elevation of *Chaetodipus* to generic status, a move that seems to have gained general acceptance. Nevertheless, interspecific relationships within the two genera are little understood, and Hafner and Hafner (1983) called for DNA and chromosomal banding data for potential elucidation.

The value of chromosomal banding data had been demonstrated in systematic studies (see Baker et al., 1987, for summary), and the abundance of standard karyological data is indicative of the level of interest in heteromyid cytogenetics. However, two features of the Heteromyidae seem to explain, at least in part, the paucity of banding data for the family. First, the diploid number is characteristically high.

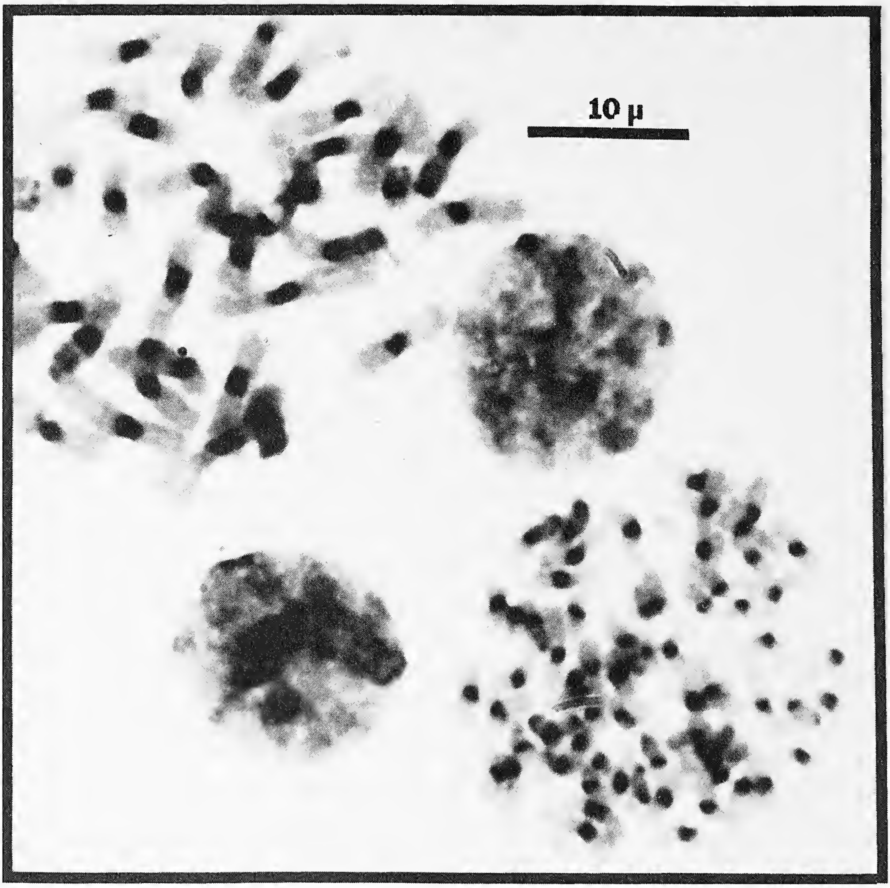

Figure 3. C-banded preparation of a male *Chaetodipus hispidus*, with side-by-side comparison (upper) of two classes of mitotic metaphase spreads: upper left is most commonly observed condition, with chromosomes; below is spread of what appear to be individual chromatids. Dark objects in center are nuclei of interphase luekocytes.

Second, there appear to be some cytological aspects of heteromyids, using conventional techniques, that hinder adequate dispersal of chromosomes in spreads, and thus do not readily yield karyotypic preparations to produce suitable chromosomal bands. A similar situation occurs in the Geomyidae, for which chromosomal banding data only recently have become available (*Cratogeomys*—Lee and Baker, 1987; *Geomys*—Qumsiyeh et al., 1988). Yet, this study, and that of Mascarello and Rogers (1988) on *Heteromys* and *Liomys*, are indicative of the systematic resolution that chromosomal banding might provide for the pocket mouse genera *Perognathus* and *Chaetodipus*.

Comparisons of the G-banded karyotype of *Chaetodipus hispidus* to those of *Dipodomys merriami* (Mascarello et al., 1974), and of *Liomys* and *Heteromys* (Mascarello and Rogers, 1988) indicate areas of possible homology. However, reduction in reproduction of those figures do not allow a definitive statement.

Two findings of this study are particularly noteworthy. The Y chromosome, while unusual for its euchromatic constitution, may be unique among mammals in that it completely lacks heterochromatin in the centric region. However, we have been informed (S. Pathak, personal communication) that C-banding techniques other than the BaHO method of Baker et al. (1982) might reveal the presence of heterochromatin not found in this study.

The second class of mitotic metaphase spreads (Fig. 3), present in consistent proportions for each of the specimens examined, cannot be explained with certainty at this time. The chromatin of such spreads is different in nature—it is readily C-banded but does not produce G-bands. The number of elements are approximately double the usual diploid number of 34. However, two observations seem inconsistent with the explanation that this second class of cells are polyploid cells (megakaryocytes or osteoclasts) as might occur in some preparations from bone marrow. These cells appear to be comprised of individual chromatids (not paired chromatids, or chromosomes), and the mass of chromatin in each of the two classes of observed cells appears about equal. This phenomenon has also been observed by other workers in the bone marrow preparations of some other mammalian taxa (S. Pathak, personal communication).

A comparative mitotic study of these mitotic cells would prove enlightening.

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LITERATURE CITED

Baker, R. J., M. W. Haiduk, L. W. Robbins, A. Cadena, and B. F. Koop. 1982. Chromosomal studies of South American bats and their systematic implications. Pp. 303-327, *in* Mammalian biology in South America (M.A. Mares and H.H. Genoways, eds.), Spec. Publ. Ser., Pymatuning Lab. Ecol., Univ. Pittsburg, 6:ii + 1-539.

Baker, R. J., M. B. Qumsiyeh, and C. S. Hood. 1987. Role of chromosomal banding patterns in understanding mammalian evolution. Pp. 67-96, *in* Current mammalogy (H.H. Genowyas, ed.), Plenum Press, New York, 1:xx + 1-519.

Bostock, C. J., D. M. Prescott, and F. T. Hatch. 1972. Timing of replication of the satellite and main band DNAs in cells of the kangaroo rat (*Dipodomys ordii*). Expl. Cell Res., 74:487-495.

Engstrom, M. D., H. H. Genoways, and P. K. Tucker. 1987. Morphological variation, karyology, and systematic relationships of *Heteromys gaumeri* (Rodentia: Heteromyidae). Pp. 289-303, *in* Studies in Neotropical Mammalogy: essays in honor of Philip Hershkovitz (B.P. Patterson and R.M. Timm, eds.), Fieldiana: Zool. (N.S.), 39:1-506.

Genoways, H. H. 1973. Systematics and evolutionary relationships of spiny pocket mice, genus *Liomys*. Spec. Publ. Mus., Texas Tech Univ., 5:1-368.

Hafner, D. J., J. C. Hafner, and M. S. Hafner. 1979. Systematic status of kangaroo mice, genus *Microdiopodops*: morphometric, chromosomal, and protein analyses. J. Mamm., 60:1-10.

Hafner, J. C., and M. S. Hafner. 1983. Evolutionary relationships of heteromyid rodents. Great Basin Nat. Mem., 7:3-29.

Hall, E. R. 1981. The mammals of North America. John Wiley and Sons, New York, 1:xv + 1-600 + *90*.

Lee, H. K., and R. J. Baker. 1987. Cladistical analysis of chromosomal evolution of pocket gophers of the Cratogeomys castanops complex (Rodentia: Geomyidae). Occas. Papers Mus., Texas Tech Univ., 114:1-15.

Lee, M. R., and F. F. B. Elder. 1980. Yeast stimulation of bone marrow mitosis for cytogenetic investigations. Cytogenet. Cell Genet., 26:36-40.

Mascarello, J. T., and D. S. Rogers. 1988. Banded chromosomes of *Liomys salvini, Heteromys oresterus*, and *H. demarestianus*. J. Mamm., 69:126-130.

Mascarello, J. T., A. D. Stock, and S. Pathak. 1974. Conservatism in the arrangement of genetic material in rodents. J. Mamm., 55:695-704.

Merriam, C. H. 1889. Revision of North American pocket mice. N. Amer. Fauna, 1:1-29.

Patton, J. L. 1967*a*. Chromosomes and evolutionary trends in the pocket mouse subgenus *Perognathus* (Rodentia: Heteromyidae). Southwestern Nat., 12:429-438.

———. 1967*b*. Chromosome studies of certain pocket mice, genus *Perognathus* (Rodentia: Heteromyidae). J. Mamm., 48:27-37.

———. 1969. Karyotypic variation in the pocket mouse, *Perognathus penicillatus* Woodhouse (Rodentia-Heteromyidae). Caryologia, 22:351-358.

———. 1977. B-chromosome systems in the pocket mouse, *Perognathus baileyi*: meiosis and C-banded studies. Chromosoma, 60:1-14.

Qumsiyeh, M. B., C. Sanchez-Hernandez, S. K. Davis, J. C. Patton, and R. J. Baker. 1988. Chromosomal evolution in *Geomys* as revealed by G- and C-banding analysis. Southwestern Nat., 33:1-13.

Seabright, M. 1971. A rapid banding technique for human chromosomes. Lancet, 2:971-972.

Stock, A. D. 1974. Chromosome evolution in the genus *Dipodomys* and its taxonomic and phylogenetic implications. J. Mamm., 55:505-526.

Williams, D. F. 1978. Karyological affinities of the species groups of silky pocket mice (Rodentia, Heteromyidae). J. Mamm., 59:599-612.

Current address of Speights: Department of Biological Sciences, Texas Tech University, Lubbock, 79409.

AB INITIO SCF CALCULATION OF THE ROTATIONAL POTENTIAL ENERGY FUNCTIONS OF POLY(ETHYLENE TEREPHTHALATE)

J. F. Kuehler, J. A. Darsey, and D. C. Kountz

Department of Physical Sciences, Tarleton State University, Stephenville, Texas 76402
and Departmental Process Research, E. I. duPont deNemours & Company,
P.O. Box 800, Kinston, North Carolina 28501 (DCK)

Abstract.—In this paper, the conformational structure of poly(ethylene terephthlate) (PET) is investigated using self-consistent-field theory in an *ab initio* manner. The relative energies of conformations were then calculated as a function of the rotation about the bonds C_3—C_4, C_4—O_1, O_1—C_5, and C_5—C_5' of a molecular segment of PET using an STO-3G basis set for the molecular orbitals. It was found that there are several conformations that lead to a structure consistent with various cyclic oligomers, especially the trigomer tris(ethylene terephthalate). *Key words*: poly(ethylene terephthalate); conformational structure; cyclic oligomers; tris(ethylene terephthalate); *ab initio* calculations.

Poly(ethylene terephthalate) (PET) is a polymer belonging to a class of molecules with the structural formula depicted in Figure 1, where m = 2 for this specific case. The general abbreviation for this class of molecules is mGT (Desborough et al., 1979). PET contains cyclic as well as linear chains (Cooper and Semlyen, 1973) and is commercially known in this country as Dacron (Daubeney et al., 1954). PET has a high melting point, 264° C, and drawn fibers of this molecule possess high tenacity and other physical properties that render this material quite useful as a textile fiber. It also maintains good mechanical properties at temperatures up to 150-175° C and has good resistance to most organic solvents (Billmeyer, 1984). In addition to the textile industry, PET has uses in tire cords, films, and blown bottles to name a few. Because of its tremendous versatility, PET is predicted to have a production estimated at 3.65 billion pounds in the United States alone in 1988 (Anonymous, 1987).

There have been several recent experimental studies concerning the conformer composition of poly(ethylene terephthalate) (Fina and Koenig, 1984; Ledbetter et al., 1984). However, to our knowledge there have been no detailed theoretical studies, especially at the *ab initio* level, on the conformational makeup of PET. We have, therefore, undertaken such a study to obtain detailed rotational potential energy functions for this polymer.

Method of Calculation

When one contemplates calculating conformational energy functions, there are several possible procedures that may be adopted. By far the most widely used methods are empirical or semiempirical techniques, or both. Specifically, the energy of a given conformation can be considered to consist of four parts: 1) intrinsic torsional potentials: 2) van der Waals repulsions; 3) dispersion attractions; and 4) energy of interaction of dipole

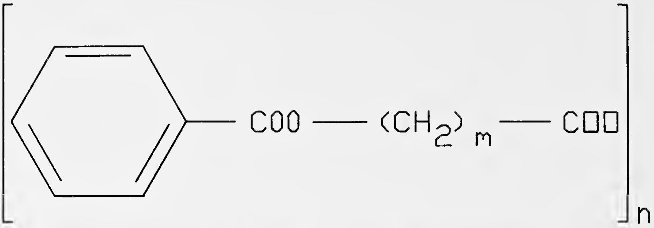

FIGURE 1. The general structure of a class of molecules designated by the formula mGT, where m = 2 for poly(ethylene terephthalate).

moments between consecutive pairs of atoms or groups (Flory, 1969; Darsey et al., 1988). In these various terms, if the parameters are determined strictly through experiment or intuition, the calculations are termed empirical; if the parameters are determined through a combination of experiment and quantum mechanical methods, they are termed semiempirical. The major disadvantage of these types of calculations, however, is that each different group of atoms must be individually parameterized. Often adjustment of the required parameters has been done arbitrarily so as to reproduce the observed energy difference between various conformations (Abe et al., 1966; Darsey and Rao, 1981).

Within the last decade or so, quantum mechanical self-consistent-field (SCF) *ab initio* calculations have made great advances (Hehre et al., 1986). Now computer programs are available that can calculate the energy of a reasonably-sized molecule in a given conformation with great accuracy in a totally *ab initio* manner. Because these programs are based upon Roothaan-Hartree-Fock SCF theory (Roothaan, 1951), they do not need any arbitrary parameters and yield *ab initio* results, the accuracy of which can be made quite high. Two versions of the Gaussian-type programs were used in *ab initio* calculations performed in this work. Geometry optimization was performed at the STO-3G level on a Gaussian-82 program (Binkley et al., 1985), available at the Cornell Supercomputer Facility, and required approximately 35 CPU hours. The calculations on various rotation states of the PET molicule were performed with a modified Gaussian-76 program (Cook, 1978), at the STO-3G level. Each rotational state required between 35 and 75 CPU minutes of computer time on our CYBER 180 computer. These rotational states were calculated at 10 degree intervals with five-degree or one-degree intervals in regions of particular interest such as maxima or minima.

The choice of using the STO-3G basis set was more out of necessity than anything else. In performing *ab initio* calculations, especially on large molecular systems, one must always choose between doing a better job using a higher level basis set on a small segment of the polymer molecule or doing a lesser job on a larger segement of the molecule. Because of the type of information we are seeking concerning PET, we chose to work on as large a segment of the molecule as possible. Unfortunately, this necessitated using the minimal basis set (that is, STO-3G). A higher basis set would have meant the need to choose a much smaller molecular segment than that shown in Figure 2. For more details concerning computational procedures, the reader is referred to Pople and Beveridge (1970) and to Hehre et al. (1986).

RESULTS AND DISCUSSION

The segment of the PET molecule used in this study is shown in Figure 2. Note that the two ends of this molecular segment are terminated by hydrogens to avoid any "dangling" bonds. *Ab initio* calculations all were performed using the STO-3G basis set of molecular orbital functions. A

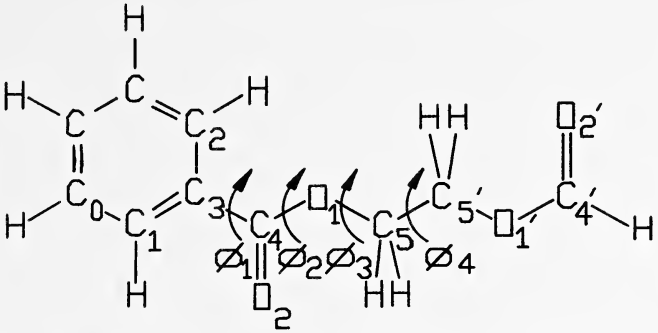

FIGURE 2. The exact molecular segment of poly(ethylene terephthalate) used in the calculations where the four specific rotations ϕ_1, ϕ_2, ϕ_3, and ϕ_4, are indicated.

higher level basis set would have been preferred, but, size restrictions prevented us from this choice. Complete geometry optimization was carried out before rotational potential energy functions were calculated. However, bond lengths and bond angles were maintained constant during all rotations.

There were four sets of rotations performed during this study. These are designated by ϕ_1, ϕ_2, ϕ_3, and ϕ_4, in Figure 2 and represent rotations about the bonds C_3—C_4, C_4—O_1, O_1—C_5, and C_5—C_5', respectively. Each rotation was carried out while all other dihedral angles were maintained in the *anti* conformation. In all cases, the *anti* conformation is designated for a dihedral angle $\phi = 180$ degrees. For all rotations, the *anti* state was the initial conformation and calculations were performed at 20-degree intervals until a relative energy was calculated to exceed 10 kilocalories per mole. A smaller interval was chosen in regions of interest such as conformational minima.

Figure 3 depicts results for the rotation about C_3—C_4. Note that the minimum in the potential energy function occurs at the *anti* and *syn* conformation where $\phi_1 = 180$ and zero degrees respectively. The maximum in this potential function occurs at $\phi_1 = 270$ degrees, obtaining a value of approximately 5.57 (kilocalories per mole). The fact that the *syn* conformational state has the same relative energy as the *anti*, has important consequences in considering various cyclic oligomers such as the important cyclic tris(ethylene terephthalate) (Fina and Koenig, 1984).

The potential energy function presented in Figure 4 is for a rotation about the $C_4 - O_1$ bond. Note that the energy begins at 0.41 kcal/mole but increases rapidly to a value exceeding 10 kcal/mole for a rotation greater than 260 degrees. It should also be noted that this potential energy function, as well as all of the potential energy functions, are symmetric about zero degrees.

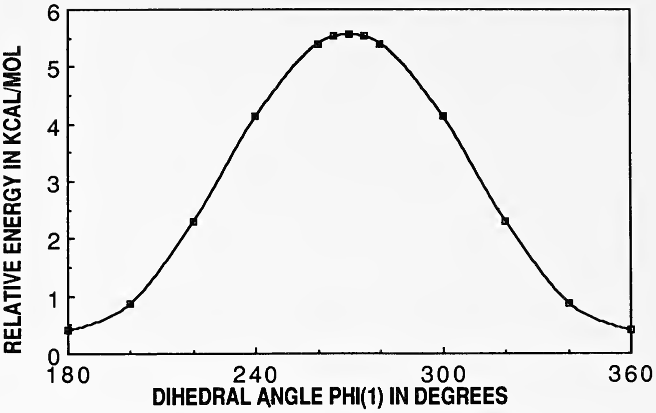

FIGURE 3. Potential energy function calculated for rotation about $C_3 - C_4$.

Figure 5 depicts the potential energy function for a rotation about $C_1 - O_5$. This function is particularly interesting because it has a small local maximum of about 1.31 kcal/mole located at $\phi_3 = 242$ degrees and a shallow minimum of about 0.1 kcal/mole for a rotation located at $\phi_3 = 258$ degrees. The energy increases rapidly beginning at about 280 degrees and exceeds 10 kcal/mole for ϕ_3 greater than 310 degrees. It should be noted that the large plateau region between 240 and 280 degrees, where the energy is only slightly above 1.0 kcal/mole, has significance in allowing the possible formation of the various cyclic oligomers, because this energy is less than 2RT at room temperature. This region can give rise to "floppy *gauche*" conformational states. Note that the minimum in this function is at 180 degrees, as it is in all of these functions except for ϕ_4, and that there is again symmetry about zero degrees.

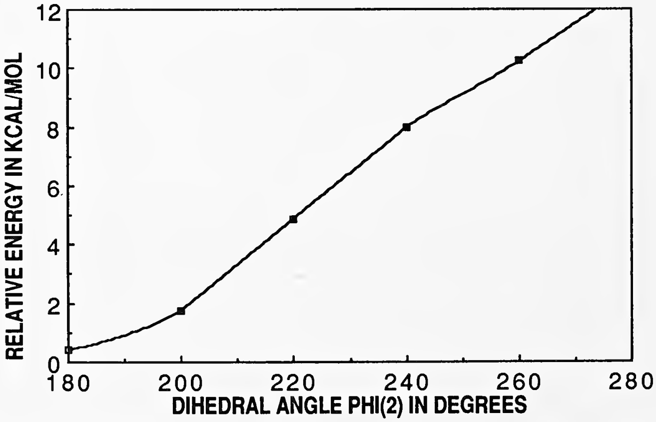

FIGURE 4. Potential energy function calculated for rotation about $C_4 - C_1$.

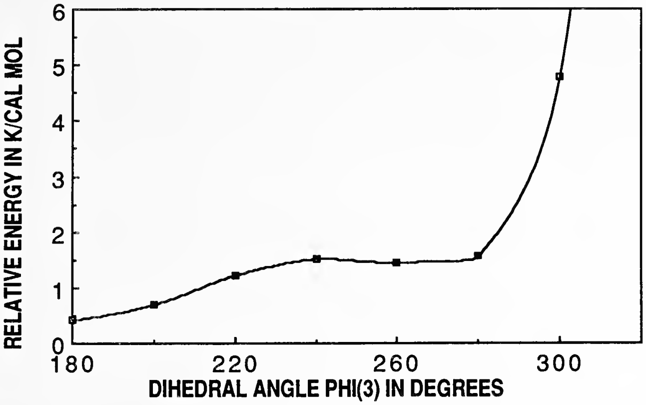

FIGURE 5. Potential energy function calculated for rotation about $C_1 - C_5$.

In examining Figure 6, the most noteworthy feature is that the minimum in the potential energy function is located at the rotational angle other than the *anti* conformation. The exact position for this minimum is $C_4 = 290$ degrees. The energy difference between the *anti* state ($C_4 = 180°$) and the *gauche* state ($C_4 = 290°$) is 0.411 kcal/mole. Inasmuch as the *gauche* state is lower than the *anti*, it would indicate that this would be a likely location for the molecule to exhibit flexibility. The *gauche* conformation for ϕ_4 is a probable conformation that one could find exhibited for the various cyclic oligomers of PET. Also the *gauche* state is a particularly stable conformation because it exists between two energy barriers, one at $\phi_4 = 273$ degrees and the other at $\phi_4 = 0$ degrees, with magnitudes of 2.1 and 5.9 kilocalories per mole, respectively. As with the other potential energy functions, symmetry

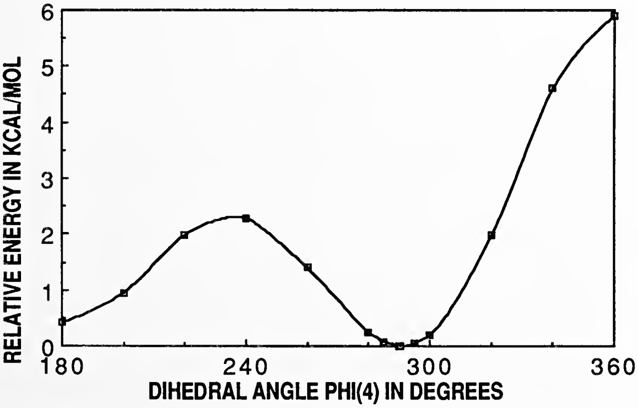

FIGURE 6. Potential energy function calculated for rotation about $C_5 - C_5'$.

dictates that this potential has mirror symmetry from 0 degrees to 180 degrees.

SUMMARY

In summary, it can be seen that the all *anti* conformational state would be, in general, the most likely conformation for poly(ethylene terephthalate). However, there is enough flexibility to allow the molecule to fold back upon itself. This is particularly true for a rotation about $C_3 - C_4$, where the *syn* structure is as probable as the *anti* structure, and for a rotation about $C_5 - C_5'$, where the *gauche* conformation has a slightly higher probability than the *anti* conformation. This flexibility allows for the formation of various cyclic oligomers and especially to the important oligomer tris(ethylene terephthalate).

ACKNOWLEDGEMENTS

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LITERATURE CITED

Abe, A., R. L. Jernigan, and P. J. Flory. 1966. Conformational energies of n-alkanes and the random configuration of higher homologs including polymethylene. J. Amer. Chem. Soc., 88:631-639.

Anonymous. 1987. Chemical & Engineering News, 28 pp.

Billmeyer, F. W. Jr. 1984. Textbook of polymer science, John Wiley & Sons, Inc., New York, 415 pp.

Binkley, J. S., M.J. Frisch, D. J. DeFrees, K. Raghavachari, R. A. Whiteside, H. B. Schelgel, E. M. Fluder, and J. A. Pople. 1985. Gaussian 82, Carnegie-Mellon University, Pittsburgh, Pennsylvania, soft-ware package.

Cook, C. M. 1978. Gaussian 76, program no. 391, QCPE, Indiana Univ., Bloomington. This is a translation of QCPE 386 (CDC Version) by Binkley et al. (1982).

Cooper, D. R., and J. A. Semlyen. 1973. Equilibrium ring concentrations and the statistical conformations of polymer chains: Part 11. Cyclics in poly(ethylene terephthalate). Polymer, 14:185-192.

Darsey, J. A., and B. K. Rao. 1981. Self-consistent-field conformational energy calculations for n-alkanes and characterizations of polymethylene. Macromolecules, 14:1575-1581.

Darsey, J. A., R. J. Voll, E. S. Younathan, and T. A. W. Koerner Jr. 1988. Ab initio SCF calculations of the rotational conformations of both exocyclic carbon groups of the ketohexose 6-*O*-methyl *β*-*D*-tagatofuranose. Carbohydrate Res., 173:197-204.

Daubeney, R. de P., C. W. Bunn, and C. J. Brown. 1954. The crystal structure of polyethylene terephthalate). Proc. Royal Soc., A 226:531-542.

Desborough, I. J., I. H. Hall, and J. Z. Neisser. 1979. The structure of poly(ethylene terephthalate). Polymer, 20:545-552.

Fina, L. J., and J. L. Koenig. 1984. Studies of chain folding in solution-crystallized poly(ethylene terephthalate). Macromolecules, 17:2572-2579.

Flory, P. J. 1969. Statistical mechanics of chain molecules. Intersciences, New York, pp. 49-204.

Hehre, W. J., L. Radom, P. V. R. Schleyer, and J. A. Pople. 1986. An *ab initio* molecular orbital theory, John Wiley and Sons, New York, 548 pp.

Ledbetter, M., J. Cuculo, and P. Tucker. 1984. Structure and properties of poly(ethylene terephthalate) crystallized by converging flow and high pressure. J. Polymer Sci.: Chem. Ed., 22:1435-1459.

Pople, J. A., and D. L. Beveridge. 1970. Approximate molecular orbital theory. McGraw-Hill, New York, 214 pp.

Roothan, C. C. J. 1951. New developments in molecular orbital theory. Rev. Modern Phys., 23:69-88.

STATUS OF *BAIOMYS TAYLORI* IN TEXAS, WITH NEW LOCALITIES OF RECORD IN THE SOUTHERN PART OF THE STATE

RICHARD M. PITTS AND MICHAEL J. SMOLEN
420th Engineer Brigade, 511 Carson, Bryan, Texas 77801, and Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, Texas 77843

ABSTRACT.—Since the first northern pygmy mouse, *Baiomys taylori*, was described in 1887 by Thomas, the species has been extending its range northwestward in Texas. *B. taylori* now has been collected north of the Red River in Oklahoma and in the Texas Panhandle. The distributional status of *B. taylori* is updated in order to clarify the geographic range in Texas. New distributional data are presented extending the known range westward in southern and south-central Texas. *Key words*: pygmy mouse; *Baiomys taylori*; distribution; Texas.

The northern pygmy mouse, *Baiomys taylori*, is a southern species that reaches its northern distributional limits in Texas (Schmidly, 1983) and extreme southern Oklahoma (Stangl and Dalquest, 1986). This mouse first was recorded in Texas from San Diego, Duval County (Thomas, 1887). Records prior to 1970 (Fig. 1) indicate a northward extension of the known range (Bailey, 1905; Osgood, 1909; Blair, 1952; Hunsaker et al., 1959; Packard, 1960; Packard and Garner, 1964; Dalquest, 1968; Packard and Judd, 1968; Baccus, 1968). Localities of capture recorded between 1970 and 1980 (Fig. 1) indicate additional northward and northeastward movement (Baccus and Greer, 1971; Hart, 1972; Davis, 1974; Waggoner, 1975; Cokendolpher et al., 1979; Diersing and Diersing, 1979). That trend (Fig. 1) has continued since 1980 (Stangl et al., 1983; Dalquest and Horner, 1984; Austin and Kitchens, 1986; Cleveland, 1986; Stangl and Dalquest, 1986; Hollander et al., 1987*a*; Hollander et al., 1987*b*). Hall (1981) and Eshelman and Cameron (1987) proposed a geographic range throughout southern Texas. Davis (1974) and Schmidly (1983), however, mapped *B. taylori* as occurring in the southeastern part of that region, with the western edge of the range extending from Hidalgo County northward through Bandera County (Figs. 1 and 2). To our knowledge, no published records exist that confirm the presence of *B. taylori* in western parts of southern Texas.

The first known documented records of the pygmy mouse in the western part of southern Texas are presented in this paper. Localities and specimens collected are as follows (listed from south to north and east to west—see Fig. 2): locality 1, an adult female was captured in an open grassy field 18 mi. N and 4.5 mi. E Oilton, Webb County, on 4 May 1983; locality 2, seven adults (five males and two females) were collected in a vacant lot in Pearsall, Frio County, on 27 January 1983; locality 3, a male was taken along a fencerow, 4.3 mi. NW Hondo, Medina, County,

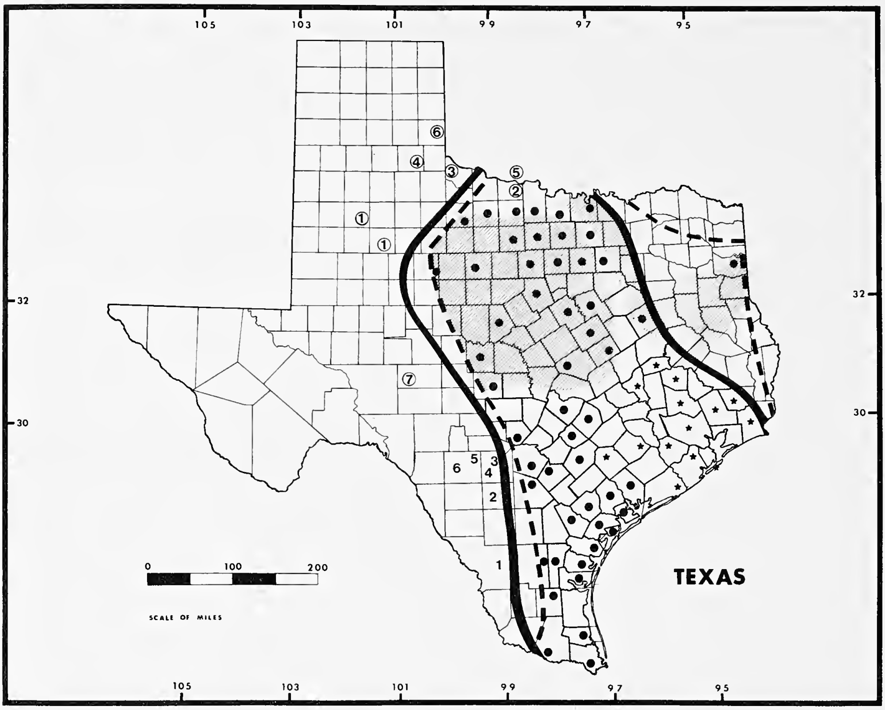

FIGURE 1. Map showing approximate distribution of *Baiomys taylori* in Texas and Oklahoma. Solid line indicates range as mapped by Davis (1974); dashed line indicates range as mapped by Schmidly (1983). Gray area represents known range prior to 1970. Hatched area represents known range prior to 1980. Circles with numbers represent locality records since 1980: 1) Stangl et al., 1983; 2) Dalquest and Horner, 1984; 3) Austin and Kitchens, 1986; 4) Cleveland, 1986; 5) Stangl and Dalquest, 1986; 6) Hollander et al., 1987*a*; 7) Hollander et al., 1987*b*. Numbers not enclosed in circles indicate range extensions described in text. Stars represent county records for *B. t. sublater*. Solid circles and numbers represent county records for *B. t. taylori*.

on 6 January 1984; locality 4, an adult female was trapped in a field of prickly pear (*Opuntia* sp.) 6.2 mi. W Hondo, on 6 January 1984; locality 5, an adult male was obtained beside FM road 1050 among some large rocks 2.8 mi. W Utopia, Uvalde County, on 12 March 1984; locality 6, an adult male trapped adjacent to the Nueces River, 5 mi. W Uvalde, Uvalde County, on 18 March 1983. Locality 6 extends the known range of *B. taylori* westward approximately 130 kilometers southwest from Boerne, Kendall County (Hall, 1981) and approximately the same distance from San Antonio, Bexar County (Bailey, 1905).

It appears that *B. taylori* is actively extending its range westward throughout southern Texas.

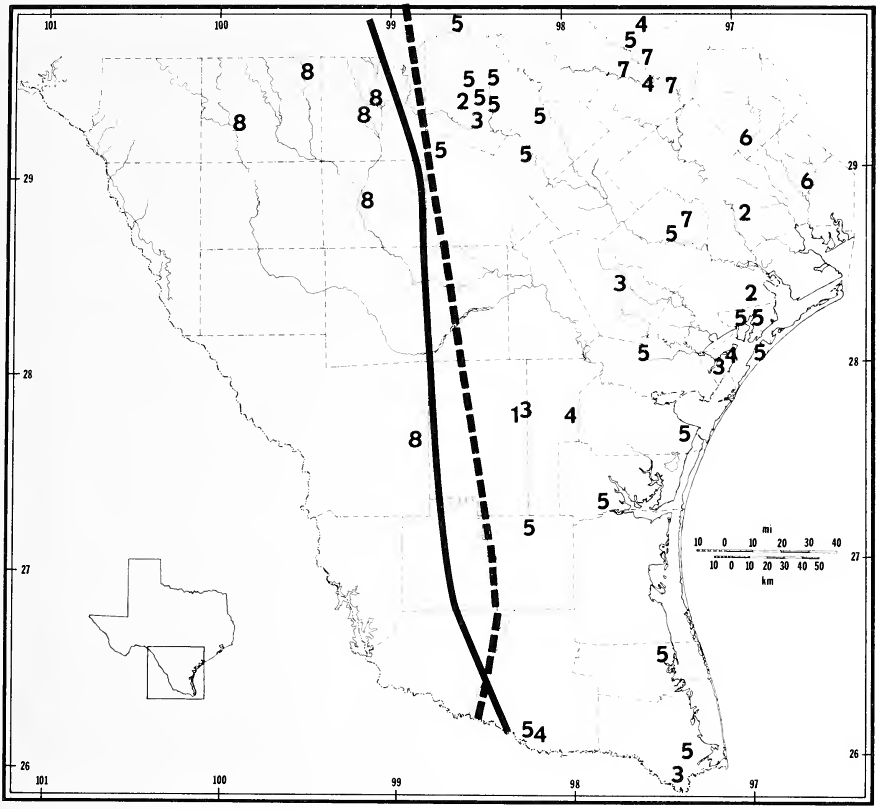

FIGURE 2. Localities from which *Baiomys taylori* have been recorded in southern Texas: 1) Thomas, 1887; 2) Bailey, 1905; 3) Osgood, 1909; 4) Blair, 1952; 5) Packard, 1960; 6) Davis, 1974; 7) Schmidly, 1983; 8) this paper. Solid line represents proposed distributional range as indicated by Davis (1974); dashed line represents proposed distributional range as indicated by Schmidly (1983).

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LITERATURE CITED

Austin, T. L., and J. A. Kitchens. 1986. Expansion of *Baiomys taylori* into Hardeman County, Texas. Southwestern Nat., 31:547.

Baccus, J. T. 1968. Two noteworthy records of rodents from Baylor County. Southwestern Nat., 13:362.

Baccus, J. T., and R. E. Greer. 1971. Additional records of *Baiomys taylori* (Rodentia: Cricetidae) for northern Texas. Texas J. Sci., 23:148-149.

Bailey, V. 1905. A biological survey of Texas. N. Amer. Fauna, 25:1-222.

Blair, W. F. 1952. Mammals of the Tamaulipan Biotic Province in Texas. Texas J. Sci., 4:230-250.

Cleveland, A. G. 1986. First record of *Baiomys taylori* north of the Red River. Southwestern Nat., 31:547.

Cokendolpher, J. C., D. L. Holub, and D. C. Parmley. 1979. Additional records of mammals from north-central Texas. Southwestern Nat., 24:376-377.

Dalquest, W. W. 1968. Mammals of north-central Texas. Southwestern Nat., 13:13-22.

Dalquest, W. W., and N. V. Horner. 1984. Mammals of northcentral Texas. Midwestern State Univ. Press, Wichita Falls, Texas, 261 pp.

Davis, W. B. 1974. The mammals of Texas. Bull. Texas Parks and Wildlife Dept., 41:1-294.

Diersing, V. E., and J. E. Diersing. 1979. Additional records of *Baiomys taylori taylori* (Thomas) in Texas. Southwestern Nat., 24:707-708.

Eshelman, B. D., and G. N. Cameron. 1987. *Baiomys taylori.* Mamm. Species, 285:1-7.

Hall, E. R. 1981. The mammals of North America. John Wiley & Sons, New York, 2:vi+601-1181+*90*.

Hart, B. J. 1972. Distribution of the pygmy mouse, *Baiomys taylori*, in north central Texas. Southwestern Nat., 17:197-216.

Hollander, R. R., J. K. Jones, Jr., R. W. Manning, and C. Jones. 1987*a*. Noteworthy records of mammals from the Texas Panhandle. Texas J. Sci., 39:97-102.

Hollander, R. R., C. Jones, R. W. Manning, and J. K. Jones, Jr. 1987*b*. Distributional notes on some mammals from the Edwards Plateau and adjacent areas of south-central Texas. Occas. Papers Mus., Texas Tech Univ., 110:1-10.

Hunsaker, D., II, G. G. Raun, and J. E. Swindells. 1959. Range expansions of *Baiomys taylori* in Texas. J. Mamm., 40:447-448.

Osgood, W. H. 1909. Revision of the mice of the American genus *Peromyscus.* N. Amer. Fauna, 28:1-285.

Packard, R. L. 1960. Speciation and evolution of the pygmy mice, genus Baiomys. Univ. Kansas Publ., Mus. Nat. Hist., 9:579-670.

Packard, R. L., and H. W. Garner. 1964. Records of some mammals from the Texas High Plains. Texas J. Sci., 16:387-390.

Packard, R. L., and F. W. Judd. 1968. Comments on some mammals from western Texas. J. Mamm., 49:535-538.

Schmidly, D. J. 1983. Texas mammals east of the Balcones fault zone. Texas A&M Univ. Press, College Station, Texas xviii+400 pp.

Stangl, F. B., Jr., and W. B. Dalquest. 1986. Two noteworthy records of Oklahoma mammals. Southwestern Nat., 31:123-124.

Stangl, F. B., Jr., B. F. Koop, and C. S. Hood. 1983. Occurrence of *Baiomys taylori* (Rodentia: Cricetidae) on the Texas high plains. Occas. Papers Mus., Texas Tech Univ., 85:1-4.

Thomas, O. 1887. Diagnosis of a new species of *Hesperomys* from North America. Ann. Mag. Nat. Hist., ser. 5, 19:66.

Waggoner, K. V. 1975. The effect of strip-mining and reclamation on small mammal communities. Unpublished M.S. thesis, Texas A&M Univ., College Station, 74 pp.

A MODIFIED EDGEWORTH EXPANSION WITHOUT SINGULARITIES

E. D. McCune and S. K. McCune
Department of Mathematics and Statistics, Stephen F. Austin State University, Nacogdoches, Texas 75962

Abstract.—In this paper, a modified Edgeworth expansion is developed that assumes only values between 0 and 1, is without cumulants, and, most importantly, has no singularities. *Key words*: Edgeworth expansion; cumulants; singularities.

Galloway and McCune (1983) introduced an Edgeworth-type expansion without cumulants and that always takes on values between 0 and 1 for the probability function to be approximated; however, their expansion possesses points of singularity and behaves erratically when evaluated near such points. In this paper, a modification of the Galloway and McCune expansion is introduced that is also without cumulants and has the property of assuming values between 0 and 1; however, this new expansion has no singularities. Moreover, asymptotic order properties of the new expansion are discussed.

Let F(; λ) and ψ be distribution functions such that

$$\lim_{\lambda \to \infty} F(x; \lambda) = \psi(x) \tag{1}$$

for all x in the support of F(; λ). Galloway and McCune (1983) introduced an approximation of F(x; λ) defined as

$$G(x; \lambda) = \left[1 + \frac{1-\psi(x)}{\psi(x)} \left\{\frac{F'(x;\lambda)}{\psi'(x)}\right\}^{M(x)}\right]^{-1} \tag{2}$$

where

$$M(x) = \frac{-\psi^{(3)}(x)\psi'(x)}{\psi^{(4)}(x)\psi(x)\{1 - \psi(x)\}} \tag{3}$$

for all values of x for which $0 < \psi(x) < 1$, $\psi'(x) > 0$, $F'(x; \lambda) > 0$, and $\psi^{(4)}(x) \neq 0$.

The approximation G has the desirable properties of always being nonnegative and never greater than one. It also possesses the following asymptotic property:

$$F(x; \lambda) - G(x; \lambda) = 0 (\lambda^{-1}). \tag{4}$$

The basic undesirable property of the approximation G is that it is undefined for all values of x at which $\psi^{(4)}(x) = 0$. We will refer to these values of x as singularity points. In fact, G takes on erratic behavior for values of x "near" these points as is clearly displayed in Table 2 of Galloway and McCune (1983).

In this paper, we introduce a modification of G that removes the singularities. Our new approximation is defined for all real x but yet still maintains the desirable properties of always being nonnegative, never greater than one, and asymptotically equivalent to G.

PRELIMINARIES

Let κ_i and α_i be the cumulants of F(; λ) and ψ, respectively, and let

$$\beta_i = \kappa_i - \alpha_i = 0\,(\lambda^{1-\frac{i}{2}}), \tag{5}$$

i = 3,4, ... The first order Edgeworth expansion may be expressed as

$$F(x;\,\lambda) = \psi(x) + \frac{-\beta_3\,\psi^{(3)}(x)}{3!} + 0(\lambda^{-1}), \tag{6}$$

with

$$F'(x;\,\lambda) = \psi'(x) + \frac{-\beta_3\,\psi^{(4)}(x)}{3!} + 0(\lambda^{-1}). \tag{7}$$

Galloway and McCune (1983) applied the series expansion for natural logarithms to equations (6) and (7) and obtained

$$\log\frac{1-F(x;\,\lambda)}{F(x;\,\lambda)} = \log\frac{1-\psi(x)}{\psi(x)} + \frac{\beta_3}{3!}\;\frac{\psi^{(3)}(x)}{\psi(x)\,\{1-\psi(x)\}} + 0(\lambda^{-1}) \tag{8}$$

and

$$\log\frac{F'(x;\,\lambda)}{\psi'(x)} = \frac{-\beta_3\psi^{(4)}(x)}{3!\;\psi'(x)} + 0(\lambda^{-1}), \tag{9}$$

which they rewrote as

$$\log\frac{1-\psi(x)}{\psi(x)} = 1\cdot\log\frac{1-F(x;\,\lambda)}{F(x;\,\lambda)} + \frac{\beta_3}{3!}\;\frac{\psi^{(3)}(x)}{\psi(x)\{\psi(x)-1\}} - 0(\lambda^{-1}) \tag{10}$$

and

$$\log \frac{\psi'(x)}{F'(x;\lambda)} = 0 \cdot \log \frac{1-F(x;\lambda)}{F(x;\lambda)} + \frac{\beta_3}{3!}\,\frac{\psi^{(4)}(x)}{\psi'(x)} - 0(\lambda^{-1}). \tag{11}$$

Results

Motivated by Cramer's rule, we "solve" (10) and (11) to obtain an approximation for β_3:

$$\beta_3 \doteq 3!\,\frac{\psi'(x)}{\psi^{(4)}(x)} \log \frac{\psi'(x)}{F'(x;\lambda)} \tag{12}$$

for all x such that $\psi^{(4)}(x) \neq 0$, $\psi'(x) \neq 0$, and $F'(x;\lambda) \neq 0$.

Now if we select a point w such that $\psi^{(4)}(w) \neq 0$, $\psi'(w) \neq 0$, and $F'(w;\lambda) \neq 0$, and then evaluate our approximation of β_3 at w and substitute into (8), we obtain a new approximation for $\log \frac{1-F(x;\lambda)}{F(x;\lambda)}$ denoted

$$\log \frac{1-D(x;\lambda,w)}{D(x;\lambda,w)} = \log \frac{1-\psi(x)}{\psi(x)}$$

$$+ \frac{\psi^{(3)}(x)\,\psi'(w)}{\psi(x)\{1-\psi(x)\}\psi^{(4)}(w)} \cdot \log \frac{\psi'(w)}{F'(w;\lambda)}. \tag{13}$$

After exponentiating (13) and solving for D(x;λ,w), we may define our new approximation of F(x;λ) as

$$D(x;\lambda,w) = \left[1 + \frac{1-\psi(x)}{\psi(x)} \left\{\frac{F'(w;\lambda)}{\psi'(w)}\right\}^{A(x;w)}\right]^{-1}, \tag{14}$$

where

$$A(x;w) = \frac{-\psi^{(3)}(x)}{\psi(x)(1-\psi(x))} \cdot \frac{\psi'(w)}{\psi^{(4)}(w)} \tag{15}$$

for all values of x for which $0 < \psi(x) < 1$ and $\psi'(x) > 0$.

It should be noted that D(x;λ,w) has no singularities, is always nonnegative, and is never greater than one. It is not necessary to know the cumulants of F and ψ in order to evaluate D(x;λ,w); instead, one uses the density function $f = F'$ and the derivatives of ψ. Furthermore,

TABLE 1. Values of x near 0 (w = 1).

λ	x	F(x;λ)	G(x;λ)	D(x;λ,1)
15	−.100	.494221	.487228	.492321
	−.090	.498210	.490408	.496368
	−.080	.502312	.493376	.500409
	−.070	.506347	.496046	.50444
	−.060	.510373	.498268	.508472
	−.050	.514390	.499781	.512492
	−.040	.518400	.500056	.516504
	−.030	.522401	.497863	.520508
	−.020	.526394	.489509	.524504
	−.010	.530376	.456633	.528491
	−.008	.531172	.439150	.529287
	−.006	.531967	.409854	.530083
	−.004	.532761	.352598	.530878
	−.002	.533556	.206991	.531673
	−.001	.533952	.056310	.532071
	.000	.534346	Undefined	.532468
	.001	.534741	.956628	.532865
	.002	.535137	.834497	.533262
	.004	.535930	.707302	.534056
	.006	.536722	.654583	.534850
	.008	.537514	.626980	.535643
	.010	.538307	610298	.536436
	.020	.542258	.578486	.540393
	.030	.546199	.570287	.544341
	.040	.550129	.568096	.548277
	.050	.554046	.568315	.552202
	.060	.557952	.569737	.556116
	.070	.561846	.571842	.560018
	.080	.565726	.574369	.563907
	.090	.569596	.577174	.567784
	.100	.573452	.580170	.571649

one need only know the value of f at a single point w in order to use D to approximate F at any point x; whereas, when using G one must know the value of f at each value x for which F is to be approximated. Also, observe that D is a generalization of G because D(x;λ,x) = G(x;λ).

We would like for D(x;λ,w) to have the same asymptotic property as G(x;λ) in (4). Substituting (10) and (11) into (13), we obtain

$$\log \frac{1-D(x;\lambda,w)}{D(x;\lambda,w)} = \log \frac{1-F(x;\lambda)}{F(x;\lambda)} - 0(\lambda^{-1}). \tag{16}$$

If we then exponentiate (16) and use the elementary properties of the order function, it follows that

$$F(x;\lambda) - D(x;\lambda,w) = 0(\lambda^{-1}), \tag{17}$$

TABLE 2. Comparison of G and D for various values of x and λ (w = 1).

λ	x	F(x;λ)	G(x;λ)	D(x;λ,1)
15	−2.25	.002171	.001432	.005157
25	−2.25	.004035	.003321	.006222
50	−2.25	.006256	.005781	.007544
100	−2.25	.007953	.007681	.008665
15	−1.75	.021343	.000344	.027824
25	−1.75	.026138	.003166	.030126
50	−1.75	.030643	.012298	.032681
100	−1.75	.033618	.022186	.034650
15	−1.25	.091990	.096794	.097564
25	−1.25	.096050	.098791	099271
50	−1.25	.099495	.100802	.101051
100	−1.25	.101592	.102223	.102351
15	1.25	.888837	.885488	.885680
25	1.25	.889570	.887493	.887613
50	1.25	.890580	.889505	.889568
100	1.25	.891472	.890925	.890958
15	1.75	.947699	.989473	.942642
25	1.75	.949959	.982095	.946911
50	1.75	.952512	.972666	.950981
100	1.75	.954493	.966016	.953728
15	2.25	.977411	.979707	.971300
25	2.25	.979567	.980966	.976122
50	2.25	.981859	.982561	.980248
100	2.25	.983545	.983894	.982780

which is the desired result.

The asymptotic property expressed by (17) is independent of the choice of w as long as D is defined; that is, when $\psi^{(4)}(w) \neq 0$, $\psi'(w) \neq 0$ and $F'(w;\lambda) \neq 0$.

ILLUSTRATIVE EXAMPLE

Let F(;λ) be the standard gamma distribution and ψ be the standard normal distribution. It is clear that G is undefined for $x = -\sqrt{3}$, 0, or $\sqrt{3}$. In fact, Galloway and McCune (1983) advised caution when using G to approximate F(;λ) for values of x near $-\sqrt{3}$, 0, or $\sqrt{3}$; and they clearly point out that for such values of x, G can take on very erratic behavior. It is extremely important to note, however, that D(;λ,w) is quite stable for values of x near 0 as well as x = 0, which is illustrated in Table 1, using λ = 15, w = 1. The authors also have obtained similar results when using values of x near $-\sqrt{3}$ and $\sqrt{3}$; when using other values of λ such as 5, 25, and 100; and when using other values for w that are not near the singularity points $-\sqrt{3}$, 0, or $\sqrt{3}$.

Finally, one would hope that D(x;λ, w) would perform well at values of x whether near singularity points of G(x;λ) or not. This certainly seems to be the case exhibited in Table 2.

One should also remember if w is selected equal to x then D is identical to G. It appears, therefore, when ψ is the standard normal, that a "good" strategy when using D to approximate F is to select $w = 1$ for values of x near singularity points of G and to select $w = x$ for values of x away from singularity points of G such as in the tails of the distribution of F.

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LITERATURE CITED

Galloway, J. G., and E. D. McCune. 1983. A new edgeworth-type expansion. Texas J. Sci., 35:221-229.

COMMENTS ON DISTRIBUTION AND VARIATION IN THE BIG BROWN BAT, *EPTESICUS FUSCUS*, IN TEXAS

Richard W. Manning, J. Knox Jones, Jr., and Clyde Jones
The Museum and Department of Biological Sciences, Texas Tech University
Lubbock, Texas 79409

Abstract.—The distribution of the big brown bat, *Eptesicus fuscus*, once thought to be widespread in Texas, is shown to be restricted to the eastern, northwestern, and Trans-Pecos parts of the state. Based on mensural data and pelage color, two subspecies are recognized as occurring in Texas. *Key words*: bat; *Eptesicus*; distribution; Texas.

The big brown bat, *Eptesicus fuscus*, is a widely distributed and common species over much of temperate North America and ranges as far south as northern South America (Davis, 1966). For many years, it was assumed that this bat occurred state-wide in Texas. Davis (1960:54), for example, wrote of this species as follows: "Occurs throughout State, but seemingly uncommon in areas lacking woodlands." However, Blair (1952*a*) and Manning et al. (1987) did not record *E. fuscus* from the Edwards Plateau nor did Blair (1952*b*) report it from the Tamaulipan Biotic Province in southern Texas. It has become increasingly apparent, therefore, that the big brown bat has a somewhat restricted distribution in the state. In point of fact, records of its occurrence are available only from eastern Texas, from the Panhandle and adjacent areas in the northwest, and from parts of the Trans-Pecos region (Davis, 1974; Schmidly, 1977, 1983).

In order to better document the range of this bat in Texas, we have examined specimens housed in most museums in the state. These, together with material recently collected by us and records from the published literature, are listed below by locality of occurrence and mapped on Figure 1.

Traditionally, two subspecies—*Eptesicus fuscus fuscus* (Palisot de Beauvois, 1796) and *E. f. pallidus* Young, 1908—have been recognized as occurring in Texas (Burnett, 1983; Hall, 1981; Jones et al., 1988), the former recorded from the eastern part of the state and the latter found in the Panhandle and Trans-Pecos regions. We analyzed both size and color of big brown bats in order to test the hypothesis that two races are present in the state. Length of forearm and nine cranial dimensions (Table 1) were measured with digital calipers and recorded to the nearest hundreth of a millimeter (cranial measurements follow those described by Martin and Schmidly, 1982). Overall color was assessed by visual inspection. Additionally, coloration of the middorsal region was measured with red, green, and blue filters using a Photovolt Photoelectric Reflection Meter, Model 610, and recorded as a percentage of pure white; the higher the readings the paler the color.

Sexual dimorphism is marked in *E. fuscus*, females being larger than males (Barbour and Davis, 1969). In mammals, the most common argument advanced for larger size in females is related to reproduction—the "big mother" hypothesis of Ralls (1976). Burnett (1983) has reviewed sexual dimorphism in big brown bats with respect to this and related hypotheses. In any event, females are sufficiently larger than males in our samples to preclude treating the sexes together with respect to external and cranial measurements. Because adult females were more numerous than males among the specimens we examined, we did not analyze measurements of the latter. Nevertheless, inspection of available mensural data for males from Texas does not suggest a departure from trends seen among females.

RESULTS AND DISCUSSION

Big brown bats from eastern Texas are of modest size and are relatively dark in color (Tables 1 and 2), and seem accurately referred to the nominate subspecies (see Burnett, 1983, and Schmidly, 1983). With the exception of a specimen taken many years ago in Waco, all *E. f. fuscus* are from the "pine-oak forest and long-leaf pine vegetational regions" (Schmidly, 1983) of the extreme eastern part of the state (west to Walker County). The species is not known from west or south of the Brazos River (again excepting the one individual from Waco). As elsewhere in the state, *E. fuscus* frequently roosts in man-made structures in eastern Texas (Schmidly, 1983).

As noted previously, bats from western Texas fall into two distinct geographic units, the Panhandle and adjacent areas in the northwestern part of the state and the Trans-Pecos region. Those from the northwest, as exemplified by series from Hall and Kent counties, are about the same size as the eastern *E. f. fuscus* (Table 1), but average noticeably paler in color (Table 2). Trans-Pecos bats, on the other hand, are smaller cranially than those from the other two regions and also are pale in color (but not quite so pale as the average of samples from the Panhandle). We are content at the moment to regard Trans-Pecos bats as more or less typical of *E. f. pallidus*, and to provisionally refer specimens from northwestern Texas to that race as well.

We believe the evident "gaps" in distribution of *Eptesicus fuscus* in central and southern Texas, as revealed in Figure 1, to be real rather than an artifact resulting from lack of collecting efforts. Too much field work has been done on the Edwards Plateau and in north-central Texas (Dalquest and Horner, 1984), for example, to completely overlook this conspicuous species if it was a resident there. We are less certain about the distributional diastema between the two western populations. Findley et al. (1975) did not record *E. fuscus* from the immediately adjacent parts

TABLE 1. Comparative measurements of females in four samples of *Eptesicus fuscus* from Texas. Sample size is indicated in parentheses following each subheading (superscript numbers denote smaller sample for some measurements).

Statistics	Length of forearm	Greatest length of skull	Zygomatic breadth	Mastoid breadth	Breadth of braincase	Postorbital constriction	Breadth across upper canines	Breadth across M3-M3	Length of max. toothrow	Length of c-m3
					Eastern Texas (16)					
Ave.±1 S.E.	48.2±0.3	20.2±0.1	13.4±0.1^{15}	10.3±0.1	8.9±0.1	4.4±0.1	6.4±0.1^{15}	8.4±0.1	7.3±0.1	8.2±0.1
Min.	46.1	19.4	12.9	9.8	8.4	4.1	6.2	8.0	7.1	7.9
Max.	50.2	20.9	13.8	10.8	9.3	4.6	6.8	8.8	7.6	8.4
C.V.	2.5	2.2	2.1	2.6	2.8	3.9	2.7	2.6	1.6	1.7
					Hall County, Texas (13)					
Ave.±1 S.E.	47.7±0.1	20.4±0.1	13.4±0.1	10.5±0.1	8.9±0.1	4.4±0.1	6.4±0.1	8.4±0.1	7.4±0.1	8.2±0.1
Min.	46.4	19.6	12.8	10.1	8.5	4.1	6.0	7.9	7.1	7.9
Max.	49.1	21.4	13.8	10.9	9.2	4.6	6.8	8.7	7.7	8.5
C.V.	1.9	2.2	2.3	2.5	2.3	3.6	3.6	3.2	2.3	2.2
					Kent County, Texas (20)					
Ave.±1 S.E.	48.1±0.2	20.4±0.1	13.5±0.1^{19}	10.6±0.1	9.0±0.1	4.3±0.1	6.3±0.1	8.4±0.1	7.5±0.1	8.2±0.1
Min.	45.9	19.6	13.2	10.1	8.6	4.1	6.1	8.1	7.2	8.0
Max.	50.5	21.2	14.0	11.0	9.3	4.5	6.6	8.8	7.7	8.4
C.V.	2.3	2.0	1.6	2.3	2.4	2.9	1.9	2.4	1.9	1.6
					Trans-Pecos Texas (14)					
Ave.±1 S.E.	49.2±0.3	19.8±0.1	12.8±0.1	10.0±0.1^{13}	8.6±0.1	4.2±0.1	6.0±0.1	8.1±0.1	7.2±0.1^{12}	7.9±0.1
Min.	47.2	19.1	12.5	9.7	8.1	4.0	5.5	7.6	6.8	7.6
Max.	51.0	21.1	13.2	10.6	9.1	4.5	6.3	8.4	7.6	8.3
C.V.	2.6	2.8	1.7	3.2	3.2	3.4	3.9	2.6	2.9	2.7

TABLE 2. Comparative reflectance (as a percentage of pure white) of middorsal pelage in four samples of *Eptesicus fuscus* from Texas as measured by a Photovolt Photoelectric Reflection Meter. Higher readings indicate paler coloration. Average, one standard error, and range are given for each measurement. Sample sizes are in parentheses following locality designations.

Sample	Red	Green	Blue
	Eptesicus fuscus fuscus		
Eastern Texas (21)	14.5±0.4 (11.5-17.5)	5.9±0.2 (4.5-7.5)	5.2±0.2 (4.0-6.5)
	Eptesicus fuscus pallidus		
Hall County, Texas (20)	18.9±0.5 (13.5-23.5)	7.9±0.3 (5.5-11.5)	6.8±0.2 (5.0-9.5)
Kent County, Texas (20)	19.0±0.6 (14.5-22.5)	9.2±0.4 (6.5-11.5)	8.0±0.3 (5.5-10.0)
Trans-Pecos Texas (26)	17.3±0.5 (12.0-22.0)	7.7±0.4 (4.5-11.5)	6.3±0.3 (4.5-9.5)

of New Mexico and Schmidly (1977) mapped this bat as occurring only in the western two-thirds of the Trans-Pecos. It certainly is possible that the limits of distribution drift westward into New Mexico to the south of the area mapped and re-enter the state in the east-central part of the Trans-Pecos region.

Unfortunately, we have incomplete data for Texas concerning one important difference between eastern and western populations of *E. fuscus*, namely that females bear two young in the east and only a single offspring in the west (Barbour and Davis, 1969). Six gravid females from the Trans-Pecos carried a single fetus, in keeping with their assignment to *E. f. pallidus*, but no fetal counts currently are available for bats from eastern Texas or from the northwest.

RECORDS OF OCCURRENCE

Specimens examined are listed below along with published records that are not duplicated among materials examined and that aid in defining the distribution of *E. fuscus* in Texas (thus not all localities from published sources are listed). Solid symbols (Fig. 1) represent localities from which bats were examined, whereas open symbols represent records from the literature. Localities in italic type are not plotted on the figure because undue crowding of symbols would have resulted; some symbols on the map are slightly offset for the same reason. Counties are arranged in alphabetical order. Localities within each county are listed from north to south, and west to east at the same latitude.

We thank those in charge of the following collections for allowing us access to specimens in their care: Angelo State University (ASU); Corpus Christi State University (CCSU); Midwestern State University (MWSU);

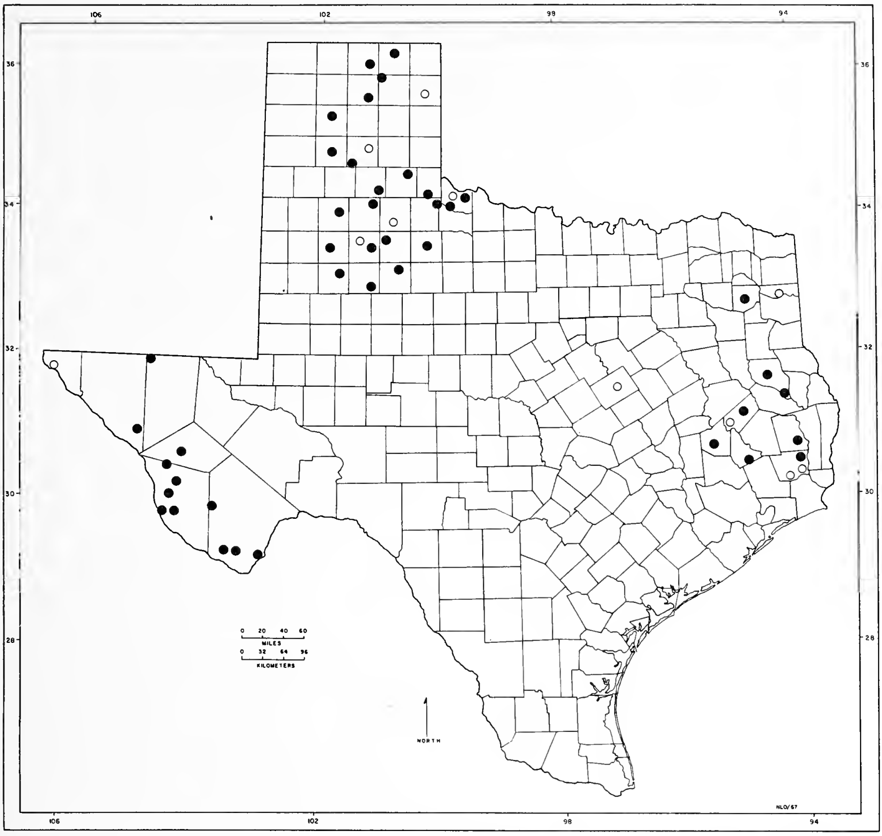

FIGURE 1. Known distribution in Texas of *Eptesicus fuscus*. Solid symbols represent specimens examined, whereas open symbols represent records from the literature.

Sul Ross State University (SRSU); Texas Cooperative Wildlife Collection, Texas A&M University (TCWC); Texas Natural History Collection, The University of Texas (UT); and West Texas State University (WTSU). Specimens in The Museum, Texas Tech University (TTU), also are listed.

Eptesicus fuscus fuscus (Palisot de Beauvois, 1796)

Specimens examined (27).—HARDIN CO.: 11 mi. N, 2.3 mi. E Silsbee, 1 (TCWC). NACOGDOCHES CO.: Nacogdoches, 1 (TTU); 2 mi. E Etaile, 1 (TTU); *approx. 5 mi. E Etaile*, 1 (TTU). SAN JACINTO CO.: 5 mi. NW Cleveland, 2 (TTU). TRINITY CO.: Pine Oak, 1 (TCWC). TYLER CO.: *1.1 mi. S, 1 mi. W Town Bluff*, 1 (TCWC); 2 mi S, 1.5 mi. W Town Bluff, 1 (TCWC); 3.8 mi. N, 1.9 mi. W Spurger, 2 (TCWC); *0.6 mi. N, 0.7 mi. W Spurger*, 2 (TCWC). UPSHER CO.: Gilmer, 12 (TCWC). WALKER CO.: 2 mi. SW Huntsville, 2 (TCWC).

Other pertinent records (Schmidly, 1983:332, unless noted otherwise).—HARDIN CO.: Grady; 7 mi. NE Sour Lake. MARION CO.: Jefferson. McLENNAN CO.: Waco. TRINITY CO.: Trinity. County undesignated: *Brazos River* (Bailey, 1905:211).

Eptesicus fuscus pallidus Young, 1908

Specimens examined (548).—ARMSTRONG CO.: 29 mi. SSW Claude, 1 (TTU). BREWSTER CO.: 7 mi. NE Bandera Mesa, 2 (MWSU); Terlingua Creek, 6 mi. E Terlingua, 1 (SRSU); Nail's Ranch, E side Burro Mesa, 3500 ft., 2 (TCWC); Rio Grande Village, Big Bend National Park, 1 (TCWC). BRISCOE CO.: *6.1 mi. N, 0.1 mi. W Quitaque*, 5 (TTU); Caprock Canyons, 3 mi. N Quitaque, 3 (TTU); 15 mi. SE Silverton, 1 (TTU); Los Lingos Canyon, 4 (TTU). CHILDRESS CO.: 12 mi. S Childress, 2 (MWSU). COTTLE CO.: Panther Cave, 22 mi. SE Childress, 1 (TTU). CROSBY CO.: 4.5 mi. E Crosbyton, 2 (TTU). CULBERSON CO.: North McKittrick Canyon at Devil's Den, Guadalupe Mts. National Park, 2 (TTU); *McKittrick Canyon, Guadalupe Mts. National Park*, 6 (TCWC); *Thrush Hollow, S McKittrick Canyon, Guadalupe Mts. National Park*, 1 (TTU); *2 mi. NW Pine Spring, Guadalupe Mts. National Park*, 2 (TTU); *The Bowl, Guadalupe Mts. National Park*, 6 (TTU); *Smith Spring, Guadalupe Mts. National Park*, 2 (TTU); *Manzanita Springs, Guadalupe Mts. National Park*, 2 (TTU); *Ligon Ranch, Guadalupe Mts.*, 2 (SRSU); *Culberson Park*, 1 (TTU). DICKENS CO.: McAdoo, 1 (TTU). FLOYD CO.: 8 mi. E Los Lingos, 2 (UT); *Los Lingos Canyon*, 3 (TTU). GARZA CO.: Justiceburg, 2 (TTU); *Salt Fork Brazos River, Justiceburg*, 1 (TTU); *3 mi. E Justiceburg*, 1 (TTU); 7 mi. E Justiceburg, 3 (CCSU). HALE CO.: Plainview, 1 (TTU). HALL CO.: Memphis, 238 (TTU). HANSFORD CO.: Spearman, 1 (TTU). HARDEMAN CO.: 12 mi. E Quanah, 1 (MWSU); *7 mi. E Quanah*, 1 (MWSU); *3 mi. SE Lazare*, 1 (MWSU); 11-13 mi. SW Quanah, 8 (MWSU). HUDSPETH CO.: Wind Canyon, Eagle Mts., 2 (SRSU). HUTCHINSON CO.: 9 mi. E Stinnett, 8 (UT). JEFF DAVIS CO.: Davis Mts., 8 mi. S jct. hwys. 118 and 166, 5 (4 SRSU, 1 TTU); old McGuire Homestead, Davis Mts. Resort, 3 (SRSU). KENT CO.: Girard, 129 (TTU). KING CO.: River Styx Cave, 8 mi. E Guthrie, 1 (TTU). LUBBOCK CO.: Lubbock, 1 (TTU). LYNN CO.: Wilson, 2 (TTU). OCHILTREE CO.: Perryton, 4 (TTU). POTTER CO.: 15-16 mi. N Amarillo, 6 (TTU). PRESIDIO CO.: 1 mi. W Valentine, 2 (UT); 18 mi. NNE Candelaria, 1 (SRSU); *SW Marfa, Pinto Canyon Rd.*, 1 (SRSU); *Wild (Dead) Horse Canyon, Chinati Mts.*, 11 (SRSU); *pool below old Fred Shely Headquarters, N side Chinati Mts.*, 6 (SRSU); *San Antonio Canyon, Chinati Mts. Lodge*, 2 (SRSU); *Sierra Parda Caballo Canyon, Chinati Mts.*, 1 (SRSU); Ruidosa, 1 (SRSU); Chinati Mts., 12 mi. E Ruidosa, 3 (TCWC); *Chinati Mts., ca. 14 mi. E Ruidosa*, 1 (TTU); 7 mi. NE Bandera Mesa, 2 (MWSU); *5 mi. SE Bandera Mesa*, 11 (MWSU); Shafter, 2 (ASU). RANDALL CO.: Canyon, 28 (WTSU). ROBERTS CO.: 10 mi. S, 15 mi. E Spearman, 2 (TTU).

Other pertinent records.—ARMSTRONG CO.: Goodnight (Strecker, 1910). CROSBY CO.: Ralls (Milstead and Tinkle, 1959:139). EL PASO CO.: Ft. Bliss (Schmidly, 1977:176). FLOYD CO.: *7 mi. SW Quitaque* (Milstead and Tinkle, 1959:39). HARDEMAN CO.: Acme (Dalquest, 1968:15); *Walkup Cave, 25 mi. SE Childress* (Milstead and Tinkle, 1959:39). HEMPHILL CO.: no precise locality (Davis, 1974:59). MOTLEY CO.: Roaring Springs (Milstead and Tinkle, 1959:139).

See also Schmidly (1977) for additional records from the Trans-Pecos region and Easterla (1973) for 10 localities in Big Bend National Park.

LITERATURE CITED

Bailey, V. 1905. Biological survey of Texas. N. Amer. Fauna, 25:1-222.

Barbour, R. W., and W. H. Davis. 1969. Bats of America. Univ. Kentucky Press, Lexington, 286 pp., 24 pls.

Blair, W. F. 1952*a*. Bats of the Edwards Plateau in central Texas. Texas J. Sci., 4:95-98.

———. 1952*b*. Mammals of the Tamaulipan Biotic Province in Texas. Texas J. Sci., 4:230-250.

Burnett, C. D. 1983. Geographic and secondary sexual variation in the morphology of *Eptesicus fuscus.* Ann. Carnegie Mus., 52:139-162.

Dalquest, W. W. 1968. Mammals of north-central Texas. Southwestern Nat., 13:13-21.

Dalquest, W. W., and N. V. Horner. 1984. Mammals of north-central Texas. Midwestern State Univ. Press, Wichita Falls, Texas, 261 pp., 72 pls.

Davis, W. B. 1960. The mammals of Texas. Bull. Texas Game Fish Comm., 27:1-252.

———. 1966. Review of South American bats of the genus Eptesicus. Southwestern Nat., 11:245-274.

———. 1974. The mammals of Texas. Bull. Texas Parks Wildlife Dept., 41:1-294.

Easterla, D. 1973. Ecology of the 18 species of Chiroptera at Big Bend National Park, Texas. Part 1. Northwest Missouri State Univ. Stud., 34(2):1-53.

Findley, J. S., A. H. Harris, D. E. Wilson, and C. Jones. 1975. Mammals of New Mexico. Univ. New Mexico Press, Albuquerque, xxii + 360 pp.

Hall, E. R. 1981. The mammals of North America. John Wiley & Sons, New York, 1:xv + 1-600 + *90.*

Jones, J. K., Jr., C. Jones, and D. J. Schmidly. 1988. Annotated checklist of Recent land mammals of Texas. Occas. Papers Mus., Texas Tech Univ., 119:1-26.

Manning, R. W., J. K. Jones, Jr., R. R. Hollander, and C. Jones. 1987. Notes on distribution and natural history of some bats on the Edwards Plateau and in adjacent areas of Texas. Texas J. Sci., 39:279-285.

Martin, C. O., and D. J. Schmidly. 1982. Taxonomic review of the pallid bat, Antrozous pallidus (Le Conte). Spec. Publ. Mus., Texas Tech Univ., 18:1-48.

Milstead, W. W., and D. W. Tinkle. 1959. Seasonal occurrence and abundance of bats (Chiroptera) in northwestern Texas. Southwestern Nat., 4:134-142.

Ralls, K. 1976. Mammals in which females are larger than males. Quart. Rev. Biol., 51:245-276.

Schmidly, D. J. 1977. The mammals of Trans-Pecos Texas . . . . Texas A&M Press, College Station, xiii + 225 pp.

———. 1983. Texas mammals east of the Balcones Fault Zone. Texas A&M Press, College Station, xviii + 400 pp.

Strecker, J. K. 1910. Notes on the fauna of northwestern Texas. Baylor Univ. Bull., 18(4-5):1-31.

GENERAL NOTES

REFINEMENT OF THE TYPE LOCALITY AND DISTRIBUTION OF *DIPODOMYS COMPACTUS SENNETTI* (J. A. ALLEN, 1891)

George D. Baumgardner
Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, Texas 77843

Confusion regarding the precise location of capture of the type specimen of *Dipodomys compactus sennetti* (J. A. Allen, 1891) has persisted for more than 80 years. Described as *Dipodops sennetti*, the original locality and other information given for the holotype was "near Brownsville, Cameron Co., Texas, March 9, 1888, J. M. Priour" (Allen, 1891). Using information provided by the collector, Bailey (1905) stated that this specimen actually was taken at "Santa Rosa stage station, 85 miles southwest of Corpus Christi . . . on the Alice and Brownsville stage road, near the northwest corner of Cameron County, 115 miles from Brownsville." The place of collection was thereafter modified to incorporate "Santa Rosa, 85 mi. SW Corpus Christi" (Baumgardner and Schmidly, 1981; Hall, 1981; Setzer, 1949). The locality of capture of the type and presumed topotypes has been plotted as in the central part of southern Texas (Setzer, 1949) and in the extreme southeastern part of that region (Baumgardner and Schmidly, 1981).

Much of the confusion likely resulted from changes in county boundaries in southern Texas and the common use of Santa Rosa as a place name. In 1887, one year prior to collection of the holotype, Cameron County extended from the Rio Grande north to Baffin Bay (Rand, McNally and Co., 1887). A Santa Rosa Ranch is plotted on the Rand-McNally map near the northwestern corner of Cameron County, in what was then Hidalgo County, and transcriptions from Vernon Bailey's 1900 field notes refer to such a ranch in this area on the Alice to Brownsville stage road south of Alice and southwest of Corpus Christi. There is a present-day Santa Rosa Viejo Ranch in this immediate area, near Sarita, in what is now Kenedy County (State Department of Highways and Public Transportation, 1980). It seems likely that this is the place where the type specimen was collected and not the city of Santa Rosa as plotted by Baumgardner and Schmidly (1981). The latter site is in current northwestern Cameron County, approximately 70 miles south of Sarita. It is impossible to decipher the mileage references given by Priour in Bailey (1905) and place the type locality in Cameron County as it was delineated in 1887. Bailey's 1900 field notes refer to traveling this region on horseback. It seems likely that Priour traveled in the same way and that the mileages were estimates following the roads or trails of the day. This probably has contributed to the confusion with regard to the site of capture. These factors should be considered when referring to the type locality of *D. c. sennetti*, and its placement should be amended to reflect that it probably is near Sarita. Therefore, in accordance with the International Rules of Zoological Nomenclature, I herewith restrict the type locality of *D. c. sennetti* to Santa Rosa, near Sarita, Kenedy Co., Texas.

The capture site of presumed topotypes discussed by Baumgardner and Schmidly (1981) and mistakenly assigned to Willacy County by Schmidly and Hendricks (1976) is uncertain. The locality of capture accompanying these specimens carries no county designation. These animals were collected in 1891 and it seems likely that they also were obtained from the Santa Rosa site now located in Kenedy County. Even if this is so, it will not greatly affect the distribution of the species because of the presence of other localities of capture in Willacy County and southern Kenedy County (Baumgardner and Schmidly, 1981). This subspecies is distributed over the eastern two-thirds of the southern Texas mainland. Marginal records, beginning in the northeastern part of the distribution of *D. c. sennetti* are as follows: 2 mi. N Nixon, Gonzales County (Raun, 1959); west-southwest to 7 mi. E Lytle, Atascosa County (Blair, 1952); south-southwest to 2 mi. NE Bustamante, Zapata County (Baumgardner and Schmidly, 1981); and east-southeast to Sauz Ranch, Willacy County (Schmidly and Hendricks, 1976).

I wish to thank W. B. Davis for permission to examine his transcriptions of Vernon Bailey's field notes, D. E. Wilson and R. D. Fisher of the U.S. National Museum for allowing me to re-examine the presumed topotypes and the staff of the Map Department for the Sterling C. Evans Library at Texas A&M University for their assistance. I am also indebted to J. K. Jones, Jr., M. J. McCoid, R. D. Owen, and an anonymous reviewer for their comments on earlier versions of this manuscript.

LITERATURE CITED

Allen, J. A. 1891. On a collection of mammals from southern Texas and northeastern Mexico. Bull. Amer. Mus. Nat. Hist., 3:219-228.

Bailey, V. 1905. Biological survey of Texas. N. Amer. Fauna, 25:1-222.

Baumgardner, G. D., and D. J. Schmidly. 1981. Systematics of the southern races of two species of kangaroo rats (Dipodomys compactus and D. ordii). Occas. Papers Mus., Texas Tech Univ., 73:1-27.

Blair, W. F. 1952. Mammals of the Tamaulipan biotic province in Texas. Texas J. Sci., 4:230-250.

Hall, E. R. 1981. The mammals of North America. John Wiley and Sons, New York, 2nd ed., 1;xv+600+*90*.

Rand, McNally and Co. 1887. New enlarged scale railroad and county map, Texas. Rand, McNally and Co., Chicago.

Raun, G. G. 1959. A new Texas locality for *Dipodomys ordi*. J. Mamm., 40:146-147.

Schmidly, D. J., and F. S. Hendricks. 1976. Systematics of the southern races of Ord's kangaroo rat, *Dipodomys ordii*. Bull. Southern California Acad. Sci., 75:225-237.

Setzer, H. W. 1949. Subspeciation in the kangaroo rat, Dipodomys ordii. Univ. Kansas Publ., Mus. Nat. Hist., 1:473-573.

State Department of Highways and Public Transportation. 1980. General highway maps of Texas. State Department of Highways and Public Transportation, Austin.

THE STANDARD AND NOR-STAINED KARYOTYPE OF *RIVULUS AGILAE* (RIVULIDAE: TELEOSTEI)

PATRICIA K. ZOCH, BRIAN G. HANKS, AND JOHN R. GOLD
Department of Wildlife and Fisheries Sciences, Texas A&M University,
College Station, Texas 77843

During a recent herpetological collection trip to South America by members of our department, a small (total length less than two centimeters) specimen of the aplocheiloid fish *Rivulus agilae* was inadvertently returned to College Station in the water used to maintain live specimens of turtles. The fish was brought to our laboratory, and we were able to obtain surprisingly good chromosome preparations, which were then stained with silver nitrate to determine the number and chromosomal locations of the nucleolar organizer regions (NORs). Herein, we document the standard karyotype and chromosomal NORs of *R. agilae*, describe the procedures used to obtain chromosomes from such a small specimen, and reference other studies that have shown that chromosomal NOR phenotypes appear to be effective taxonomic and systematic characters in fishes. Our primary intent in this note is to stimulate further chromosome research into the diverse and cytogenetically variable aplocheiloid fishes of the New World tropics.

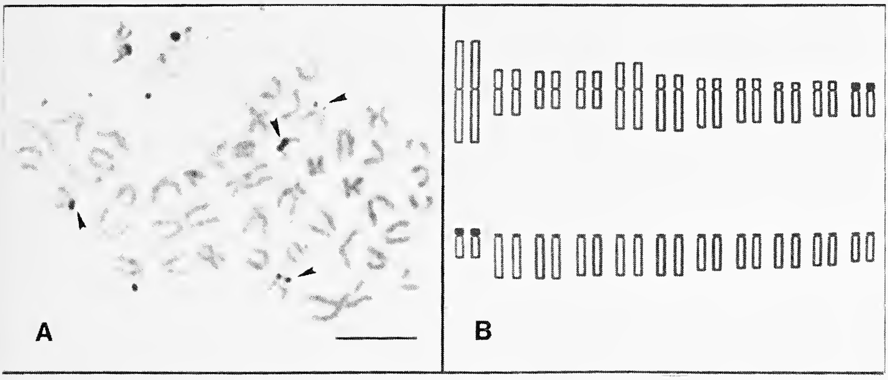

FIGURE 1. (A) Silver-stained metaphases of *Rivulus agilae* (chromosomal NORs are indicated by arrowheads; bar equals 5 μm). (B) Computer-generated idiogram of the *Rivulus agilae* NOR karyotype (NORs are indicated by darkened areas).

The specimen of *R. agilae* was discovered in water obtained from a small ditch near the Hotel Le Grillardin in Matoury (Guyane Province), French Guyana, on 13 June 1987. Upon return to Texas, the individual was injected with 0.1 cubic centimeters per gram body weight of a 0.5 percent colchicine solution and maintained under aerated conditions for 50 minutes. The gills were removed, placed into fresh hypotonic solution (0.4 percent KCl) for 30 minutes (two changes), and then fixed (several changes) in freshly prepared methanol:acetic acid, 3:1. Metaphases were obtained using the slide warmer procedure of Kligerman and Bloom (1977) as modified by Rayburn and Gold (1982) and using fresh 50 percent acetic acid to dissociate cells. NOR staining was accomplished using the controlled silver nitrate procedure of Howell and Black (1980) as modified by Gold and Ellison (1983). Chromosomes stained with silver (and counterstained with Giemsa) were photographed in bright-field using Kodak Technical Pan 2415 film (ASA 40) developed in Diafine (Acufine). Determinations of NOR band positions and size, and of relative size and centromere position of NOR-bearing and other chromosomes, were made off positive prints using a digitizer, a small laboratory computer, and the BANDSCAN program described in Gold and Amemiya (1986).

Fourteen good metaphases were examined from the specimen of *R. agilae.* A representative silver-stained metaphase and a computer-generated diploid idiogram of the metaphase are shown in Figure 1. More than 90 percent of the metaphases had 2N=44 chromosomes, which is assumed to be the chromosome number of the species. The *R. agilae* karyotype is noticeably asymmetric (*sensu* Stebbins, 1971) and contains several "marker" chromosomes. These include an exceptionally large metacentric pair, a medium- to large-sized submetacentric pair, and three pairs of metacentric chromosomes, one of which is measurably larger than the other two (Fig. 1B). The remaining chromosomes are all medium- to small-sized subtelo- or telocentrics (acrocentrics). The arm number (NF) of *R. agilae* is estimated to be 54. In most silver-stained metaphases, a maximum of four (two pair) NOR-bearing chromosomes was observed (Fig. 1A). In all cases, the NORs were located terminally on the short arms of small acrocentric chromosomes.

Recent studies in our laboratory (Gold and Amemiya, 1986; Amemiya et al., 1987; Amemiya and Gold, 1988) have shown that chromosomal NORs are effective taxonomic and systematic markers in fishes, particularly when morphologically similar types (differing in NOR phenotypes) are found sympatrically. Chromosomal NORs represent the sites for the 18S and 28S ribosomal RNA genes (Ritossa and Spiegelman, 1965; Wallace and Birnstiel, 1966), and hence identify homologous genes that if located on morphologically different chromosomes serve to identify the past occurrence of chromosomal rearrangements. Intraspecific NOR variants occur, but are qualitatively different from the types of variants observed between species (Gold and Amemiya, 1986). In cyprinid fishes, we have been able to unequivocally identify 15 of the 24 taxa examined solely on the basis of chromosomal NOR phenotypes (Amemiya and Gold, 1988).

The fish suborder Aplocheiloidei (*sensu* Parenti, 1981), which includes the tropical families Rivulidae (New World) and Aplocheilidae (Old World), contains more than 500 nominal species (more than 40 nominal genera) and is one of the most taxonomically and systematically troublesome fish groups in the world. Standard karyotypes are known for species in both families (particularly the Aplocheilidae) and indicate the past occurrence of numerous chromosomal rearrangements (Scheel, 1972). The inability to homologize chromosomes or chromosomal regions across species, however, has somewhat precluded efforts to use the chromosomal information effectively in a taxonomic or systematic context. The use of NOR and other types of chromosome banding (Gold et al., 1986, for example) on fish chromosomes should overcome the homologization problem, and the tropical aplocheiloid fishes should represent a prime group on which to use the recent developments in fish chromosome staining.

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LITERATURE CITED

Amemiya, C. T., and J. R. Gold. 1988. Chromosomal NORs as taxonomic and systematic characters in North American cyprinid fishes. Genetica, 76:81-90.

Amemiya, C. T., S. W. Kelsch, F. S. Hendricks, and J. R. Gold. 1987. The karyotype of the Mexican blindcat, *Prietella phreatophila* Carranza. Copeia, 1987: 1024-1028.

Gold, J. R., and C. T. Amemiya. 1986. Cytogenetic studies in North American minnows (Cyprinidae). XII. Patterns of chromosomal NOR variation among fourteen species. Canadian J. Zool., 64:1869-1877.

Gold, J. R., and J. R. Ellison. 1983. Silver-staining for NORs of vertebrate chromosomes. Stain Technol., 58:51-55.

Gold, J. R., C. T. Amemiya, and J. R. Ellison. 1986. Chromosomal heterochromatin differentiation in North American cyprinid fishes. Cytologia, 51:557-566.

Howell, W. M., and D. A. Black. 1980. Controlled silver-staining of nucleolus organizer regions with a colloidal developer: a 1-step method. Experientia, 31:260-262.

Kligerman, A. D., and S. E. Bloom. 1977. Rapid chromosome preparations from solid tissues of fishes. J. Fish. Res. Board Canada, 34:266-269.

Parenti, L. R. 1981. A phylogenetic and biogeographic analysis of cyprinodontiform fishes (Teleostei, Atherinomorpha). Bull. Amer. Mus. Nat. Hist., 168:335-557.

Rayburn, A. L., and J. R. Gold. 1982. A procedure for obtaining mitotic chromosomes from maize. Maydica, 27:113-121.

Ritossa, F. M., and S. Spiegelman. 1965. Localization of DNA complementary to ribosomal RNA in the nucleolus organizer region of *Drosophila melanogaster*. Proc. Nat. Acad. Sci., 53:737-745.

Scheel, J. J. 1972. Rivuline karyotypes and their evolution (Rivulinae, Cyprinodontidae, Pisces). Zeit. Zool. Syst. Evol., 10:180-209.

Stebbins, G. L. 1971. Chromosomal evolution in higher plants. Edward Arnold Publ., Ltd., London, viii+216 pp.

Wallace, H., and M. L. Birnstiel. 1966. Ribosomal cistrons and the nucleolus organizer. Biochim. Biophys. Acta, 114:296-310.

FIRE IN AN OLD FIELD ADJACENT TO A SABAL PALM GROVE IN SOUTH TEXAS

Robin S. Vora
Rio Grande Valley National Wildlife Refuge, Alamo, Texas 78516

In 1519, Spanish explorer Alonzo Alvarez de Pineda travelled up the Rio Grande in a small boat. He described a vast palm forest and named the river Rio de las Palmas (Wilson, 1979). The Texas Sabal Palm Sanctuary, operated by the Audubon Society, is a small remnant (70 hectares) of the large palm forest described by Pineda. Natural Texas sabal palm, *Sabal texana* (Cook) Becc., communities in the United States are limited to the Brownsville, Texas, area, although other *Sabal* species are found in the southeastern United States.

Adjacent to the Audubon sanctuary is a 149-hectare tract acquired by the U.S. Fish and Wildlife Service to increase the size of the remnant forest. A small portion of the tract is native brush, including scattered Texas sabal palm trees. The remainder is an old field that is being slowly colonized by woody species such as false willow, *Baccharis neglecta* Britt., tepeguaje, *Leucaena pulverulenta* (Schlecht.) Denth., honey mesquite, *Prosopis glandulosa* Torr., and Texas sabal palm. Several portions of the field have been planted with Texas sabal palm seedlings by refuge staff, Youth Conservation Corps crews, and a Boy Scout group. The understory is a dense mat of grasses, forbs, and vines 30 to 80 centimeters tall.

The presence of palms has spurred speculation that fire once may have played a natural ecological role in the palm community. Man-caused fires have thrice burned the old fields in the Bosque de la Palma tract in the past five years. On March 1982, an estimated 130 hectares burned. By 1984, there was no evidence of the fire except for fire scars on large Texas sabal palms, and the community described above characterized the old fields.

On 3 April 1986, a fire swept through the southern and western portions of the tract at midday. Wind drove a fast-moving head-fire that burned with short duration in most areas. National Weather Service records for nearby (5.5 kilometers) Brownsville airport for that day reveal wind speeds of 40 kilometers per hour, with gusts up to 56 kilometers per hour. Winds within the fire were probably higher. The temperature between noon and 2 PM was 28°C, the humidity 65 percent, and the dew point 21°C. Fuel moisture was low due to drought conditions the previous five months.

A visit to the site seven days after the fire showed trees of all species up to four meters tall were scorched badly and had few green leaves. Sabal palm seedlings taller than 50 centimeters were visible, but brown. It was not apparent whether any of these palm seedlings were those that had been planted; although it had been observed during a previous visit in March that most planted seedlings had died. The tall, dense grass layer was removed completely, yet some scattered green grass was emerging despite the absence of rain.

The site was revisited three months after the fire (3 July 1986), and after unusually late "spring" rains had dropped 190 millimeters of precipitation at the Brownsville airport within that period. Woody plants appeared to have been damaged by the fire, but few plants taller than 0.8 meters had been killed. The above-ground portions of trees and shrubs, including false willow, tepeguaje, black willow, *Salix nigra* Marsh., honey mesquite, retama, *Parkinsonia aculeata* L., Texas sugarberry, *Celtis laevigata* Willd., and colima, *Zanthoxylum fagara* (L.) Sarg., had been killed, but almost all were resprouting from the base. The tallest top-killed tree observed was a black willow 10 meters in height, with a diameter of 17 centimeters at 1.4 meters height. A few false willow bushes were killed in a small area where fire duration was longer. Texas sabal palm seedlings as short as 0.3 meters survived the fire. There appeared to be more Texas sabal palms in the burned than unburned areas in the southern portion of the tract. No such difference was observed in the northern portion. A planted row of exotic date palms, *Phoenix canariensis* Chab., survived the fire. The cover of vines was far greater in unburned areas in the southern portion of the tract. Most prevalent were Texas virgin's bower, *Clematis drummondii* DC., and ivy treebine, *Cissus incisa*

(Nutt.) Des Moul. Buffelgrass, *Cenchrus ciliaris* L., cover appeared to be higher before the fire than after. Except for the cover of buffelgrass and vines, no major differences were observed in understory species composition of abundance between burned and unburned areas.

On 1 October 1986, another man-caused fire burned much of the southern portion of the tract that had not been burned by the April fire. Despite warm weather (temperature 33°C, humidity 60 percent, and dew point 24°C at 3 PM), and relatively dry conditions, the October fire did not burn the herbaceous regrowth (still green) in the area of the April fire, and instead went out at its boundary.

A visit to the site on 22 December 1986 showed that the effects of the October fire were similar to those of the April fire. Tepeguaje, false willow, honey mesquite, Texas virgin's bower, and southern dewberry, *Rubus trivialis* Michx., were all resprouting, and sprouts that had appeared to have been top-killed by the April fire had new growth in portions of the upper branches. The ground cover in both areas was dominated by grasses, primarily Angleton bluestem, *Dicanthium aristatum* (Poir.) C. E. Hubb, Johnson grass, *Sorghum halepense* (L.) Pers., and silver bluestem, *Bothriocloa saccharoides* (SW.) Rydb. Also common were southern dewberry and peppervine, *Ampelopsis arborea* (L.) Koehne. Regrowth probably was enhanced by the 267 percent higher than normal precipitation in October, November, and December (normal is 140 millimeters), including the wettest November on record (195 millimeters) (Brownsville National Weather Service data). Fire duration had been longer in some small areas (one-fifth to one-tenth of a hectare) and woody plants in those "hot spots" were killed (no sprouts).

The fires consumed the dense ground mat of dead plant material (grasses, vines). The cover of bareground immediately after the fires varied from 20 to 80 percent in the burned portions in comparison to almost no exposure of bareground in the unburned portions. In December, two months later, bareground cover in the burned areas was reduced to about five percent. Thus the fire exposed mineral soil, released nutrients into the soil, and made more light available to a seedling. Prior to the fire, buffelgrass may have inhibited woody species germination and growth through competition for soil moisture, light and space, and possibly by allelopathy (Akhtar et al., 1978; Hussain et al., 1982); fire may remove some of this inhibitory effect.

Experimentation with control burns in areas where stocking of desirable woody species is low is recommended, because burning may provide the seed bed necessary for establishment of woody species. Once seedlings have emerged, they may need protection from fire until canopy closure results in elimination of most of the herbaceous vegetation needed to carry a fire. Woody plants greater than 0.8 meter tall resprouted, and smaller-sized Texas sabal palm seedlings (less than 0.3 meter) survived the fire, but their growth was probably set back for at least a year, and the scorching may have left the plants more susceptible to insects and diseases.

The author wishes to express appreciation to Zachary Labus and Ruben Cavazos for their assistance with making field observations, to Robert Lonard for plant identification, and to James Everitt, Timothy Fulbright, Joe Ideker, and Curtis Halvorson for editorial assistance.

LITERATURE CITED

Akhtar, N., H. H. Naqvi, and F. Hussain. 1978. Biochemical inhibition exhibited by *Cenchrus ciliaris* Linn. and *Chrysopogon aucheri* (Bioss) Stapf. Pakistan J. Forestry, 28:194-200.

Hussain, F., H. H. Naqvi, and I. Iiahi. 1982. Interference exhibited by *Cenchrus ciliaris* and *Bothriochloa pertusa.* Bull. Torrey Bot. Club, 109:513-523.

Wilson, M. C. 1979. *Sabal texana*: a sanctuary with a history. Plant Life, 35:120-122.

Current address of author: U.S. Forest Service, 1170 4th Avenue South, Park Falls, Wisconsin 54552.

BIG FREE-TAILED BAT, *TADARIDA MACROTIS* (GRAY, 1839), FROM BRAZOS COUNTY, TEXAS

David L. Scarbrough
Department of Wildlife and Fisheries Sciences, Texas A&M
University, College Station, Texas 77843-2258

On 14 October 1988, a female big free-tailed bat, *Tadarida macrotis* (Gray, 1839), was received at the Texas A&M University veterinary diagnostic laboratory for rabies testing. The bat had entered a home in Bryan, Texas, via the fireplace chimney and alighted on the resident's arm. This is the first record of *T. macrotis* from Brazos County and only the second record from eastern Texas.

T. macrotis is an uncommon seasonal inhabitant of Texas that is known primarily from the Trans-Pecos. Borell (1939) discovered the only known nursery colony of these bats in Big Bend National Park (Brewster County), but subsequent investigators (Easterla, 1973) have been unable to relocate this site. Nursery colonies are suspected to occur in McKittrick Canyon, Guadalupe Mountains National Park, Culberson County (LaVal, 1973), and Fern Canyon, Chihuahua (Easterla, 1972), a site near Big Bend National Park. Other Texas records include individual specimens from Hale, Lubbock, El Paso, Reeves, Jeff Davis, Presidio, and San Patricio counties (Schmidly, 1989).

The nearest locality of record to that of the Brazos County specimen is Welder Wildlife Refuge (San Patricio County), a straight-line distance of 296 kilometers (184 miles). This bat was captured on 23 December 1959 while hanging on a screen door (Raun, 1961), and is the only winter record of *T. macrotis* from Texas.

Big free-tailed bats appear to segregate by sex in the nonbreeding period and may wander extensively in autumn (Barbour and Davis, 1969). Only three male *T. macrotis* have been captured in Texas (Constantine, 1961; Easterla, 1973; Raun, 1961). Specimens from eastern Texas and the Panhandle probably represent stray migrants.

External measurements of the bat were total length, 136 mm; wingspan, 410; forearm length, 61; tail, 55; ear, 22; hind foot, 11; weight, 25 grams. No embryos were present and the bat tested negative for rabies. The skin and skeleton have been deposited in the Texas Cooperative Wildlife Collection at Texas A&M University.

I thank Dr. R. M. Robinson for bringing this specimen to my attention. Dr. D. J. Schmidly and Andrew V. Sipocz provided helpful reviews of the manuscript. This paper represents contribution number TA-24256 of the Texas Agricultural Experiment Station.

Literature Cited

Barbour, R. W., and W. H. Davis. 1969. Bats of America. Univ. Press Kentucky, Lexington, 286 pp.

Borell, A. E. 1939. A colony of rare free-tailed bats. J. Mamm., 20:65-68.

Constantine, D. G. 1961. Locality records and notes on western bats. J. Mamm., 42:404-405.

Easterla, D. A. 1972. A diurnal colony of big freetail bats, *Tadarida macrotis* (Gray), in Chihuahua, Mexico. Amer. Midland Nat., 88:468-470.

———. 1973. Ecology of the 18 species of Chiroptera at Big Bend National Park, Texas. Northwest Missouri State Univ. Stud., 34(2-3):1-165.

LaVal, R. K. 1973. Occurrence, ecological distribution, and relative abundance of bats in McKittrick Canyon, Culberson County, Texas. Southwestern Nat., 17:357-364.

Raun, G. G. 1961. The big free-tailed bat in southern Texas. J. Mamm., 42:253.

Schmidly, D. J. 1989. The bats of Texas. Texas A&M Univ. Press, College Station, in press.

THE NORTHERN PYGMY MOUSE, *BAIOMYS TAYLORI*, ON THE TEXAS LLANO ESTACADO

J. Knox Jones, Jr., and Richard W. Manning
The Museum and Department of Biological Sciences, Texas Tech University, Lubbock, Texas 79409

The northern pygmy mouse, *Baiomys taylori*, originally was described by Thomas (1887) from San Diego, Duval Co., Texas. Since that time, the species has dispersed both northward and westward in the state. Pitts and Smolen (1989) recently summarized the distributional status of this mouse in Texas, listing the westernmost localities of record (north to south) as follows: 9 mi. E Lutie, Collingsworth County, on the Rolling Plains in the southeastern part of the Panhandle (Hollander et al., 1987*a*); Buffalo Spring Lake, 4 mi. S and 7 mi. E Lubbock, Lubbock County, in Yellowhouse Canyon at the foot of the Llano Estacado (Stangl et al., 1983); and 3 mi. S Eldorado, Schleicher County, on the western part of the Edwards Plateau (Hollander et al., 1987*b*).

On 22 October 1988, we trapped an adult female pygmy mouse along a grassy-weedy fencerow, with some *Acacia, Yucca*, and mesquite, bordering a pasture 5 mi. ENE Key, Dawson Co., Texas, approximately 100 yards west of the scarp of the Llano Estacado, and the westernmost locality from which the species has been recorded in the state. The following day, we took seven more *Baiomys* about half a mile northwest of the break of Llano at a place 3.5 mi. N and 8.5 mi. W Gail, Borden County. These individuals were trapped in fencerows on either side of FM 1054 in good grassy cover—principally side oats grama, blue grama, and Johnson grass—along with an occasional mesquite bush; the fence separated rangeland from the right-of-way of the farm road. All specimens have been deposited in the collection of The Museum, Texas Tech University (TTU 53332-39).

That *B. taylori* has reached the eastern edge of the High Plains proper is not particularly surprising because much of the area immediately to the east is devoted to cattle grazing, and rangeland continues up the relatively gentle breaks of the Llano in Borden and Dawson counties to at least a fringe atop the scarp. Continued dispersal from that point could be difficult owing to the virtual monoculture of cotton on the High Plains and the acute farming practices attendant thereto. With the advent of the Conservation Reserve Program, however, future dispersal on the Llano Estacado may be possible, even probable in some areas.

Literature Cited

Hollander, R. R., J. K. Jones, Jr., R. W. Manning, and C. Jones. 1987*a*. Noteworthy records of mammals from the Texas Panhandle. Texas J. Sci., 39:97-102.

Hollander, R. R., C. Jones, R. W. Manning, and J. K. Jones, Jr. 1987*b*. Distributional notes on some mammals from the Edwards Plateau and adjacent areas of south-central Texas. Occas. Papers Mus., Texas Tech Univ., 110:1-10.

Pitts, R. M., and M. J. Smolen. 1989. Status of *Baiomys taylori* in Texas, with new localities of record in the southern part of the state. Texas J. Sci., 41:85-88.

Stangl, F. B., Jr., B. F. Koop, and C. S. Hood. 1983. Occurrence of Baiomys taylori (Rodentia: Cricetidae) on the Texas High Plains. Occas. Papers Mus., Texas Tech Univ., 85:1-4.

Thomas, O. 1887. Diagnosis of a new species of *Hesperomys* from North America. Ann. Mag. Nat. Hist., ser. 5, 19:66.

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Jones, T. L. 1971. Vegetational patterns in the Guadelupe Mountains, Texas. Amer. J. Bot., 76:266-278.

———. 1975. An introduction to the study of plants. John Wiley and Sons, New York, xx+386 pp.

Jones, T. L., A. L. Bain, and E. C. Burns. 1976. Grasses of Texas. Pp. 205-265, *in* Native grasses of North America (R. R. Dunn, ed.), Univ. Texas Studies, 205:xx+1-630.

Smith, J. D. 1973. Geographic variation in the Seminole bat, *Lasiurus seminolus*. J. Mamm., 54:25-38.

Smith, J. D., and G. L. Davis. 1985. Bats of the Yucatan Peninsula. Occas. Papers Mus., Texas Tech Univ., 97:1-36.

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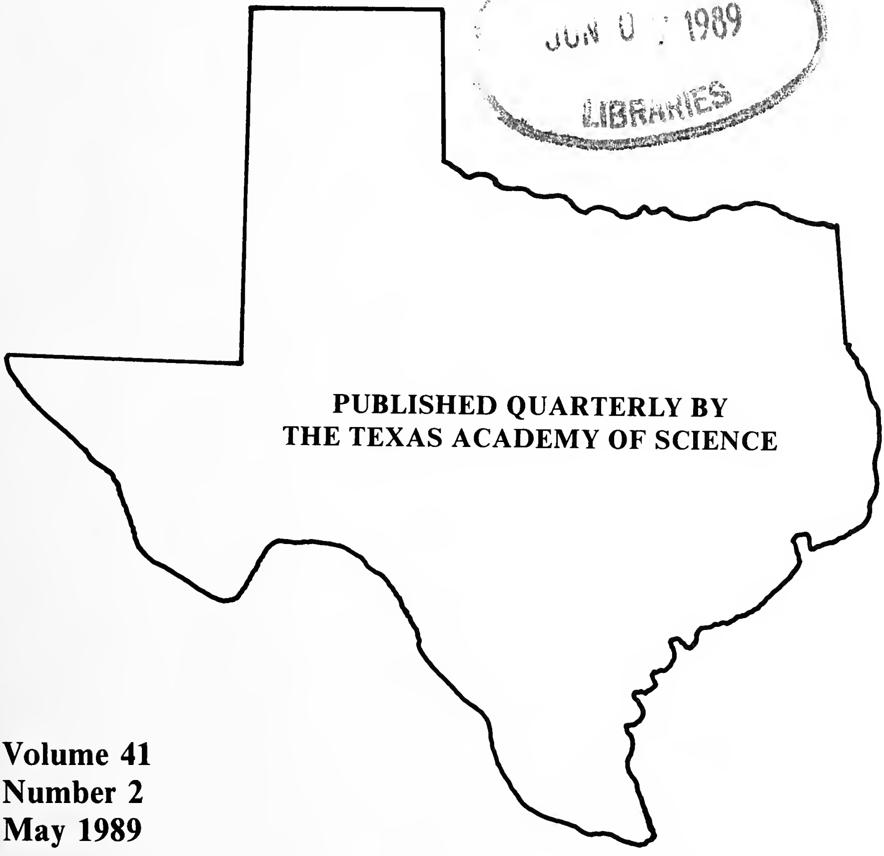

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ASPECTS OF THE BIOLOGY OF THE CONCHO WATERSNAKE (*NERODIA HARTERI PAUCIMACULATA*)

Francis L. Rose
Department of Biological Sciences, Texas Tech University, Lubbock, Texas 79409

Abstract.—Concho watersnakes (*Nerodia harteri paucimaculata*) were found in the Colorado River from FM road 3115 in Runnels County to Sulphur Springs, San Saba County, and the Concho River downstream from San Angelo to the confluence with the Colorado River. No Concho watersnakes were observed in the San Saba and Llano rivers. Mean body length of adults was less than 400 mm and snakes rarely exceeded 500 mm. Follicle number increased with body length: the mean was 14.5. The sex ratio was essentially equal. Snakes were found clearly associated with riffles and rocky shoals, frequently being found under rocks. They fed on minnows that inhabited the riffles, although captive individuals fed on a variety of organisms. These snakes are thought to hibernate away from the riffles in the interstital spaces under the river banks. *Key words*: watersnake; habitat; range; feeding; follicles; ecology.

Trapido (1941) described *Nerodia* (=*Natrix*) *harteri* from a series of 23 specimens collected by Mr. Phillip Harter along the Brazos River in Palo Pinto, County, Texas. Correspondence with Mr. Harter indicated that the new taxon was the most common "...watersnake in rocky habitat along the Brazos River." The snake now is known to inhabit a limited segment of the Brazos River and its tributaries from near Lueders, Jones County, to Somervell County (Flury and Maxwell, 1981).

Marr (1944) reported two specimens from the South Fork of the Concho River near Cristoval, Tom Green County. This was the first record of the snake in the Colorado River drainage. Tinkle and Conant (1961) remarked that Mr. Floyd Potter had collected a specimen in Dove Creek (Tom Green County) and noted that the snake was abundant in the upper Colorado River at Robert Lee, Coke County. Tinkle and Conant, noting differences in meristic characters, color, and ventral pattern, recognized the Colorado River drainage population as a distinct subspecies, *N. h. paucimaculata.*

William (1969) studied a population at Robert Lee along a 1000-meter stretch of the Colorado River. During his one-year study, he estimated the population to be composed of 52 adults (sex ratio 1:1). This population, however, was extirpated within two years after the construction of the E. V. Spence dam and reservoir immediately upstream of the study site (Williams, personal communication).

Aside from the study by Williams (1969) and the comments in Tinkle and Conant (1961), little has been written about this fascinating watersnake. Baker et al. (1972) described its karyotype and Lawson (1987), using protein electrophoresis, ascertained that its closest relative was probably *N. sipedon.* Conant (1943) had allied *N. harteri* with the *sipedon* group and suggested that its closest relative was *Clonophis* (=*Natrix*) *kirtlandi.*

Extirpation of the population at Robert Lee following dam construction and the proposed construction of the Stacy reservoir several miles below the confluence of the Concho and Colorado rivers generated concern regarding the continued survival of the Colorado River drainage populations. Flury and Maxwell (1981) made surveys of the Colorado River drainage. In addition, surveys were made by Scott and Fitzgerald (1985). Whereas the geographic range of the Concho watersnake now is well known, almost nothing has been published regarding its general biology. In September 1986, *N. h. paucimaculata* was placed on the Federal list as Threatened.

METHODS

Various segments of the research reported here were conducted as independent blocks. This was done to avoid reworking areas and including the same snake multiple times in analyses. I did not have permission (State) to mark individuals. To report sex ratios as the sum of all captures might bias the results because some of the sites were visited eight to 10 times and others, only once.

Surveys

Various segments of the Colorado and Concho rivers were surveyed (Fig. 1) for watersnakes from 1984 to 1986 with two objectives: 1) to ascertain the geographic range of *N. h. paucimaculata*, and 2) to determine if various portions of the river basins had higher concentrations of these snakes. Searches also were conducted in the San Saba and Llano rivers from their confluence with the Colorado River to their origins. To estimate population sizes in different river segments, the Colorado River was divided into four segments: 1) Hwy. 277 (Coke County) to Ballinger (Hwy. 83); 2) Ballinger to the confluence of the Concho River; 3) confluence to Stacy crossing (Hwy. 503); and 4) the Stacy crossing to Hwy. 283. The Concho River was divided likewise into four segments: 1) Hwy. 381 (Concho County) to Paint Rock; 2) Paint Rock to the community of Concho; 3) Concho community to the Tickle crossing (Hwy. 1928); and 4) Tickle crossing to the confluence of the Colorado River.

Body Size

Body lengths—[snout-vent distance is used throughout and is presented as the mean ± SD (range)]—were taken on 77 individuals found in the Colorado and Concho rivers between Paint Rock and the Stacy crossing in June and July 1985. In addition, 58 preserved specimens collected in the Colorado River in the 1960s, and deposited in the Texas Tech University herpetological collection, were measured. Data from snakes less than 225 mm body length were not included in the analyses. Body lengths were determined with a wooden rule.

Follicle Number

Williams (1969) reported on the follicle number of 20 adult Concho watersnakes taken during June from below his study site. I extrapolated body length and follicle number data from his figure 8. In addition, new data on follicle number were available from 12 females that were salvaged: killed in minnow traps or by fishermen. I counted only follicles that were five millimeters or larger in diameter. Follicles were measured with vernier calipers.

Data were subjected to a regression analysis with follicle number log transformed. Assuming that the slopes of the two data sets were equal, a comparison of intercepts (ANCOVA) was made.

Rock Size

Concho watersnakes were routinely found under rocks during daylight. Ninety-six rocks under which snakes were found on the Concho River from Paint Rock to the Tickle crossing in 1985 and 1986 were measured. Twelve rocks sheltered more than one snake. The short and long axes of each rock were determined to the nearest centimeter and each rock was marked with red food dye. Thirty-seven of the rocks were revisited after approximately two weeks to evaluate whether particular rocks were reused by the snakes.

Sex Ratios

Sex was determined for the 108 snakes collected at the time that rock size was ascertained. Enlarged tail base, penal extrusion, or probing of the penal invagination were used to confirm sex.

In-Stream Distance from Riffles

Riffles are shallow extensions across a stream bed where the bedrock is higher than it is immediately upstream. During much of the year, water flow is interrupted as it cascades through the shallows. Concho watersnakes often are closely associated with these riffles. Although is is sometimes difficult to determine the limits of a riffle, a choice was made visually and stakes were used as markers. Each snake's distance within or outside the riffle was measured with an extension tape to the nearest 10 centimeters. This work was done between 1000 and 1600 hours during low water flow.

Distance From Water

The distance of 101 snakes was marked from the nearest water, flowing or static, with a minimum depth of one centimeter. Snakes for this study were found in the Concho River between the entrance of Fuzzy Creek to the Tickle crossing and on the Colorado River from the confluence of the Concho River to below the Stacy crossing. This work also was done between 1000 and 1600 hours during low water flow.

Basking Height and Pool Depth

The distance of basking snakes above the water surface as well as the depth of the water below the basking site was determined.

Water Depth for Feeding

Concho watersnakes with a body length of more than 325 mm (N=23) were considered adults; those more than 225 mm but less than 325 mm (N=29) were considered subadults; juveniles (N=20) were obvious young-of-the-year, less than 225 mm in length. These size classes are arbitrary as there are no data regarding size and reproductive status. Adults and subadults judged to be feeding were observed throughout the study period; however, juveniles were observed only between 17 August and 15 September. When a snake was determined to be foraging, its position was marked and the depth of the water was measured to the nearest centimeter with a wooden rule.

Food Items

When a snake was found with an abdominal bulge, it was manipulated so as to regurgitate the item(s) by gently rubbing its venter. All items were stored in 10 percent formalin.

RESULTS

Surveys

No Concho watersnakes were found in the E. V. Spence basin (about 10 man-hours) and none was found in the Colorado River in Coke County. Four Concho watersnakes were found between Farm to Market (FM) road 3115 and Hwy. 83 at Ballinger, Runnels County (see Fig. 1); seven between Ballinger and the confluence of the Concho River; 31 between the confluence and the Stacy crossing (Hwy. 503); and, 22 from the Stacy crossing to Hwy. 283. On other occasions, snakes were found sporadically downstream at Winchell, Brown County (two snakes); near the entrance of Bull and Little Bull creeks southwest of Rockwood, Coleman County (two snakes); down to Bend (two snakes); and Sulphur Springs, in San Saba County (three snakes). Three trips were made to Bend and on two of these no snakes were found after extensive searching. On the third trip, a second snake was found within two minutes after the first snake was captured. This pattern was repeated at several localities throughout the study—long searches with two or more snakes being found under the same rock or adjacent rocks.

A single dead Concho watersnake was found in Elm Creek approximately two miles north of Ballinger. It was found under a rock after a sudden cold front in 1986. I was told by J. Johnson (USFWS) that snakes had been found in Elm and Coyote creeks by Colorado River Municipal Water District (CRMWD) personnel. Earlier searches by me in Elm and Coyote creeks had produced no snakes. No Concho watersnakes were found in Brady Creek.

On the Concho River, no snakes were found west of Hwy. 381 (Concho County). Nine snakes were found from that crossing to Paint Rock, 37 from Paint Rock to the Concho community, 29 from Concho to the Tickle crossing (Hwy. 1929), and 39 Concho watersnakes were found from the Tickle crossing to the confluence with the Colorado River.

A single specimen (TTU 11300) was found (dead) in a minnow trap at the Hwy. 915 crossing of Spring Creek near the town of Mertzon, Irion County. Although previously known from Dove Creek and the South Concho River in Tom Green County (Marr, 1944; Tinkel and Conant, 1961), I found no Concho watersnakes there, nor in the Middle Concho River. Flury and Maxwell (1981) and Scott and Fitzgerald (1985) found no Concho watersnakes in any of the drainages entering Twin Buttes Reservoir. This suggests that in this area population levels of this snake are exceptionally low or that the snake now is extirpated there.

Body Length

Concho watersnakes are the smallest of the three congeners inhabiting the Colorado River system. Rarely did I observe a Concho watersnake of

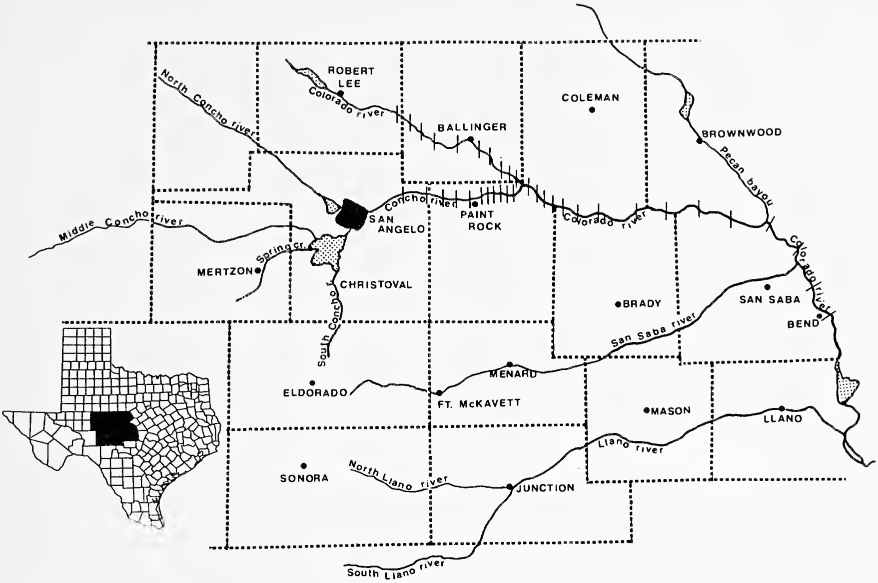

FIGURE 1. Map of Coke County, Texas, showing location of place-names mentioned in text.

more than 500 mm in body length. Mean body length (mm), followed by one standard deviation and range in parenthesis, of the 81 individuals measured in June and July was 315 ± 3.5 (260-470). This is less than values of 392 ± 7.5 (260-580) for 58 individuals measured in the Texas Tech University collection. Because the latter animals were preserved, their body lengths were undoubtedly shortened by preservation. The 12 females used for follicle analysis had corresponding values of 477 ± 59 (375-575). The clear separation in body lengths observed by Williams (1969) between adults and yearlings was not evident, primarily because of the small number of animals that exceeded 500 mm in body length.

Follicle Number

The mean number of follicles, standard deviation, and range was 14.5 ± 4.3 (7-24). There was a significant regression (Fig. 2) between body length and follicle number ($y = 0.4259 + 0.0015x$; $R^2 = 0.42$; $P = <0.05$). The mean of William's data was 18.6 ± 5.3 (9-29). There was a positive regression between body size and follicle number ($y = 0.6788 + 0.0012x$; $R^2 = 0.59$; $P = <0.05$). Significant differences in log of follicle number for fixed body sizes between my data and those of Williams (1969) were obtained from a comparison of intercepts ($b_R = 0.520$, $b_W = 0.649$; $t = 3.61$, $P = 0.001$).

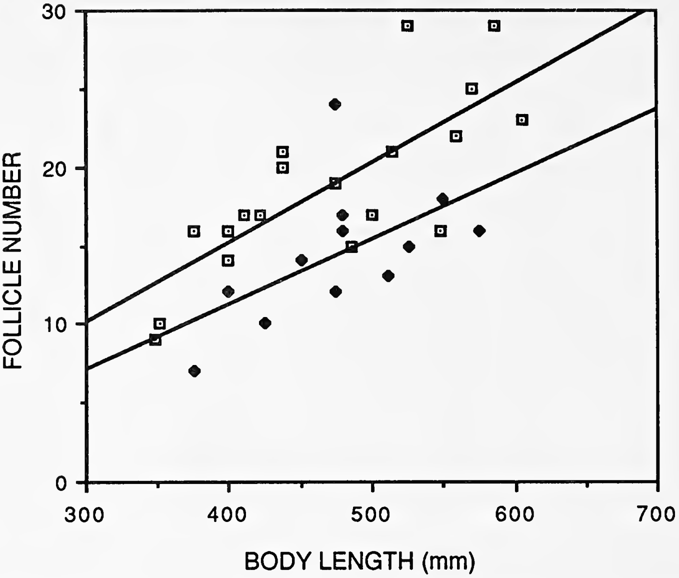

FIGURE 2. The relationship between body length and number of follicles for female Concho watersnakes. Boxes indicate data points extrapolated from Williams (1969); diamonds indicate data collected in this study.

Rock Size

Throughout the study period, a majority of Concho watersnakes was found beneath rocks near riffles. The preferred resting site appeared to be under a flattened rock, resting upon smaller rocks that were imbedded in a sandy-gravel substrate. During dry spells, in habitats where silt dominated, snakes and their body impressions were found under rocks and trash, such as discarded automobile tires. The shape and condition of the body impressions indicated that the snakes had been under the rock or debris for an extended period. Young-of-the-year were most frequently found under small rocks. Larger snakes tended to be under large rocks. Heads of Concho watersnakes were seen frequently, especially at night, protruding from the water from under rocks too large to move.

Of the 96 rocks under which snakes were found, 37 were investigated approximately two weeks after the original search. Only four (11 percent) of the rocks sheltered Concho watersnakes. Snakes were found on three separate occasions under an aluminum boat that had been pulled onto a gravel bar the previous afternoon.

When snakes were located under a rock, they frequently remained motionless, if the rock was away from water. If at the waters edge, however, they frequently bolted to the water. Only rarely did they attempt to escape into an opening that was under the original rock. Once

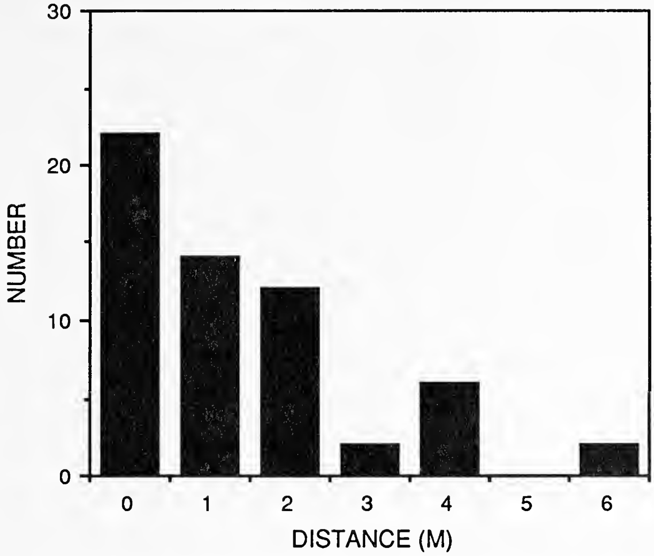

FIGURE 3. In-stream distance from a riffle and point of capture or observation of Concho watersnakes.

in the water, they usually swam a short distance at right angles to the current, then turned into the current. They exhibited great ease in navigating swift flows. If the water flow was slow or a pool was nearby, the snake frequently would cross the water to the opposite bank. On cool, overcast days, or in early morning, snakes tended to remain stationary when the rock was removed.

Sex Ratios

The 108 Concho watersnakes observed when rock size was determined had a sex ratio that was essentially equal (51 males:57 females). Williams (1969) also found a one-to-one sex ratio for the population at Robert Lee. In late August through September, more adult males than females were noted.

In-Stream Distance From Riffles

Of the 58 Concho watersnakes, 36 (62 percent) were observed within one meter of a riffle (Fig. 3). Only two snakes were observed well away from a riffle: one of these was basking and one was under a flattened rock that leaned against the bank at an angle of 15 degrees. A much larger Concho watersnake and a young *Nerodia erythrogaster* were observed under this rock two months earlier. The remaining 20 Concho

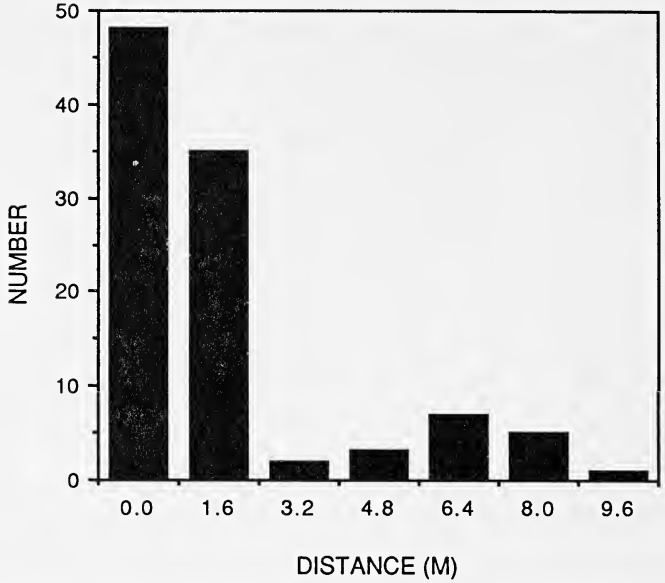

FIGURE 4. Distance from water and the point of capture or observation for Concho watersnakes.

watersnakes were found up to four meters from a riffle but were associated with the rocky habitat leading up to or away from a riffle.

Distance From Water

Eighty-two percent of the 101 Concho watersnakes observed were in water, over water, or within two meters of water (Fig. 4). No snakes were found farther than 10 meters from water (mean distance was 1.5 ± 2.3 (0-9) meters.

Basking Height

Of 59 observations on basking Concho watersnakes, only four were made away from riffle areas. Exposed roots, overhanging vegetation, and fallen trees were the most frequently used sites. Rocks were not used, nor were sites that were higher than two meters above the water surface. In fact, 78 percent of the snakes observed basking were less than one meter from the water surface. The mean distance was 0.87 ± 0.34 (0.15-2.1) meters. At the Tickle crossing on the Concho River, Concho watersnakes were observed frequently in the afternoon basking on the metal conduit edges on the downstream side of the road. This was one of the few sites, however, where snakes could be found basking routinely.

All Concho watersnakes basked over water. Water depth below the basking sites varied from 0.1 to 0.9 meter. Generally, when a snake was disturbed while basking, it plummeted into the water. If the bank was undercut the snake disappeared under the overhang. If undercut banks were not present, the snake would disappear underwater and resurface within two minutes either moving directly away from the observer or moving along the waters edge. Frequently a snake would enter an area where it placed itself at risk of capture, for example, in shallow, clear water. Snakes escaping under banks did not emerge in less than five minutes.

Feeding

Concho watersnakes generally feed in the morning and early afternoon. In riffles, the snakes moved along and among the rocks, probing with their head. If the snake was successful in capturing a fish, its body suddenly jerked and the snake moved backward wedging itself in the rocks for support. Snakes swallowed small food items under water; larger items were brought to the edge of the water. On sandy substrates (in pools) snakes moved along the bottom with the body in large, "S"-shaped curves, the head usually pointing upstream. Minnows darting away from the approaching snake readily settled into its body curves. The hunting snake apparently located these minnows by a thigmotaxic response. Minnows were swallowed rapidly (usually in less than a minute) and I saw one snake capture and swallow three minnows in less than four minutes. Snakes presumed to be feeding were frequently observed moving about at night. During high water, they were seen moving upstream, near the bank, but they did not appear to be feeding.

Concho watersnakes routinely were captured (and usually drowned) in minnow traps set by fishermen. In addition, I saw young snakes come upstream and feed on dead minnows placed at the edge of the water. This suggests that some of there feeding behavior is governed by olfactory cues.

Only 18 individuals were found with food items in their stomachs; 16 of these were under rocks and one was basking. One snake regurgitated three minnows (all *Notropis lutrensis*); eight regurgitated two *Notropis* sp.; six, a single *Notropis* sp.; one, a *Hybopsis* sp.; and two (juvenile snakes) *Gambusia affinis*.

In captivity, Concho watersnakes fed on a variety of minnows including *Notropis lutrensis, Pimephales* sp., *Hybognathus plicata, Ictalurus punctatus*, and *Carassius auratus*. When fish were not an option, they took *Rana blairi* tadpoles, and hellgrammites that had their mandibles removed. They did not eat dead tadpoles although they took dead minnows. Young snakes were coaxed to take *Acris crepitans*. Opportunistic piscivory best describes the feeding habits of the Concho watersnake.

It was difficult to determine the maximum water depth of a feeding snake because it becomes more difficult to observe snakes as the water

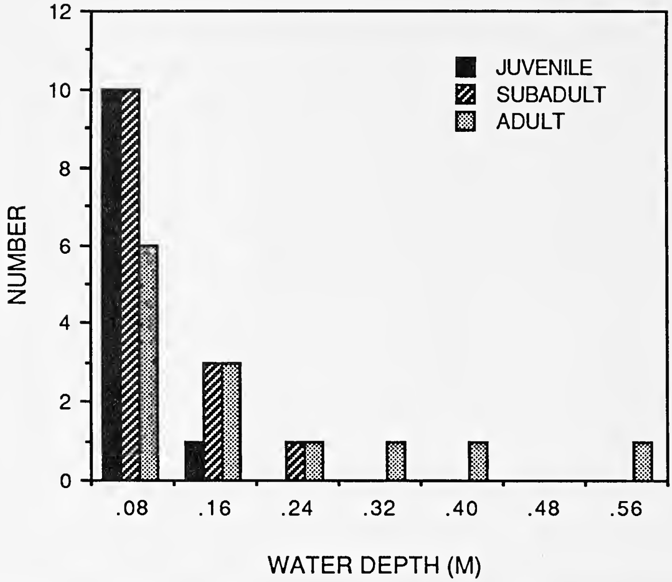

FIGURE 5. Water depth at which adult, subadult, and juvenile Concho watersnakes (N=38) were observed feeding.

depth increases. Also, smaller snakes were less visible than larger individuals. A clear plastic container placed on the water surface eliminated glare but this was rarely unnoticed by the snake. In addition, the plastic container was useful only after a snake was observed in deep water. Sixty-nine percent of all adult snakes (more than 325 mm in body length), 93 percent of the subadults (more than 225 mm and less than 325 mm), and 100 percent of the young-of-the-year (less than 225 mm), were observed feeding at depths less than 0.2 meter. Results pictured in Fig. 5 suggest that the Concho watersnake utilized riffle and shallow water habitats as foraging sites for all size classes.

Hibernacula

I could find no snakes in the Colorado and Concho rivers after 15 November. Williams (1969) suggested that the snakes used burrows that permeated the banks along pools. This suggestion seems likely as the snakes abandoned the riffle areas and the options are limited. On two occasions in late March I saw two Concho watersnakes resting near an opening in the bank along the north wall of the Concho River near the community of Concho. Both snakes on each occasion moved into the burrow that was about 15 centimeters from the water surface. The snakes were adults. Although they were watched for more than 15 minutes of each observation, no courtship behavior was noted. Perhaps they had recently emerged from their winter hibernaculum.

Congeners

Nerodia rhombifera and *Nerodia erythrogaster transversa* are common throughout the range of the Concho watersnake, as is *Thamnophis proximus rubrilineatus.* Young of the two congeners frequently are found under rocks associated with riffles. In fact, on occasion, I observed all three species under the same rock. In optimum habitat, the Concho watersnake is the most common snake. In the Concho River from Paint Rock to the Tickle crossing, 98 snakes were observed on one survey: 60 of these were Concho watersnakes; 18 *N. rhombifera*; 12 *N. erythrogaster*; and eight *Thamnophis proximus.* This does not include six *N. rhombifera* and two *N. erythrogaster* adults that were observed moving about after dark. Although Williams (1969) stated that there was no interspecific competition for food between the Concho watersnake and the other natricines, he was generally addressing adults. Young of all three congeners utilize the riffle habitat and probably share the same food sources.

Discussion

I found the distribution of the Concho watersnake in the upper Colorado River drainages as approximately that described by Flury and Maxwell (1981). More recent surveys by Colorado River Municipal Water District personnel revealed Concho watersnakes in E. V. Spence reservoir. This is surprising even in view of the occurrence of a small population in Possum Kingdom Reservoir on the Brazos River. Snakes occur in these two reservoirs along wave-washed, rocky shores that are reminiscent of rocky shoals in the river beds. Further work by the CRMWD personnel will greatly enhance our knowledge about the distribution of the Concho watersnake.

It was impractical for me to standardize time and distance covered in making surveys for the snakes. A boat was used to survey the river between Robert Lee and Ballinger. There are approximately 25 riffles in this section of the river with long stretches between riffles. The river course from Paint Rock to the community of Concho is shorter and the distance between riffles is less; thus, more time might be spent searching. An hour searching at high water was not equivalent to an hour of searching at low water. Differences in snake numbers per river segment more properly reflect habitat quality.

The greatest number of Concho watersnakes was found in the Concho River, especially from Paint Rock to the confluence of the Colorado River, and down the Colorado River to about two miles below the Stacy crossing. Below this point, the pools between rocky shoals are quite deep and long. All of the snakes that I found from this point to Bend and Sulphur Springs were young snakes, less than 300 mm in body length.

No Concho watersnakes have been found in the San Saba River even though its confluence with the Colorado River is well within the range of this species. Riffles and rocky shoals that sustain large populations of riffle minnows are commonplace on the San Saba River. One apparent difference is that the bed of the San Saba River is washed of most of the interstitial matrix that supports the cover rocks on the Concho River. Perhaps the under-rock microhabitat (so prevalent on the Concho River) is not adequate to sustain populations of this snake on the San Saba. The larger flood pulses in the San Saba River also might be a contributing factor.

The Concho watersnake is one of the smallest of the *Nerodia* in North America. Mecham (1982) noted that the species rarely exceeds 900 mm. Based on Williams' (1969) data, the average-sized adult seems to be less than 600 mm; I found only a few snakes that exceeded 600 mm body length and most did not exceed 400 mm. The congruity of the body length data from preserved individuals collected in the 1960s with my data confirm that the Concho watersnake is indeed small.

The positive correlation between increased body length and fecundity in snakes is well documented (see Siegel and Ford, 1987). Williams (1969) noted that Concho watersnakes longer than 500 mm produced a mean of 20 ± 1.34 (mean ± standard deviation) follicles; those less than 500 mm long produced a mean of 17 ± 1.27. The ANCOVA confirmed that the number of follicles I observed per female was significantly less than that reported by Williams for a given body length. The degree of difference noted probably is well within the annual degree of variation expected. In addition, Williams did not specify his cutoff point regarding the minimum size follicle counted. McCallion (1944) received two adult female *N. h. harteri* from Phillip Harter: one was 798 mm long (this is assumed to be snout-vent length), the other 753 mm. Both snakes died, the larger one contained 16 embryos. The smaller snake extruded one dead snake, then died. She was found to have 22 near-term embryos between 174 to 216 mm in length. The number of developing embryos in these two snakes is less than the projected number based on female size; however, one would expect attrition during development. In fact, caution should be exercised in using follicle number to estimate production.

Concho watersnakes appear to be strongly associated with rocky shoals and riffles. Flattened rocks serve as resting sites that provide protection from predators and provide thermal shields. Snakes seem to select rocks that provide some moisture through moist gravel and sand. Microhabitat probably allows the snake to rest at relatively high humidity but the skin is allowed to dry. This appears to be important, because snakes maintained in moist conditions developed life-threatening integumetal infections; both of the females maintained by McCallion (1944), died, one with a respiratory infection.

Within the size range of movable rocks, small snakes selected small rocks for refugia. In gravel piles, they were occasionally found under rocks less than seven centimeters in diameter. When found under larger rocks, the rocks had small interstitial spaces suggesting a thigmotaxic response. Routinely, when small snakes were found under larger rocks, small, flat rocks were not available.

Concho watersnakes were found under only four of 37 rocks that sheltered snakes two weeks previously. This suggests that there are numerous rocks or other microhabits serving this need. The snakes use a wide array of flat rocks. The perceived tendency of small snakes to use small rocks might reflect a thigmotaxic response. Clearly, brush piles were not used as refugia. In another study, sites were visited periodically and observed snakes were diminished from them within three visits, three days apart. If the visitation intervals were seven days apart, no diminution of snake numbers was noted. At some sites, Rose and Scioli (unpublished data) found that the presence of snakes followed a Poisson distribution and that one would expect to find no snakes at those sites 30 percent of the times. Other sites yielded snakes on each visit, provided time between visits was sufficient.

Because the vast majority of Concho watersnakes are found under rocks, it appears that this habitat characteristic is necessary for high densities observed at these sites. Snakes might occur in the intervening areas between riffles and in habitats lacking a rocky substrate, but in my experience, their densities are low in such situations.

Eighty-three percent of the Concho watersnakes in the in-stream distance study were within three meters of a riffle. Eighty-two percent were within two meters of water. Although no data are available, the Concho watersnake appears to desiccate rapidly in captivity and this physiological parameter might play an important role in limiting movements on land; however, general feeding habits might provide a behavioral barrier to overland dispersal. The degree to which Concho watersnakes disperse between riffles is unknown. One might suppose that as the distance between riffles increases, dispersal would decrease, that is, site fidelity would increase. The large flood pulses in the rivers certainly would disrupt, if only temporarily, associations with riffles. Snakes seeking refuge in floating trees and debris would be washed downstream, perhaps for great distances. The perceived stability of the riffle populations after floods, in regards snake numbers, suggests that most snakes seek refuge in habitat adjacent to the river bed. It is conceivable, however, that many snakes are swept downstream to less favorable habitats. Movements of snakes after violent flood pulses were not investigated by me.

The degree to which Concho watersnakes utilize adjacent riffles, and subsequently intervening pools, is not known. If my experiences are reflective, males tend to range farther than females. Perhaps females will be found to be more sedentary because of their thermal requirements during pregnancy; thus, when their thermal and feeding needs are met, they tend to remain in that environment. Captive Concho watersnakes that were pregnant remained near a heating coil and moved about less than males.

Basking is a critical behavior to many watersnakes. This might be true especially for pregnant females. The mean basking height for the 50 Concho watersnakes was less than one meter, yet higher sites were frequently available. *Nerodia rhombifera* and *N. erythrogaster* occasionally would exit the water and climb into a tree and descend on a branch over water to bask. On two occasions, *N. rhombifera* was found basking on limbs in excess of three meters above the water. Concho watersnakes basking at heights above 1.2 meters generally did so in trees that had fallen into the water or were on root stumps of overturned trees.

All Concho watersnakes observed basking were over water. The actual depth of the water does not appear to be a mitigating factor in selecting a site. In shallow, clear water, the snakes appeared to utilize predetermined escape routes, usually under the bank. In deeper water, they appeared to rely on the water for cover. More than 80 percent of the 59 observations of basking were associated with riffles, or were in pools within three meters from a riffle.

Feeding of all three size groups was concentrated in riffles. Eighty-seven percent of the Concho watersnakes observed feeding were in water less than 0.2 meter deep. Thirty-seven percent of the adults were observed feeding at water depths in excess of 0.2 meter, but in all cases these snakes were associated with riffles, usually in a parallel and lateral flowing channel.

Although Concho watersnakes are known to eat amphibians and other nonriffle dwelling fish in captivity, they appear to be more restricted in their food intake in their natural habitat. The association between this snake and riffles and shallow, rocky shoal areas is clear. In this habitat, the primary food sources are riffle-dwelling minnows and a myriad of invetebrates. It was impossible for me to ascertain the ultimate prey of a foraging snake and I suspect that invertebrates will be found to make up a significant portion of the diet of newborn snakes prior to their first hibernation.

The young of *N. rhombifera* and *N. erythrogaster* frequently are found associated with the riffle habitat and might share the same rock as a Concho watersnake. Young of these three species appear to be piscivorous, feeding on those minnows inhabiting the riffles. I never collected a *N. rhombifera* in excess of 40 centimeters under a rock in a riffle area. Two *N. erythrogaster* in excess of 40 centimeters were collected under rocks associated with riffles on the Colorado River (no

Concho watersnakes were found at this locality), but in general, these snakes were transients in the riffles. Large *Nerodia rhombifera* are known to feed primarily on large fish (Bowers, 1969; Plummer and Goy, 1984; Sisk and McCoy, 1964) associated with slow-flowing water and that is where this snake is frequently observed at night. Large *N. erythrogaster* are thought to feed primarily on frogs supplimented with fish (Mushinsky and Hebrard, 1977; Mushinsky and Lotz, 1980). I found few ranid frogs on the Colorado and Concho rivers. Perhaps large *N. erythrogaster* move out of the rivers and forage in the smaller tributaries and farm ponds where ranid frogs are more plentiful. Certainly this species is abundant around the numerous low water dams in the Concho River. Other than catfish, a single subadult *Bufo speciosus* was the only food item found in large *N. erythrogaster*. In essence, Concho watersnakes maintain a "juvenile" feeding behavior and *N. rhombifera* and *N. erythrogaster* undergo an ontogenetic food niche shift and leave the riffles. Both of these snakes become large, robust, and cruising predators but little is known of their feeding habits in the upper Colorado River drainages. *Thamnophis proximus* feeds on minnows (primarily *Gambusia*) associated with the shallow, rocky areas and on *Acris crepitans*. On one occasion, a large *T. proximus* was observed swimming rapidly on the water surface, catching and swallowing minnows breaking the surface in its path, without slowing its pace.

On one occasion an adult Concho watersnake was observed at night swimming into overhanging vegetation. A large *N. rhombifera* lunged from the vegetation and caught the Concho watersnakes. This encounter was interrupted by the observer and it is not known if the *N. rhombifera* would have swallowed the Concho watersnake. The encounter does, however, raise the possibility that larger congeners might occasionally prey on the Concho watersnake. Great blue herons were seen occasionally in the riffles. Although I never saw one of these birds catch a snake, they probably prey on young.

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Literature Cited

Baker, R. J., G. A. Mengden, and J. Bull. 1972. Karyotypic studies of thirty-eight species of North American snakes. Copeia, 1972:257-265.

Bowers, J. H. 1966. Food habits of the diamond-backed water snake, *Natrix rhombifera rhombifera* in Bowie and Red River counties, Texas. Herpetologica, 22:225-229.

Conant, R. 1943. Studies on North American water snakes—I. *Natrix kirtlandii* (Kennicott). Amer. Midland Nat., 29:313-341.

Flury, J. W., and T. C. Maxwell. 1981. Status and distribution of *Nerodia harteri paucimaculata*. Final Rept. to U.S. Fish Wildlife Serv., Albuquerque, New Mexico, 73 pp.

Lawson, R., 1987. Molecular studies of thamnophine snakes: 1. The phylogeny of the genus *Nerodia* J. Herpetology, 21:140-157.

Marr, J. C. 1944. Notes on reptiles and amphibians from the central United States. Amer. Midland Nat., 32:478-490.

McCallion, J. 1944. Notes on *Natrix harteri* in captivity. Copeia, 1944:63.

Mecham, J. S. 1982. *Nerodia harteri*. Catalogue of American Amphibians and Reptiles, 330:1-330.2.

Mushinsky, H. R., and J. J. Hebrard. 1977. Food partitioning by five species of water snakes in Louisiana. Herpetologica, 33:162-166.

Mushinsky, H. R., and K. H. Lotz. 1980. Chemoreceptive responses of two sympatric water snakes to extracts of commonly ingested prey species: ontogenetic and ecological considerations. J. Chem. Ecol, 6:523-535.

Plummer, M. V., and J. M. Goy. 1984. Ontogenetic dietary shifts of water snakes (*Nerodia rhombifera*) in a fish hatchery. Copeia, 1984:550-552.

Scott, N. J., and L. A. Fitzgerald. 1985. Status survey of *Nerodia harteri*, Brazos and Concho-Colorado rivers, Texas. Status Rept. to U.S. Fish Wildlife Serv., Albuquerque, New Mexico, 44 pp.

Seigel, R. A., and N. B. Ford. 1987. Reproductive ecology. Pp. 210-252, *in* Snakes. Ecology and evolutionary biology (R. A. Seigel, J. T. Collins, and S. S. Novak, eds.), Macmillan Publ. Co., 529 pp.

Sisk, M. E., and C. J. McCoy. 1964. Stomach contents of *Natrix r. rhombifera* (Reptilia:Serpentes) from an Oklahoma lake. Proc. Oklahoma. Acad. Sci., 44:68-71.

Tinkle, D. W., and R. Conant. 1961. The rediscovery of the water snake, *Natrix harteri*, in western Texas, with a description of a new subspecies. Southwestern, Nat., 6:33-44.

Trapido, H. 1941. A new species of *Natrix* from Texas. Amer. Midland Nat., 32:673-680.

Williams, N. R. 1969. Population ecology of *Natrix harteri*. Unpublished MS thesis, Texas Tech Univ., Lubbock, 51 pp.

EXPERIMENTAL MECHANICAL POLLEN DEGRADATION AND ITS APPLICATION TO QUATERNARY AGE DEPOSITS

Richard G. Holloway

Department of Social and Behavioral Sciences, Eastern New Mexico University, Portales, New Mexico 88130

Abstract.—The role of temperature and moisture fluctuations in the eventual preservation of fossil pollen assemblages was experimentally tested over a 50-day period. Both acetolyzed and unacetolyzed pollen were used in order to simulate the effects of fossilization upon the pollen exines of the taxa chosen for study. Fluctuating temperatures caused no demonstrable effects on the pollen exines, whereas moisture fluctuations were responsible for severe alterations of the assemblage, sometimes exceeding 80 percent. Much of the observed degradation by moisture may be attributed to the evaporative process. Further, a distinct color change occurred in the unacetylated pollen during the first 10 days of this experiment. This color change may be related to the temperature of evaporation that was used and thus is an artifact of the experimental design. The results of this experiment revealed the differential susceptibility of certain pollen grains to the effects of moisture fluctuations, and these data are examined in relation to the interpretation of fossil assemblages. *Key words*: pollen; degradation; mechanical; preservation; Quaternary.

Pollen analysis is predicated on the identification of pollen grains and spores to one of several taxonomic levels that are then used to interpret paleovegetation and, by inference, paleoclimates. An assumption inherent in all investigations requires the palynologist to draw these conclusions not from the pollen grains of the biocenose, but rather from the thanatocenose (Birks and Birks, 1980). Previous reports have indicated that certain types of environments of deposition, such as lakes and bogs, are more suitable for palynological investigations (Faegri and Iversen, 1975; Jacobson and Bradshaw, 1981) than are others, yet even in these deposits some deterioration of the pollen exine occurs.

Pollen exine preserves well in the fossil record because it is extremely resistant to destruction but, nonetheless, can be broken down or even completely destroyed under certain conditions. Loss of selected pollen taxa or entire pollen assemblages can have an enormous effect on the interpretation of a fossil pollen record; thus a thorough understanding of factors involved in the selective preservation and destruction of pollen exine is essential for accurate interpretations of fossil pollen data. In this study, I have concentrated on two aspects of mechanical agents of weathering: freezing-thawing and hydration-dehydration conditions. Mechanical deterioration of the pollen exine involves natural forces inherent in the weathering process. Weathering is initiated at anthesis and may typically be caused by collision or abrasion with other objects such as sand or clay particles (Polak et al., 1962; Bryant, 1978). External physical conditions such as temperature and moisture also are included within this category and form the basis of this investigation.

Little previous research has centered on the mechanical aspects of pollen exine degradation inasmuch as most studies have approached this as a secondary area of emphasis, or mention it only in passing (Polak et al., 1962). Other researchers have investigated the affects of certain soil environments on pollen exine degradation (Sangster and Dale, 1961, 1964; Havinga, 1971), but these studies usually were conducted in conjunction with investigations of the chemical and biological milieu as well and did not concentrate specifically on the mechanical agents of degradation.

Likewise, effects of temperature and moisture on pollen exine largely have been ignored, at least in terms of their application to paleopalynology. Available literature generally has concentrated on investigations dealing with low temperatures and their effects on pollen enzymes and pollen viability (for example, Farrant and Morris, 1973), which are not directly applicable to this study.

Experimental laboratory degradation of the pollen exine by high temperature and pressure recently has been investigated by Sengupta (1974, 1977), Sengupta and Rowley (1974), and Sengupta and Muir (1974). Gray and Boucot (1975) and Manum et al. (1976), have reported on the apparent color changes that accompany the high temperatures and pressures present during lithification of pre-Quaternary sediments. Gray and Boucot (1975) found that color changes in pollen exines accompanied metamorphogenesis of sediments and occurred earlier in pollen than in other organic-walled material. However, this color change does not appear to correlate with a specific temperature but rather with temperature ranges. In their study of thermal alteration of Tertiary material, Manum et al. (1976) suggested that "the effect of heat on palynomorphs as seen in preparations where no oxidation has been applied, is a general darkening" (Manum et al., 1976:123).

METHODS AND MATERIALS

Thirteen pollen taxa were used in this study and were obtained from the Hollister-Stier laboratory. These consisted of: (*Amaranthus palmeri* Wats., *Artemisia tridentata* Nutt., *Carya illinoensis* (Wang.) K. Koch., *Iva angustifolia* D. C., *Juniperus monosperma* (Englem). Sarg., *Picea pungens* Engelm., *Pinus edulis* Englem., *Populus alba* L., *Pseudotsuqa menziesii* (Mirb.) Franco., *Quercus virginiana* Miller., *Salix nigra* Marsh., *Typha angustifolia* L., *Typha latifolia* L., and *Zea mays* L. Only one species of *Typha* was used in any one pollen mixture in order to facilitate identification and to anticipate any degradation that might alter the morphological characters used in identification.

A representative mixture of the 13 pollen taxa was obtained by adding small amounts of fresh pollen of each taxon to a single vial. The resulting mixture was spot-checked by placing a drop of the mixture on a microscope slide and examining the pollen using 200X magnification. Additional pollen of weakly represented taxa were added to this mixture until each taxon was present in at least two percent frequency.

Half of this pollen mixture was acetylated, following Erdtman's (1960) method, whereas the remaining half was unaltered. In that way, I was able to approximate conditions of freshly deposited pollen (represented by the unacetylated samples) and pollen that previously had been incorporated into the sediment (acetylated samples) in each of the ensuing experiments.

Although mixtures were prepared separately for each of the experiments, procedures for the preparation of these mixtures were identical. Acetylated and unacetylated pollen samples were suspended in distilled water and placed in separate centrifuge tubes. Tubes were autoclaved to sterilize the sample and prevent contaminate biological growth, and small subsamples of the pollen mixture were removed and prepared for microscopic analyses. These samples were used as controls.

In the experiment testing the effects of temperature, pollen samples were subjected to 25 alternating temperature cycles of freezing and thawing with limited oxygen. During each cycle, the samples were placed in tightly capped centrifuge tubes for a period of 24 hours at room temperature (21°C) and then transferred to a freezer (−10°C) for an additional 24-hour period.

A different set of pollen samples was used to test the effects of moisture by subjecting them to 25 cycles of alternating wet and dry environments but this time with free access to oxygen. During each cycle, the centrifuge tubes were covered with NYTEX screen (15 μm mesh) and placed in a drying oven (30°C) for 24 hours while the autoclaved water evaporated. A small amount (five millimeters) of autoclaved distilled water than was added to each of the centrifuge tubes and these samples were rehydrated at room temperature (21°C) for an additional 24-hour period.

After the 25 cycles had been completed, both sets of samples were washed twice in 95 and 100 percent ETOH, transferred to 1000 cs silicon oil with Butanol, and examined using Transmitted Light Microscopy (TLM). Samples to be examined by Scanning Electron Microscopy (SEM) were stored in 100 percent ETOH and then critical-point dried using the method of Lewis and Nemanic (1973). Dried specimens were mounted on aluminum stubs, coated with gold palladium and examined using a JOEL JSM-U135 Scanning Electron Microscope.

Routine examination of the samples was completed at 400× magnification. Pollen grains first were assigned to the appropriate taxon and secondarily to one of four degradation categories modified from Cushing (1967). These categories were: 1) unaffected; 2) broken; 3) corroded; and 4) degraded. Grains that were intact yet crumpled or folded were assigned to the unaffected category because it was impossible to determine if the crumpling was a result of the experiments or of the dehydration procedure. In cases where grains exhibited more than one form of damage, they were counted as belonging to the more severely degraded category. Unaffected grains were defined as those having no observable form of deterioration. Broken grains included those in which the exine had ruptured. Included within this category were those exhibiting small tears as well as continuous splits along the surface. The phenomenon of "pitting," which appears as small punctures on the exine surface, was included within this category because structurally the pitting is a rupture of the exine.

Corroded and degraded grains are similar in the type of degradation exhibited. Corroded grains can be distinguished because they have a noticeable thinning of the exine surface so that the aperture is less distinct yet still intact. Degraded grains, on the other hand, show an advanced stage of deterioration in which the grains are severely thinned and in many cases remain only as ghost images with aperatures no longer distinct.

RESULTS

Effects of Temperature

Two separate analyses of the data were performed and the results are presented in tabular form. An initial scan of the control slides was made before the start of the experiment, and the first 25 grains encountered of each taxon were identified and recorded as to the type of degradation observed. Table 1 summarizes the percentage of degradation occurring to pollen of each of these taxa.

Prior to the 25 cycles of freezing and thawing temperatures the majority of the pollen types exhibited only minor (less than one percent) natural degradation before the start of the experiment. Exceptions were pollen of *Juniperus monosperma* and *Pseudotsuga menzieii*, which showed initial large percentages of degradation. However, almost all degradation of these two grain types can be assigned to type 2 (broken) and may be a function of their harmomegarthic effect. Alternatively, Duhoux (1982) has shown that rehydration of *Juniperus communis* pollen after maturation often is accompanied by exine rupture. This is interpreted as an adaptive feature common to taxoid pollen types. Thus, in my study the rupture may have occurred simply in response to rehydration. *Amaranthus palmeri, Carya illinoensis*, and *Salix niqra* pollen showed intermediate frequencies of degradation (one percent) and because most of this deterioration was of type 3 (corroded), it may be due to abortion of the grain during microsporogenesis.

After 25 cycles of alternating freezing and thawing temperatures, the percentages of deteriorated pollen in the unacetylated samples before and after the experiment were quite comparable. Acetylated samples likewise revealed close agreement between percentages of degradation observed before and after the cycles. Only pollen of *Populus alba* showed an increase in the percentage of degradation to any large extent. After the completion of these 25 cycles only 11.0 percent of the unacetylated pollen and 4.9 percent of the acetylated pollen showed any evidence of alteration in some form. These percentages are similar (8.8 percent and 5.6 percent) to those obtained at the beginning of the experiment. Due to the relatively small degree of deterioration occurring in this experiment, these data are not presented here. Those interested may obtain copies of the tables by contacting the author.

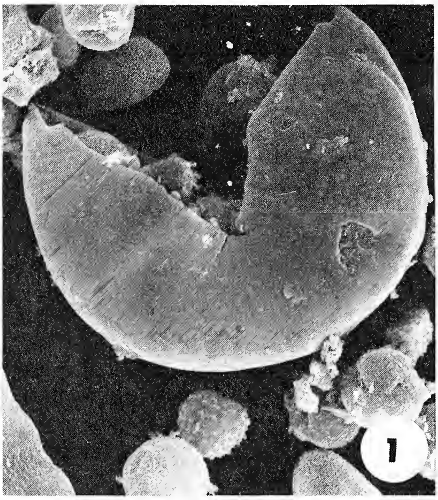
Coniferophyta pollen.—Pinus edulis pollen was generally well preserved except in a single case where a bladder had broken off and was missing. The other bisaccate pollen type, *Picea pungens*, also preserved extremely well. Other conifer type pollen as such as *Pseudotsuga menzieii* (Fig. 1) generally ruptured in one spot although in some cases the grains were so badly crumpled that the entire exine was marked by small tears or cracks. Likewise, *Juniperus monosperma* pollen almost always was found in a broken condition.

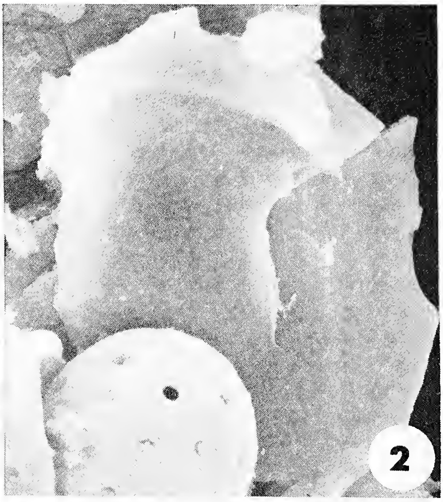
Magnoliophyta pollen.—Pollen of members of the Magnoliophyta all exhibited a wider variety of effects, none of which was severe. *Populus alba* (Fig. 3) and *Amaranthus palmeri* generally were crumpled and often exhibited a noticeable thinning of the exine. In many cases, especially

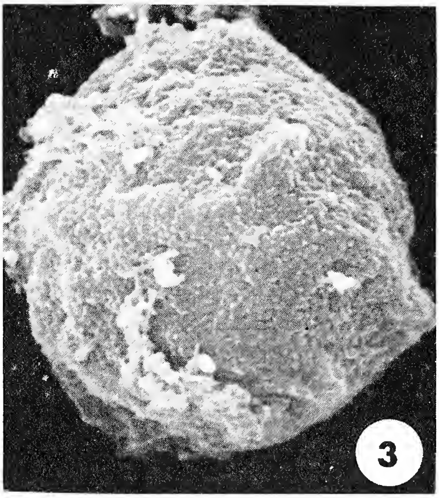
TABLE 1. Percentages of pollen degradation by taxa. A total of 25 grains was examined for each taxon.

	Amaranthus palmeri	*Artemisia tridentata*	*Carya illinoensis*	*Iva angustifolia*	*Juniperus monosperma*	*Picea pungens*	*Pinus edulis*	*Populus alba*	*Pseudotsuga menziesii*	*Quercus virginiana*	*Salix nigra*	*Typha* sp.	*Zea mays*
Freeze/thaw													
Acetylated													
0 cycles	20	8	28	0	76	4	0	8	92	0	12	0	40
50 cycles	16	0	28	0	88	12	0	48	96	4	8	0	72
Unacetylated													
0 cycles	16	4	8	0	88	0	0	8	52	0	24	0	12
50 cycles	12	0	16	4	96	0	8	8	92	8	28	4	12
Wet dry													
Unacetylated													
0 cycles	28	8	8	0	96	0	0	8	28	4	40	4	16
50 cycles	48	4	20	0	96	20	16	96	100	12	48	44	64
Acetylated													
0 cycles	4	0	40	0	72	4	0	28	84	8	20	4	12
50 cycles	88	32	56*	64*	100*	100*	93*	100	92	56	92	100	100

*=less than 25 grains covered







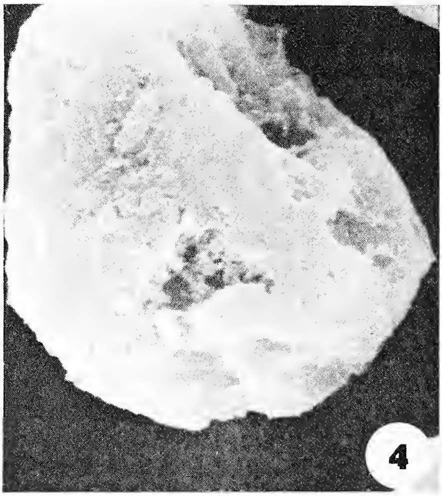


FIGURE 1. *Pseudotsuga manziesii* after 25 cycles of freezing and thawing temperatures. 413×
FIGURE 2. Fragment of *Pseudotsuga menziesii* grain at 25 cycles wetting and drying. 1050×
FIGURE 3. *Populus alba* pollen after 25 cycles freezing and thawing. 212×
FIGURE 4. *Populus alba* pollen after 25 cycles wetting and drying. 212×

with *Amaranthus palmeri* pollen, there was no evidence of destruction of the superficial morphological sculpturing. Pollen of *Artemisia tridentata, Iva angustifolia, Quercus virginiana, Carya illinoensis, Salix nigra*, and *Typha angustifolia*, all preserved well and appeared in almost pristine condition at the conclusion of the experiment. Pollen of *Zea mays* often was crumpled and broken.

Effects of Moisture

A major difference was noted between the acetylated and the unacetylated samples during this experiment. Unacetylated samples hydrated more or less completely during each cycle of the experiment, whereas the acetylated samples clumped into a compact pellet at the conclusion of the first dehydration. After the first rehydration the acetylated pollen was still clumped. No attempt was made to disperse this clump because of the unknown effects of using either chemicals, or ultrasonic vibration on pollen exine. Inasmuch as I was investigating the effects of moisture, I did not choose to introduce an extraneous varaible into the research design by artifically disaggregating the pollen. Instead of adding sterile water on the last day of the experiment, I added a 0.5 percent solution of trisodium phosphate (Na_3PO_4) to each centrifuge tube. This extremely weak solution was not thought to disturb the integrity of the experiment, yet did succeed in minimally deflocculating the acetylated pollen.

Additionally, another phenomenon occurred with this set of experiments that was absent in the freeze-thaw experiment. After 10 days, a distinct color change occurred in the centrifuge tube containing the unacetylated pollen. The mixture was originally yellow yet changed progressively to a dark brown, comparable to that of the acetylated pollen.

The wetting and drying cycle had much more pronounced effect on the pollen exines than did the temperature cycles. Results of the examination of 25 grains of each taxon (Table 1) showed a dramatic increase in the percentage of deteriorated pollen. Only acetylated *Iva augustifolia, Juniperus monosperma, Picea pungens*, and *Pinus edulis* were noticeably decreased in proportion at the end of the experiment. This may have been caused by the inability to completely disaggregated the clumped pollen.

At the conclusion of the experiment, a total of 76.29 percent of the unacetylated pollen grains and 86.02 percent of the acetylated pollen was affected by degradation to some degree (Table 2). This marked increase as compared to the control sample (15.90 percent and 12.10 percent) in the amount of degradation indicates the severity of the wetting and drying cycles on pollen exine and its importance as a factor related to the eventual preservation of a pollen assemblage.

Coniferophyta pollen.—Pinus edulis pollen in this experiment, as in the temperature experiment, preserved well. The only major difference was that in the moisture experiment occasional pine grains showed evidence of severely collapsed bladders and a crumpled configuration to the cappa area. *Picea pungens*, like *Pinus edulis*, showed evidence of the same type of bladder collapse and crumpling phenomena. In many cases, the bladders of *Picea pungens* were intact yet the cappula was ruptured along the region of the germinal furrow. In other specimens, the entire grain was collapsed and sometimes folded. The remaining conifer types, *Juniperus monosperma* and *Pseudotsuga menziesii*, have pollen with thin-walled exines that were generally broken. *Pseudotsuga* pollen (Fig. 2), in addition to being broken, often was severely distorted.

Magnoliophyta pollen.—Pollen, such as *Amaranthus palmeri* (Fig. 5) often was broken and commonly crumpled. Opercula of many of the *Amaranthus* grains often were missing, presumably as the result of the experiment although some of this way may have occurred naturally. *Populus alba* showed evidence of severe degradation in my sample (Fig. 4). Among the most severely altered grains of *P. alba*, I found evidence of rupturing, crumpling, thinning of the exine, and the loss of ornamentation (Fig. 4). *Carya illinoenis* pollen, which in the freeze-thaw experiments preserved well, was crumpled by the wetting and drying cycles. *Zea mays* pollen showed evidence of exine rupture (Fig. 6). The two species of the Asteraceae, *Iva agustifolia* and *Artemisia tridentata* (Fig. 7), generally preserved well, although there was some minor distortion of the exines in both taxa. During the moisture experiments the exines of *Salix nigra* frequently weakened along a plane parallel to the apertures, which resulted in the mesocopial exine collapsing in on itself. This phenomenon gave the *Salix* grains the appearance of an elongated pollen grain. Also, in some of the degraded examples of *Salix nigra*, the erosion of the raised muri left only eroded margins of the lumina as an ornamentation feature. *Quercus virginiana* pollen was virtually unaffected by this experiment, whereas the grains of *Typha latifolia* exhibited a great deal of crumpling and the individual grains of the tetrad often were collapsed. In one extreme case, there appears to be an almost complete fusion of the four grains of the tetrad into one mass with a concurrent loss of individual integrity (Fig. 8).

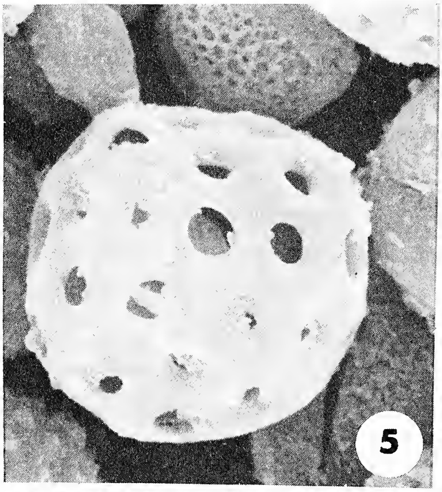
DISCUSSION

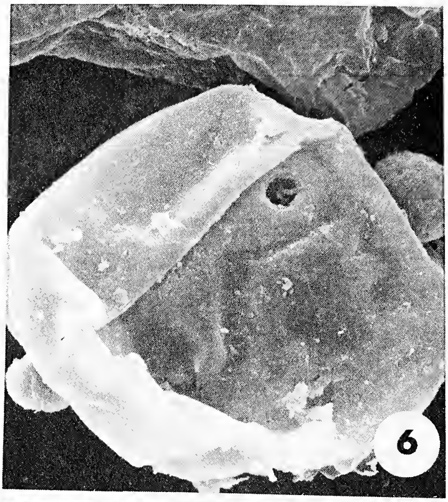
At the initiation of the experiment, it was noted that some of the pollen grains exhibited a morphological appearance similar to that which I had defined as a deteriorated condition. These grains cannot *sensu strictu* be termed degraded pollen because by definition this term implies the action of external forces. For ease of comparison, I determined the original conditions of the samples in an attempt to illustrate the effects of weathering agents as evidence by the increase in percentage of "degraded" pollen (Table 2).

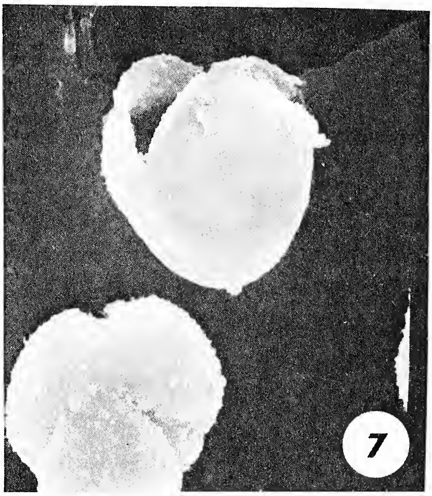
Results of the freeze-thaw experiments showed little increase in the percentages of degraded pollen. Apparently, the temperature extremes utilized in the experiment were not severe enough nor of long enough duration to induce alteration of the pollen exine and, for the purpose of this discussion, need not be considered further.

TABLE 2. Percentage calculations, wet/dry experiment.

	Amaranthus palmeri	*Artemisia tridentata*	*Carya illinoensis*	*Iva angustifolia*	*Juniperus monosperma*	*Picea pungens*	*Pinus edulis*	*Populus alba*	*Pseudotsuga menziesii*	*Quercus virginiana*	*Salix nigra*	*Typha* sp.	*Zea mays*
Unacetylated pollen													
Control sample (N = 327, total degradation = 15.90%)													
Unaffected	9.17	20.48	3.36	8.56	.61	1.83	2.75	4.58	1.83	7.95	4.89	17.43	1.22
Broken					9.48								
Corroded	1.52	.91	.61					1.22			1.52		.30
Degraded											.30		
TOTAL	10.69	21.39	3.97	8.56	10.09	1.83	2.75	5.80	1.83	7.95	6.71	17.43	1.52
25 cycles (N = 270, total degradation = 76.29%)													
Unaffected	1.85	5.18	.74	7.03	.37	1.85	4.07			1.85	.74		
Broken		.74			1.85	.74							
Corroded	5.18	.74	10.74	.37	3.70	2.22	12.22	.74		4.07	1.11	1.48	2.96
Degraded	.74	1.85	1.11		.37		2.59	5.18	2.59	1.85	5.92	4.44	.74
TOTAL	7.77	8.51	12.59	7.40	6.29	4.81	18.88	5.92	2.59	7.77	7.77	5.92	3.70
Acetylated pollen													
0 cycles (N = 314 total degradation = 12.10%)													
Unaffected	10.82	19.74	4.45	8.59	1.91	1.27	4.14	3.18	1.91	12.42	3.50	13.69	2.22
Broken			.63		1.27			.95					
Corroded	.63	.95	.63					3.18	.31	1.59	1.29		.31
Degraded													
TOTAL	11.45	20.69	5.71	8.59	3.18	1.27	4.14	7.31	2.22	14.01	4.77	13.69	2.84
25 cycles (N = 336 total degradation = 86.02%)													
Unaffected	5.06	1.19	.89	1.19					.30	4.46	.89		
Broken	.60									.89			.30
Corroded	29.46	1.49	.60	14.29			.30		.60	1.49	1.79		3.27
Degraded	10.71	2.68		2.98			.89	2.08	.89	5.65	2.38	2.08	.60
TOTAL	45.83	5.36	1.49	18.46			1.19	2.08	1.79	12.49	3.06	2.08	4.17







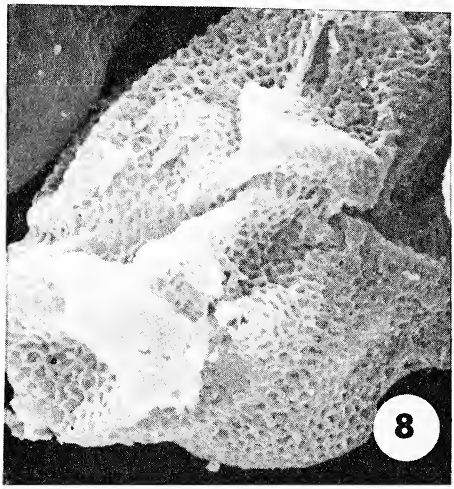


Figure 5. *Amaranthus palmeri* pollen after 25 cycles wetting and drying. 1376×

Figure 6. *Zea mays* pollen after 25 cycles wetting and drying. 498×

Figure 7. *Juniperus monosperma* (top) and *Artemisia tridentata* (bottom) after 25 cycles wetting and drying. 1270×

Figure 8. *Typha latiflia* pollen after 25 cycles wetting and drying. 1270×

The experiments testing the effects of wetting and drying produced marked increases in percentages of deteriorated pollen. This deterioration may be explained, at least in part, by phenomena associated with the evaporative process involved in changing a fluid from a liquid to a gaseous state. Experiments by Burstyn and Bartlett (1975) demonstrated that several tons of pressure are exerted on an organic surface during evaporation when water is used as a solvent. Application of pressure of this magnitude appears likely to cause major structural damage to the exine.

A second major phenomenon associated with the wetting-drying experiments was the observed color change occurring only in the unacetylated pollen samples between day 10 and 20 of the experiment. Gray and Boucot (1975) observed that spore color change, induced by a variety of causes, is indicative of a metamorphic environment. They further attempted to correlate these data with degrees of geologic metamorphosis. While the metamorphosis that occurred in many samples was minor, in terms of laboratory induced prelithification, observed changes in coloration do suggest that early stages of diagenesis had occurred.

Previous experimental studies, notably those of Brooks (1978), McIntyre (1972), and Sengupta (1974) suggested that little chemical or color alterations occur to palynomorphs at temperatures below 200° C. McIntyre (1972) reported no color change at the lower temperatures. Results of my current investigations have not substantiated this temperature threshold.

Evaporation of the water in my experiment was accomplished using a temperature of 30° C., with free access to oxygen. This temperature corresponds to that reported by Brooks (1978) involving coalification and carbonization. In the experiments conducted by McIntyre (1972) and Sengupta (1974), their pollen samples had only limited access to oxygen. Thus, the presence of oxygen in my experiment may have contributed to the observed color change at lower temperatures.

The change in coloration closely approximated the color produced as a result of acetolysis. The thermal conditions possibly may be working on the temperature-sensitive molecules affected by acetolysis, but at this point, the suggestion is merely speculative.

Results of the analysis of dehydration by taxon (Table 1) revealed a markedly different rate of preservation. Pollen of *Carya, Juniperus, Populus, Pseudotsuga, Salix, Typha*, and *Zea* showed that effects of the 50 cycles of wet and dry conditions were quite pronounced. *Amaranthus* pollen likewise was affected but differed from the others in being easily recognizable even after severe degradation. The percentages of these above-listed taxa, when treated as a pollen assemblage (Table 2), reveal a marked shift in the composition between 0 and 50 cycles. This, I believe, can be most easily explained by assuming loss of some pollen of these taxa showing large degradation percentages. I exclude *Amaranthus* from this latter group due to its recognizability and, in fact, the percentage composition of *Amaranthus* in the assemblage does increase during the experiment. *Zea mays*, and *Typha* also appear to increase slightly in terms of their representation within the assemblages at the end of 50 cycles. This may be a function of recognition, but at present I cannot quantitatively control for this factor.

Effects of mechanical agents of degradation to the pollen exine also have direct applicability to the recovery of palynological samples from buried soils, such as those from archaeological sites. In the American Southwest, for example, the climate is characterized by alternating periods of precipitation and periods of drought, the effects of wetting and drying on buried palynomorphs would be an important factor determining which grains were preserved and which grains were destroyed.

This may be illustrated by an examination of several palynological investigations in which the phenomenon of alternating periods of wet and dry is presumed to have had an effect on the preservation of the pollen assemblage. In a recent study, Holloway and Valastro (1983) reported on fossil pollen assemblages recovered from alluvial deposits associated with the Yazoo River Basin in east-central Mississippi. A total of 15 sediment cores was recovered from both backswamp and oxbow lake deposits. Both of these types of deposits are routinely, but only periodically, flooded. In spite of careful laboratory extraction procedures applied to this series of cores, pollen assemblages were intermittently present and there does not appear to be any direct correlation between the preservation of any particular pollen assemblage and other factors such as pH, percentage of organic matter, and so forth. Quite possibly, the preservation or degradation of these pollen assemblages may have been determined mainly by their environment of deposition.

In another study, organic deposits were routinely recovered from Meadowcroft Rock Shelter, Pennsylvania (Adovasio and Carlisle, 1984). As long as samples were taken from within the shelter, the preservation was fine. However, as Adovasio and Carlisle (1984) observed, pollen and macrofossil materials recovered from areas outside the drip-line, where repeated wetting and drying occurred, produced only poorly preserved specimens. Quite likely, the alternatively wet and dry conditions played an important role in the degradation of some specimens.

In Texas, there are a number of rockshelters, sites that were occupied by prehistoric man. Many of these have been examined previously by Bryant (1969), Johnson (1963), and McAndrews and Larson (1966). One of the archaeologically most promising rockshelters in central Texas, Levi Rockshelter, was sampled for fossil pollen by Bryant (1969). However, in spite of processing the soil samples using a number of different laboratory techniques, Bryant (1969) was able to obtain pollen from only three of 26 samples and even those three produced no more than 20 grains each. Other rockshelters in Texas, such as Bonfire Shelter (Bryant, 1969), Eagle Cave (McAndrews and Larson, 1966), and Hinds Cave (Dering, 1979) have yielded well documented pollen records within the sediments. Levi Rockshelter differs from these other sites, however, in that a seep spring is present along the back wall of the Levi rockshelter. The seep flows only during the rainy season and for the remainder of the year the area is a typical, dry rockshelter (Bryant, personal communication, 1988). Thus, it is highly probable that these alternating sequences of wet and dry conditions may have contributed to the loss of pollen contained in these sediments.

Perhaps the most diagnostic evidence is provided by Larson et al. (1972) in their report of the pollen analysis of Hershop Bog, Texas. The upper portions of the bog deposit, except for the surface sample itself, were devoid of pollen. Larson et al. (1972) noted that during the 1940's the surface vegetation of the bog was destroyed by an attempt to drain the bog and subsequent over-grazing. Denuding and trenching of the bog surface lowered the water table and allowed the upper sediments to become exposed to intermittent periods of wetting during the rainy seasons. Based on the results of my experimental studies, much of the loss of the fossil pollen assemblages within this upper bog section may have been the result of these alternating periods of wet and dry during the intervening three decades, because all remaining deposits below the water table still contained excellent pollen preservation.

These data are important criteria to be evaluated in selecting sites for study, be they archaeological or palynological. Effects of weathering and biological activity on the pollen exine in completely submerged environments, such as recently reported by Holloway (1981a, 1981b) from Brady Reservoir, Texas, are minor in comparison to the effects of alternating wet and dry environments. This pronounced effect of potential loss of entire fossil pollen assemblages must be accounted for, and anticipated by palynologists during the formulation of research proposals. Alternatively, we are faced with the prospect of only marginal recovery of data at best.

CONCLUSIONS

These experiments have revealed that environmental conditions can affect the eventual preservation of fossil pollen assemblages in a variety of ways. While brief differences in temperature, in the range commonly occurring in temperate North America, were found to have virtually no effect on the pollen exines, these same pollen taxa were severely altered by fluctuations in moisture. In addition, the individual pollen types differed drastically in their susceptibility to degradation. This factor is unfortunately complicated by differential ease of recognition of certain pollen taxa, even when they have been severely altered. Much of the observed degradation may be related to the pressure generated during the evaporative process, whereas some is determined by the inherent differences between discreet plant taxa. In Quaternary sediments, the effects of alternating wet and dry environments appears to be the most damaging and this must be recognized as an important contributing factor prior to site selection if we are to obtain good reliable data sets.

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LITERATURE CITED

Adovasio, J. M., and R. C. Carlisle. 1984. An Indian hunter's camp for 20,000 years. Sci. Amer., 25):130-136.

Birks, H. J. B., and H. H. Birks. 1980. Quaternary paleoecology. Belknap Press, Baltimore, 289 pp.

Brooks, J. 1978. Diagenesis of organic matter: some microbiological, chemical, and geochemical studies on sedimentary organic matter, in pp 287-308. Environmental biogeochemistry and geomicrobiology. Ann Arbor Science, Ann Arbor, Michigan. 756pp. (Krumbein ed.)

Bryant, V. M. Jr. 1969. Late fullglacial and postglacial pollen analysis of Texas sediments. Unpublished Ph.D. dissertation, Univ. Texas, Austin. 258 pp.

———. 1978. Palynology: a useful method for determining paleoenvironment. Texas J. Sci., 30:25-42.

Burstyn, H. P., and A. A. Bartlett. 1975. Critical point drying: application of the physics of the PVT surface to electron microscopy. Amer. J. Physics, 43:414-419.

Cushing, E. J. 1967. Evidence for differential pollen preservation in late Quaternary sediments in Minnesota. Rev. Paleobot. Palynol., 4:87-101.

Dering, J. P. 1979. Pollen and plant macrofossil vegetation record recovered from Hinds Cave, Val Verde County, Texas. Unpublished M.S. thesis, Texas A&M Univ., College Station, 79 pp.

Duhoux, E. 1982. Mechanism of exine rupture in hydrated taxoid type of pollen. Grana, 21:1-7.

Erdtman, G. 1960. The acetolysis method: a revised description. Svensk. bot. Tidskr., 54:561.

Faegri, K., and J. Iversen. 1975. Textbook of pollen analysis. Munksgaard Press, New York, 295 pp.

Farrant, J., and G. J. Morris. 1973. Thermal shock and dilution shock as the causes of freezing injury. Cryobiology, 10:134-140.

Gray, J., and A. J. Boucot. 1975. Color changes in pollen and spores: a review. Geol. Soc. Amer. Bull., 86:1019-1033.

Havinga, A. J. 1971. An experimental investigation into the decay of pollen and spores in various soil types. Pp. 446-480, *in* Sporopollenin (J. Brooks et al., eds.) Academic Press, New York, 718 p.

Holloway, R. G. 1981*a*. Pollen exine deterioration and preservation in Brady Reservoir. Nat. Park Serv. Tech. Rept., Santa Fe, 93 pp.

———. 1981*b*. Preservation and experimental diagenesis of the pollen exine. Unpublished Ph.D. dissertation, Texas A&M Univ., College Station, 317 pp.

Holloway, R. G. and S. Valastro. 1983. Palynological investigations along the Yazoo River, Items 3 & 4. Cultural resources survey of the Yazoo River, Items 3 & 4, and a paleoenvironmental model of the lower Yazoo Basin (Thorne et al., eds.), Archaeol. Papers Cent. Archaeol. Res. Univ. Mississippi, 3:1-307.

Jacobson, G. L., Jr., and R. H. W. Bradshaw. 1981. The selection of sites for paleovegetational studies. Quat. Res., 16:80-96.

Johnson, L. 1963. Pollen analysis of two archaeological sites at Amistad Reservoir, Texas. Texas J. Sci., 15:225-230.

Larson, D. A., J. J. Skvarla, and C. Lewis. 1972. An electron microscope study of exine stratification and fine structure. Pollen et Spores, 4:2333-2346.

Lewis, E. R., and M. K. Nemanic. 1973. Critical point drying techniques. IITRI Symposium, 1973:767-774.

Manum, S. G., T. Bjaerke, T. Throndson, and M. Eien. 1976. Reservation and abundance of palynomorphs and observations on thermal alteration in Svalbard, Norway. Nor. Polarinst. Arbok., pp. 121-130.

McAndrews, J. H., and D. A. Larson. 1966. Pollen analysis of Eagle Cave. Pp. 179-184, *in* Preliminary paleoecology of the Amistad Reservoir. Processed report to National Science Foundation.

McIntyre, D. J. 1972. Effect of experimental metamorphism on pollen in a lignite. Geoscience and Man, 4:111-117.

Polak, B., G. C. Maarleveld, and D. J. G. Nota. 1962. Palynological and sedimentary petrologic data of a section in ice pushed deposits (southern Veluwe, Netherlands). Geol. Mijnbouw, 41:333-350.

Sangster, A. G., and H. M. Dale. 1961. A preliminary study of differential pollen grain preservation. Canadian J. Bot., 39:35-44.

———. 1964. Pollen grain preservation of underrepresented species in fossil spectra. Canadian J. Bot., 42:437-449.

Sengupta, S. 1974. Size reduction and structural change in Lycopodium clavatum spores produced by temperature and pressure changes. IITRI Symposium 1974:381-383.

———. 1977. A comparative study of the gradual degradation of exines resulting from the effects of temperature. Rev. Paleobot. Palynol., 24:239-246.

Sengupta, S., and M. D. Muir. 1974. The use of light and electron microscopy in the study of experimentally altered spores and pollen grains. J. Microscopy, 109:153-158.

Sengupta, S., and J. R. Rowley. 1974. Re-exposure of tapes at high temperature and pressure in the Lycopodium clavatum spore exine. Grana Palynologica, 14:143-151.

A NOTE ON THE EFFECT OF CORRELATED OBSERVATIONS ON BARTLETT'S TEST FOR EQUAL VARIANCES

Patrick L. Odell and Dean M. Young
Baylor University, Waco, Texas 76798

Abstract.—In this note, we show that dependency structures exist for which the population variances are unequal and the distribution of Bartlett's (1937) test statistic for testing the homogeneity of variances, assuming these dependency structures, is identical to the distribution when the population variances are equal and the observations are independent. *Key words:* Chi-squared distribution; equal population variances; robustness; dependent observations.

Much research concerning the effect of correlation on statistical procedures that require independence for validity has been completed in the last 30 years. Primarily, two types of correlation structures have been investigated—intraclass and serial correlation. One of the first such investigations involving intraclass correlation structures was performed by Walsh (1947), who showed how the presence of intraclass correlation affects the magnitude of the confidence coefficients of various confidence interval procedures and, therefore, how it affects the magnitude of the significance level of corresponding significance tests. Since then, many investigators have examined the effect when the observations have specialized correlation structures rather than the usual independence structure. For instance, Basu et al. (1974) have examined the effect of equicorrelated data on Hoetelling's T^2 test, and Basu et al. (1975) have given necessary and sufficient conditions for the covariance structure in order that the sample mean and any translation invariant statistic are independent. Basu et al. (1976) have investigated the robustness of confidence sets based on Chi-square statistics. Guttman and Tiao (1978) have considered the lack of robustness of location estimators, and Srivastava (1980) has examined the robustness of Grubbs' test against equicorrelated observations. Smith and Lewis (1980) have considered the effect on conclusions reached on the basis of the analysis of factorial experiments, and Smith and Lewis (1982) have considered the effect of equicorrelation on hypothesis tests in analysis of covariance. Pavur and Davenport (1985) have examined the effect of correlation on ANOVA procedures. Turner et al. (1986) have demonstrated the robustness of Lilliefors' test for normality against equicorrelated covariance structures.

Several of the articles mentioned above have shown that correlation of observations in the form of equicorrelation has an adverse effect on normal-based statistical procedures. However, the correlation pattern rather than the magnitude of the correlations often invalidates certain test procedures. Basu et al. (1976), Srivastava (1980), Stadje (1984), Marco et al. (1987), and Pavur (1987) have discovered several dependency structures that allow the assumption of independence to be relaxed but leaves the distribution of the test statistic invariant from the independence case.

This note presents sufficient conditions for Bartlett's test for equal variances of k normal distributions to yield the same null distribution under a general equicorrelation model as attained under the usual independence model. In the second section, the general intraclass covariance structure is defined and the main result is proven. A brief discussion of the implications of results is given in the third section.

Relaxing the Assumption of Independence in a Test for Equal Population Variances

One of the older and more popular test statistics for testing the equality of the variances of k univariate normal populations is Bartlett's (1937) statistic, which is expressed as

$$B = (\ln S_p^2) \left[\sum_{i=1}^{k} (n_i - 1) \right] - \sum_{i=1}^{k} (n_i - 1) \ln S_i^2, \tag{1}$$

where

$$S_p^2 = \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_i)^2 / (n_i - 1),$$

$S_p^2 = \sum_{i=1}^{k} S_i^2$, X_{ij} represents the j^{th} observation from the i^{th} population, $\bar{X}_i = \sum_{j=1}^{n_i} X_{ij} / n_i$, n_i is the number of observations from the i^{th} population, and k is the number of populations. The following notation, definitions, and lemma facilitate proving the main result.

Let the $n \times 1$ observation vector $x = (x_1, x_2, \ldots, x_n)'$ be a sample from an n-variate normal distribution such that $X \sim N_n(\mu j, \sigma^2 I)$ where j is an $n \times 1$ vector of ones, μ and σ^2 are scalars denoting the population mean and variance, and I is the usual independence structure assumed for Bartlett's test for homoscedastic variances.

Now consider an alternative covariance-structure model, which has been examined by Stadje (1984) and Baldessari and Gallo (1981). Let

$$\Sigma_2 = cI + A + A', \tag{2}$$

where $A = a' \otimes j$ for some $a \in R^n$, and $c > [(na'a)^{1/2} - j'a] > 0$. We shall refer to the covariance structure given in (2) as the generalized intraclass structure. The following lemma, which is utilized in the theorem below, has been proven by Stadje (1984).

Lemma.—Let $X \sim N_n(0,\Sigma)$ and let

$$S^2 = \sum_{i=1}^{n} \frac{(X_i - \bar{X})^2}{n-1}.$$

Then $c^{-1}S^2$ is distributed as a $\chi^2(n\text{-}1)$ if and only if Σ has the generalized intraclass covariance structure defined in (2).

The following theorem defines sufficient conditions for the null distribution of Bartlett's test under the generalized intraclass structure defined in (2) to remain identical to the null distribution under the usual independence structure.

Theorem.—Suppose X_i, $i = 1,2,\ldots,k$, are mutually independent vectors such that each $X_i \sim N_{n_i}(\mu_i, V_i)$, where i represents the i^{th} population, μ_i is a $p \times 1$ vector, and $V_i = c_iI_i + A_i + A_i'$, where I_i is the $n_i \times n_i$ identity matrix and $A_i = a_i{}' \otimes j$ for $a_i \in R^{n_i}$. If $c_i = c_2 = \ldots = c_k$, then the distribution of Bartlett's test for equal variances remains unchanged from the case where $X_i \sim N_{n_i}(\mu_i,\sigma^2 I)$ for $i = 1,2,\ldots,k$.

Proof.—By Lemma 1 each

$$S^2 = \Sigma\,(X_{ij} - \bar{X}_i)^2$$

is distributed as $c_i\chi^2\,(n_i - 1)$ when the population covariance matrix is V_i. Under the standard assumption that the population covariance matrix is $\sigma^2 I$, each S_i^2 is distributed as $\chi^2(n_i - 1)$. If $c_i = c_2 = \ldots = c_k = c$, it is straight-forward to show that B is invariant to the value of c. Because the distribution of B is determined by the distribution of the S_i^2's, the result follows.

COMMENTS

The Theorem in the second section states that the distribution of B remains the same under the null hypothesis when the n_i observations from each population have the generalized intraclass covariance structure with $c_i = c$ for $i = 1,2,\ldots,n$, as in the independence structure model with covariance matrices $\sigma^2 I$. However, under the general intraclass covariance structure, the marginal random variables do *not* necessarily have equal population variances. This fact follows because each a_i can be any scalar such that $c_i > [(na_i'a_i)^{1/2} - j'a_i]$. Thus, caution is advised and one should consider the plausibility of the independence assumption prior to the application of Bartlett's test for equal variances. The assumption of independence may possibly be masked by the existence of the generalized intraclass covariance structure with $c_i = c_j$ for all i and j less than or equal to k.

LITERATURE CITED

Baldessari, B., and F. Gallo. 1981. Statistical analysis of dependent data: analysis of variance. Rev. Roum. Math. Pures. Appl., 26:363-374.

Bartlett, M. S. 1937. Some examples of statistical methods of research in agriculture and applied biology. J. Roy. Stat. Soc. Suppl., 4:137-170.

Basu, R., J. P. Basu, and T. O. Lewis. 1976. Effect of intraclass correlation and confidence coefficients of confidence sets based on chi-square statistics. IEEE Trans. Systems, Man, and Cyber., 6:445-447.

Basu, J. P., P. L. Odell, and T. O. Lewis. 1974. The effects of intraclass correlation on certain significance tests when sampling from multivariate normal populations. Comm. Stat., 3:899-908.

Basu, J. P., P. L. Odell, T. O. Lewis, and A. Kinderman. 1975. On independence of sample mean and translation invariant statistics of samples from mulitvariate normal populations. J. Amer. Stat. Assn., 70:480-481.

Guttman, I., and G. C. Tiao. 1978. Effect of correlation on estimation of a mean in the presence of spurious observations. Comm. Stat., 2:229-247.

Marco, V. R., D. M. Young, and D. W. Turner. 1987. A note on the effect of simple equicorrelation in detecting a spurious multivariate observation. Comm. Stat., A16:1027-1036.

Pavur, R. J. 1987. Distribution of multivariate quadratic forms under certain covariance structures. Canadian J. Stat., 15:169-176.

Pavur, R. J., and J. M. Davenport. 1985. The (large) effect of (small) correlations in ANOVA and correction procedures. Amer. J. Math. Management Sci., 5:77-92.

Smith, J. H., and T. O. Lewis. 1980. Determining the effects of intraclass correlation on factorial experiments. Comm. Stat., A9:1353-1364.

———. 1982. Effects of intraclass correlation on covariance analysis. Comm. Stat., A11:71-80.

Srivastava, M. S. 1980. Effect on equicorrelation in detecting a spurious observation. The Canadian J. Stat., 2:249-254.

Stadje, W. 1984. A note on sample means and variances of dependent normal variables. Statistics, 15:205-218.

Turner, D. W., D. M. Young, and V. R. Marco. 1986. A note on the robustness of the Lilliefors test for univariate normality with respect to equicorrelated data. Comm. Stat., A15:2355-2361.

Walsh, J. 1947. Concerning the effect of intraclass correlation of certain significance tests. Ann. Math. Stat., 18:88-96.

BEHAVIOR OF MALE FATHEAD MINNOWS IN THE PRESENCE OF AN ADDITIONAL MALE OR FEMALE FATHEAD MINNOW

Mark Pyron and Thomas L. Beitinger
Department of Biological Sciences, University of North Texas, Denton, Texas 76203

Abstract.—Male and female fathead minnows, *Pimephales promelas*, were introduced individually into the territory of a male fathead minnow. Behaviors by the territorial male were observed and compared relative to the gender of the added fish. Territorial male fathead minnows showed similar behaviors in the presence of nonreproductive male and female fathead minnows. Gender recognition by territorial males also was demonstrated.
Key words: fathead minnow; *Pimephales promelas*; reproductive behavior; gender.

The reproductive behavior of the fathead minnow, *Pimephales promelas*, has been described both in the laboratory (McMillan and Smith, 1974; Cole and Smith, 1987) and field (Isaak, 1961). McMillan and Smith (1974) observed spawning behavior, egg-laying, and fertilization in the laboratory. Courtship of male fathead minnows in the laboratory (Cole and Smith, 1987) includes approach, leading, lateral display, jump-swim, butting, and lateral quiver behaviors. No attempt has been made to compare the behavior of a territorial male in the presence of an introduced conspecific male. Behaviors previously designated as courtship may actually be multifunctional. Agonistic behavior by territorial males toward males (Markus, 1934; McMillan and Smith, 1974; Unger, 1983) and aggression towards females have been witnessed (McMillan and Smith, 1974). Aggressiveness is related to body coloration and presence or absence of eggs (McMillan, 1972). We designed an experiment to determine if behaviors of a territorial male in the presence of an introduced male are similar to behaviors in the presence of an introduced female.

Methods and Materials

Fathead minnows six to 10 months old (standard length in centimeters, $\bar{X} \pm SD$: females, 4.1 ± 0.51, males, 4.4 ± 0.44) were obtained from a stock culture at the University of North Texas. The fish were raised and maintained in dechlorinated tap water (either 110 or 38 liter) at 22 to 26°C (controlled with electric heaters) under a 18L:6D photoperiod. Fish were fed twice daily with TetraMin staple food flake food supplemented with frozen and freshly hatched brine shrimp (*Artemia*).

Behavioral data from observation trials (1000 seconds each) were collected manually using a portable computer with an event recorder program (written by J. Baylis, Department of Zoology, University of Wisconsin, Madison) that measured the duration of each behavior. Five white cloud minnows, *Tanichthys albonubes*, as dither fish (see Barlow, 1977; Cole and Smith, 1987) were provided. Each of the 38-liter aquaria used for behavioral observation contained a nesting site consisting of PVC pipe (seven centimeters inside diameter) cut in lengths of about eight centimeters and cut in half lengthwise. Fathead minnows will spawn eggs on the ceiling of such a structure. A single territorial male exhibiting breeding coloration, tubercles, and dorsal pad was added to each of two observation aquaria; each male subsequently defended the PVC pipe nesting site. An additional (test) fish, either male or female, was introduced after 24 hours, and at least 30 minutes prior to the collection of behavioral data. After each recording session the gender of the test fish was determined by internal gonad inspection (squash mount examined under a light microscope for ova or spermatozoa). The number of trials in which the added (test) fish was female and male were 33 and 34, respectively. Data were collected using video tape replays and direct observations. All sessions occurred from either 0700 to 1000 or 1600 to 1800 and at least 30 minutes after feeding. Territorial males appeared to be most aggressive following feeding at these times, as reported in an earlier study (for example, Smith, 1979).

The following seven categories of behavior from McMillan and Smith (1974) and Cole and Smith (1987) were monitored during trials.

1. Approach—male approaches introduced (test) fish.
2. Leading—male swims from near the test fish directly to his territory and the other fish follows. This is not the same behavior as defined by Cole and Smith (1987) as difficulty was encountered determining whether the territorial male was simply returning to the territory or "leading" a possible partner. As a result, fewer entries were recorded as leading behavior than Cole and Smith (1987).
3. Lateral display—(same as Cole and Smith, 1987). The male moves in front of, or at right angles to, the test fish and hovers, extending dorsal, caudal, anal, and pectoral fins.
4. Jump-swim—(same as Cole and Smith, 1987). The male makes a quick upward swimming motion, turning onto his side, and then quickly swims downward.
5. Tailbeating—the lateral quiver of Cole and Smith (1987) seemed to be the same as tail-beating as defined by McMillan and Smith (1974).
6. Butting—(same as McMillan and Smith, 1974). The male moves toward the introduced fish and pushes at it with the snout.
7. Chasing—(same as McMilland Smith, 1974). The male rapidly moves toward and pursues the other fish.
8. Movement of male and female fathead minnows into the shelter was monitored as a behavior.

Contact of the shelter ceiling with the dorsal pad of the territorial male—that is, rubbing behavior—was not included in our study. This action occurred during nearly every entrance to the territory by the male, and was difficult to quantify because a male would make many contacts with the ceiling while in the territory. No egg laying was witnessed, although some male-female pairs went through spawning sequences. Frequencies of behaviors were analyzed by comparing the territorial male responses to test female as opposed to test male fish with the Mann-Whitney two-sample U test (SAS, 1985).

RESULTS AND DISCUSSION

Territorial males performed all monitored behaviors in the presence of both male and female test fish. The frequencies of territory, approach, chase, jump-swim, butting, and leading behaviors were not significantly different in the presence of male or female fish (Table 1). However, there were significantly more tailbeat and lateral display behaviors by territorial males toward test males than toward test females. Behaviors by male fathead minnows in the presence of females previously identified as courtship behavior (approach, lateral display, and leading) by Cole and Smith (1987) commonly occurred in the presence of another male; however, differences in the frequencies of two of these behaviors in the presence of introduced males and females were observed. Whether these behaviors serve a courtship or agonistic function is difficult to determine.

TABLE 1. Total frequencies and percentages of observed behaviors of territorial male fathead minnows, *Pimephales promelas*, by gender of the introduced conspecific fish. Significant differences in behavior frequencies of territorial males towards introduced female and males (Mann Whitney two-sample U test, $\alpha \leq 0.05$) are indicated by an asterisk.

	Female (N = 33)		Male (N = 34)	
Behavior	Total	Percentage	Total	Percentage
Male swim in shelter	1019	59.3	1014	45.1
Test fish swim in shelter	39	2.3	49	2.2
Approach	484	28.2	439	19.5
Leading	23	1.3	15	0.7
Tailbeat	3	0.2	86	3.8*
Butting	14	0.8	84	3.7*
Jump-swim	58	3.4	58	2.6
Lateral display	54	3.1	484	21.5*
Chase	23	1.3	21	0.9
Total	1717	99.9	2250	100.0

Kortmulder (1972) concluded that in several species of *Barbus*, "male courtship is almost entirely built out of agonistic components." Courtship in fathead minnows perhaps consists of similar agonistic components.

Lateral display and tailbeat behaviors were observed significantly more often in the presence of test male than test female fathead minnows. These seem to be forms of male aggression toward possible intruders. Lateral display behavior appeared to be a similar and less aggressive form of tailbeat behavior, and sometimes was followed by tailbeat behavior. Both test males and females were approached frequently by territorial males.

Low gonadal somatic indices (GSIs) in the female fathead minnows suggested that they were not in a reproductive state. Mean (± SD) GSI, were 6.2 percent (3.1) and 1.3 percent (0.4) for introduced females and males, respectively. GSIs were not measured in the two territorial males; however, all external characters indicated that they were in a reproductive state. Breeding female fathead minnows in nature have GSIs several times those measured in our study (Smith, 1978). Smith (personal communication) suggested that territorial males may treat nonreproductive fish of either gender in similar ways because they are neither competitors nor potential mates but are possible egg predators.

As suggested by McMillan and Smith (1974), confining mature males in aquaria may invoke behaviors that do not occur in nature. An unaggressive male being harassed by a territorial male in an aquarium does not have the choice of fleeing. Yet, mutual butting has been witnessed in the field (McMillan and Smith, 1974) where fleeing is an option. Males not returning aggressive actions were observed in our study to be repeatedly approached, and had tailbeat and lateral display behaviors directed towards them. Seemingly aggressive behavior towards an intruding male did not necessarily reflect that the intruder was aggressive.

CONCLUSIONS

These observations contribute to our knowledge of fathead minnow behavior. Territorial males demonstrate similar behaviors in the presence of nonreproductive males and females, including behaviors previously identified as having a courtship function. These behaviors (approach, lateral display, and leading) may appear in other contexts than courtship alone, such as aggression. The low GSIs of the test fish may minimize the gender differences expressed by individuals in reproduction condition. Our behavior data do indicate, however, gender recognition by territorial males. Further studies may demonstrate the influence of reproductive condition on behavior.

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LITERATURE CITED

Barlow, G. W. 1977. Dither—a way to reduce undesirable fright behavior in ethological studies. Z. Tierpsychol., 25:315-318.

Cole, K. S., and R. J. F. Smith. 1987. Male courting behavior in the fathead minnow *Pimephales promelas*. Env. Biol. Fish., 18:235-239.

Isaak, D. 1961. The ecological life history of the fathead minnow, *Pimephales promelas* (Rafinesque). Unpublished Ph.D. dissertation, Univ. Minnesota, Minneapolis, Minnesota, 150 pp.

Kortmulder, K. 1972. A comparative study in colour patterns and behavior in seven Asiatic barbus species (Cyprinidae, Ostariophysi, Osteicthyes) a progress report. Behav., Supp., 19:1-331.

Markus, H. C. 1934. Life history of the blackhead minnow (*Pimephales promelas*). Copeia, 3:116-122.

McMillan, V. E. 1972. An ethological study of agonistic and reproductive behaviour in the fathead minnow (*Pimephales promelas* Rafinesque). Unpublished, M.S. thesis, Univ. Saskatchewan, Saskatoon, Saskatchewan, 146 pp.

McMillan, V. E., and R. J. F. Smith. 1974. Agonistic and reproductive behavior of the fathead minnow (*Pimephales promelas* Rafinesque). Z. Tierpsychoo., 34:25-58.

SAS (Statistical Analysis System). 1985. SAS user's guide: statistics. SAS Instit., Cary, North Carolina, 956 pp.

Smith, R. J. F. 1970. Effects of food availability on aggression and nest building in brook stickleback (*Culaea inconstans*). J. Fish. Res. Bd. Canada, 27:2350-2355.

Unger, L. M. 1983. Nest defense by deceit in the fathead minnow *Pimephales promelas*. Behav. Ecol. Sociobiol., 13:125-130.

SOLAR POND POTENTIAL ON THE HIGH PLAINS OF TEXAS AND NEW MEXICO

M. A. K. Lodhi

Department of Physics, Texas Tech University, Lubbock, Texas 79409

Abstract.—Solar ponds are probably the simplest technology available for useful conversion of solar energy. The basic technology is well established. Solar ponds have been shown to be technically feasible and economically viable for many applications, particularly for thermal use. The electrical conversion and use of solar energy via solar ponds is still questionable in general for economic viability. However, putting the untapped sources together in the High Plains region of Texas and New Mexico for thermal and electrical conversions of solar energy through salt gradient, solar ponds look economically promising. There are a number of alkaline lake basins randomly scattered in the High Plains region of the United States. In that area, there also are thousands of crude oil producing wells that also produce brine in abundance. Selection of suitable alkaline lake basins as sites for solar ponds and as depository sites of brine from oil wells, and use of this brine and salty water from alkaline lakes, makes the solar pond economically viable for both thermal and electrical demands in the area. The salt excavated from the nuclear waste repository also may be used, which will further reduce the total cost of the pond. *Key words:* High Plains; alkaline lake basins; oil wells brine; solar energy; solar pond.

Solar pond technology has been demonstrated on the world-wide scene since the 1960s. The salt-gradient solar pond is a simple and low-cost device for collecting and storing solar energy. General conclusions are that solar ponds are technically and economically viable solar energy converters that can and should be exploited in the regions and markets where the potential is high. Regions deserving particular attention in North America are those where salt deposits are abundant. Among those salt abundant regions, the Southwest and the High Plains in the United States are of special interest, where the pond potential is highest, the sources (sun and salt) are most abundant, and the energy demands are high.

This paper involves an assessment of the availablity and costs of energy from salt gradient solar ponds in the Southwest with special reference to western Texas and eastern New Mexico, the High Plains region. The High Plains region is a strong viable candidate for solar ponds for many good reasons. This region provides abundant solar energy, naturally level ground required for ponds, salt and water sources, and a demand for energy at moderate temperatures. Alkaline lake basins with stagnant water, offering most promising sites for salt-gradient solar ponds, are distributed on the High Plains. Brine dumping from oil field operations in the area provides a negative price as a nuisance charge on one hand and the massive amounts of brine required for initial pond development on the other hand. Salt and brine also might be available from a site to be converted for a nuclear waste repository. These convincing features warrant the conceptual study of salt-gradient solar ponds with their technical feasibility and long-term economic attractiveness.

I shall discuss the essential features of solar ponds first and then natural resources in the High Plains region for their economic feasibility.

SALT-GRADIENT SOLAR PONDS

Solar ponds are both collectors as well as storage sites of solar radiation in the form of heat. The principle and application potential of solar ponds first were reported in the literature in the early 1900s. Natural solar ponds have existed in nature for millenia, unnoticed by man until the turn of the last century when one was discovered with its amazing properties by Kalecsinsky (1902). Lake Madoc (Medie Lagoon) located at latitude 42° 44′ N and longitude 26° 45′ E in Transylvania was found to have temperatures up to 70°C at a depth of about 1.32 meters at the end of summer. These high temperatures apparently were due to the salinity gradient in the lake. Kalecsinsky reported this discovery and indicated its potential as a source of low-grade heat. The world was not interested in such sources of energy for apparent reasons at that time, and about half a century elapsed without any further follow up on it. Following nature's example, a study of building an artificial solar lake was initiated under the Dead Sea Works project in Israel in 1950s (Tabor, 1963). These efforts were abandoned in the 1960s because of the high cost of the energy produced from solar ponds compared to the plentiful amount of conventional energy at a lower rate. Work on solar ponds initiated in Australia, about the same time when it ceased in Israel, did not continue long for similar reasons (Davey, 1968). As fossil fuels were considered to be more than adequate for many centuries, the idea of solar ponds for developing a means of solar energy was shelved along with other ideas for the next decade. However, it was only after the energy crises of the 1970s that a worldwide realization occurred. Accordingly, a number of theoretical investigations and experimental and commercial studies of solar ponds appeared in the literature. Tabor (1981) presented an extensive survey of existing projects throughout the world until 1980. Edesses (1982), Lin (1982), Ortabasi and Gurgenci (1983), and Lodhi (1987*a*, 1987*b*) have summarized further developments since then. An up-to-date list of existing solar ponds is given in Table 1.

Storage is one of the most critical problems of almost all solar energy applications due to its intermittent nature. The low storage efficiencies and the consequential energy losses, and the construction and maintenance of storage devices, usually add up to a considerable fraction to the total cost of solar energy transduction systems into some usable form of energy. A realistic solution to the storage problem for low-temperature applications is provided by solar ponds. In a solar pond, no distinction

TABLE 1. List of major solar ponds in the world.

No.	Location	Area (m^2)	Depth (m)	Max. temp. (°C)	Capacity (kW)	Efficiency (%)	Application
1.	Ein Bokek, Israel, 1979	7500	2.6	92	150-170	15-19.4	Electricity production
2.	Chattanooga, Tennessee, 1982	4000					
3.	Alice Spring, Australia, 1981	2100	2.3	82	20		Electricity production
4.	Miamisburg, Ohio 1978	2020	3.5	66		15	Swimming pool heating
5.	Yavne, Israel, 1977	1500		90	6		Electricity production
6.	Dead Sea Potash Works, Israel, 1975	1100		103		15	Heat extraction experiments
7.	Eilat, Israel, 1977	1100		82			Heat source
8.	Argonne, Illinois, 1980	1082	4.3				
9.	Flagstaff, Arizona, 1982	800					Heating a 1500 m^2 building
10.	Montreal, Canada, 1981	700	2	70	360GJ/yr		To preheat the air injected into an industrial air dryer
11.	Dead Sea Potash Works, Israel, 1960	625	0.8	96			Investigation of the feasibility of the solar pond idea
12.	Ohio State Univ., Columbus, 1980	400	4.5				Heat extraction, grain drying, and other purposes
13.	Ohio State Univ., Columbus, 1975	200	2.5	66			
14.	University of New Mexico, 1975	175	2.5	109	Produced 63 GJ in 12 months	9	Experimental heat extraction
15.	Wooster, Ohio, 1975	155	3.0		From 26 Oct to 8 Dec 1979 provided 20 GJ		Greenhouse heating
16.	Aspendale, Australia, 1964-66	100	Less than 1	60			Experimental
17.	India, 1980	100					
18.	Iowa, 1978	76	3.6				
19.	St. Lucia, Australia, 1982	16		60			Using a honeycomb top to suppress the convection

Table 1. Continued.

20. Desert Research Inst., Nevada, 1979	10	1.0			Saturated ponds using $MgCl_2$, $CaCl_2$ and borax
21. Truscott, Texas				1200	Under construction
22. Dead Sea, Israel	250×10^3			5000	Under construction
23. Salton Sea, California	10^6			5000	In design
24. University of Texas at El Paso	3355	3	87	100	Desalting water at 5000 gal/day

exists between the collecting and storage devices. The same bulk of water serves both purposes simultaneously.

Physics of Working of Solar Ponds

In general, when a body of fluid (water in case of solar pond) is heated from beneath its density decreases as its temperature increases. The warmer and lighter fluid rises to the surface where it loses some of its heat due to the difference of the warm surface temperature and relatively cooler ambient temperature, and through evaporation from the surface. As the surface fluid cools, it gets heavier and sinks back to the bottom again. In this way, convection currents are set up in the fluid due to the buoyancy effects. Because of this continuing mixing and thus the loss of heat, it is impossible to capture and store heat in a covered pond. Several techniques have been proposed to suppress this convection effect (Tabor, 1963; Rabl and Nielsen, 1975; Dickinson et al., 1976; Cavalleri and Folizno 1977; Beard et al., 1978; Margen, 1978; Jayadev et al., 1979; Ortabasi and Gurgenci, 1983; Ortabasi et al. 1989). The salt gradient nonconvecting solar poond is the most studied and most common type. It is a pond in which temperature and salt concentration (almost zero at the surface to about 20 percent at the bottom) vary with depth. The bottom layers have higher densities due to the high salt concentration. As the temperature of the fluid rises at the bottom layers by direct solar heating, the buoyancy effects are reduced due to high salt concentration until it is balanced and then overcome. Consequently, hot water stays at the bottom where heat losses due to evaporation and temperature difference between the fluid and the surrounding are minimal. Because convection is suppressed and infrared radiation is sufficiently blocked by water in the pond, the only heat transfer is due to conduction. A one- to two-meter thick layer of water can provide sufficient thermal insulation to allow water temperature to rise to the boiling point if desired (Bryant, 1981, Weeks et al., 1981).

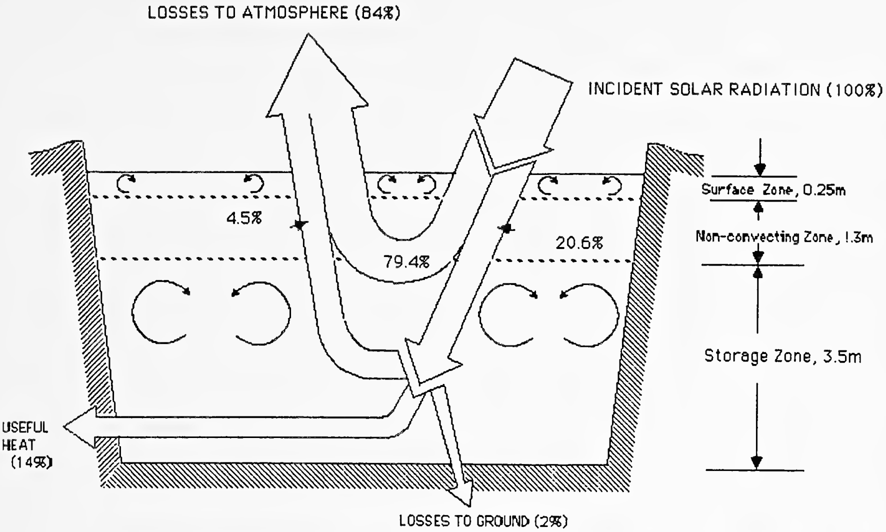

FIGURE 1: Energy balance for salt-gradient solar ponds at various levels.

In an actual salt-gradient solar pond, there are three distinct layers (as shown in Fig. 1): A) surface zone, B) nonconvective zone, and C) storage zone. The surface zone is the topmost layer of about 0.25 meter in thickness. In this zone, convection takes place because of wind, evaporation, and surface cooling. In this zone, the salinity is minimum but uniform. The nonconvecting or gradient zone is just below the surface zone and has a steep salinity and temperature gradient. In this zone, convection is suppressed. This zone is about 0.8 to 1.5 meter thick with the optimum thickness of about 1.0 meter. The third zone has almost uniform temperature and salt concentration. This layer is typically 1.0 meter deep for a workable pond. It can, however, be lowered to several meters.

The performance of a salt-gradient solar ponds is controlled by several parameters pertaining to thermal, optical, and other physical properties of the pond, and also ambiental effects such as insolation, temperature, wind, soil properties, and so forth. To understand its working, a pond requires a mathematical modeling, which can be found in the literature (see, for example, Lodhi, 1987*c*, and Ortabasi and Grugenci, 1983).

ECONOMIC FEASIBILITY OF SOLAR PONDS ON THE HIGH PLAINS

Experience has proved clearly that for thermal application salt-gradient solar ponds are quite competitive. For example, energy cost is about \$0.44 per kWhr based on the analysis of Tabor (1982). In terms of equivalent cost of fuel oil, the cost of thermal energy available from solar ponds is \$41 per ton at a conversion efficiency of 75 percent. The current oil prices in most places are in the order of $250 to $300 per ton. The energy extracted from solar ponds thus is six times cheaper than fuel oil heating. As far as the electricity production is concerned, solar ponds do not have such a clear edge over competitors when land, water, and salt, have to be bought. These items, as they are priced at the present time, would make electrical power production too costly from solar ponds, thus limiting the use of solar pond electrical power plants. However, even at those rates solar pond electrical power production becomes competitive in areas of low-density population where other alternatives are not available or are expensive.

If the cost of the land, liner, water, and salt are eliminated or cut down appreciably, salt-gradient solar ponds would become a great gift for low-grade thermal energy, electrical energy, and even for hydrogen energy. Consider this possibility on the Southern High Plains, which extend over western Texas and eastern New Mexico. In this area, climatological and geological features are highly favorable for solar ponds. There are water and salt sources for this purpose in alkaline lake basins. Crude oil production in this area produces a bulk of brine as nuisance value from a great many producing wells. The use of this brine would be not only an asset for solar ponds in this region but it would generate a revenue by providing the dumping site for the disposal of brine. Utilization of this brine would reduce the cost of energy production from the salt-gradient solar ponds in the High Plains region. There has been some concern recently about disposal of the excessive amount of salt available from the underground cavity to be dug in the salt stratum for deposition of radioactive waste material, if and when one of the potential sites is used. This excavated salt could become a substantial saving in the cost and transportation of salt for proposed solar ponds. The disposal fee for removing the salt from the radioactive material repository site, if handled by the same establishment that also operates the proposed solar pond project, would generate an income. The land to be used would be in one of the nearby alakaline lake basins, which is not otherwise of much use. The soil texture is such that one would require a minimal liner. The clay texture would provide a reasonably natural insulation. The absence of organic material in the clay does not offer any potential threat of formation of gas. A brief review is given of these alkaline lake basins on the Southern High Plains as potential sites for salt-gradient solar ponds and thus a huge source of cheap thermal, electrical, and even hydrogen energy.

Parameters Important for Construction and Maintenance of Solar Ponds

The cost of a salt-gradient solar pond depends on a number of factors that may include the climatological conditions existing at the proposed site and its geotechnical features, land in relation to environmental impact, water, salt, cost of earth moving, labor needed at different stags of construction, cost of liner with respect to the soil, and size of the pond. One should investigate well before starting the design of a solar pond at a particular location in order to make it cost effective. These features are naturally favorable in the High Plains region.

Climatological Conditions

The importance of knowing insolation and ambient temperature is obvious. Other important parameters involved are precipitation, evaporation, and wind data. While precipitation is important for collecting water for maintenance of the required level of the solar pond, severe rainfall can adversely affect pond temperature. It may excessively dilute the brine and overflow the pond or accumulate water in the proximity of the pond. It is desirable to have some rain but not enough to exceed evaporation. The large amount of isolation and high ambient temperature in the High Plains region do favor the efficient working of a solar pond. The evaporation rate should be determined as it will in turn determine the water requirements for operating the pond.

The sheer stress due to wind can create waves on the large surface area of the pond. A rough estimate indicates that wind blowing in the neighborhood of 15 meters per second (54 kilometers per hour) can create waves of six centimeters amplitude and 40 centimeters length on the surface of a pond 25 meters long. Strong winds on the High Plains are quite frequent in spring, which may thus affect adversely the working of a solar pond. However, this can be handled by using various types of wave suppressors and stabilizers. The technique is so well proven that even violent gusts of wind blowing at 100 meters per second have been reported to have no adverse effect of any consequence on the pool.

A pollution-free environment is important for efficient functioning of the pond. It is desirable not to have airborn material rejected from the industrial process like organic particles and dust.

Water Source

Availability and quality of the water is essential. The water used should be clear and transparent to solar radiation. Use of brackish water from regional alkaline lakes, as long as it is clear, is more desirable in saving the cost of salt. These alkaline basins are abundantly found on the High Plains, thus offering most promising potential for solar bonds (see Table 2). In eastern New Mexico some of the alkaline lake basins to be mentioned are:

Big Salt Lakes—The Big Salt Lake basin is about 19 square kilometers in area and is located about 25 kilometers southeast of Portales, New Mexico.

TABLE 2. Alkaline lake basins of the Southern High Plains in Texas (a partial list).

Western Texas	Salinity*	Area (km^2)	Remarks
Terry County			
Brownfield Lake	High	9	Unutilized
Mound Lake	Very high	10	Unutilized
Rich Lake	Very high	7	Salt mining
Gaines County			
Cedar Lake	Very high	9	Salt Depository
McKenzies Lake	Low	13	
Lamb County			
Bull Lake	High	5	Unutilized
Lynn County			
Mound Lake	Very high	10	Unutilized
Double Lake	Very high	9	Unutilized
Twin Lake	Moderate	5	Unutilized
Gooch Lake	High	4	Unutilized
Gutherie Lake	High	4	Unutilized
Skeen Lake	High	3	Unutilized
Tahoka Lake	High	5	Unutilized
Wilson Lake	High	2	Unutilized
Frost Lake	High	1.5	Unutilized
Bailey County			
Coyote Lake	Very high	8	Unutilized
Baileyboro Lake	High	4	Unutilized
Monument Lake	Moderate-high	7	Unutilized
Muleshoe Lake	High	5	Unutilized

*Salinity: Low—0 to 2 percent; moderate—two to four percent; high—four to six percent; very high—six percent and more.

Small Salt Lake—The Small Lake basin is about eight square kilometers in area and is located about 22 kilometers southeast of Portales, New Mexico.

Tierra Blanca Lake—The Tierra Blanca Lake basin is about five square kilometers in area and is located about 25 kilometers west of Portales, New Mexico.

An unnamed saline lake is about four square kilometers in area and is located about 3.2 kilometers northwest of Floyd, New Mexico.

Salt and Its Availability

Availability of salt obviously is important for salt-gradient solar ponds. The amount of salt needed is huge. For example, in the surface layer where the density is minimum about 25 kilograms per cubic meter of salt is needed for maintaining a specific gravity of 1.018 in the solution. In the nonconvecting zone and lower zone, it is much higher. In the storage layer, the salt concentration is about 260 kilograms per cubic meter for maintaining a specific gravity of 1.170 there. In the salt-gradient zone, salt concentration is between the two aforementioned figures. If the cost of the salt is more than $15 per ton the economic feasibility goes against the solar pond. There are three potentionally plentiful sources of salt in the High Plains region which are not now utilized. They are: a) brackish water in alkaline lakes, b) brine produced from oil fields, and c) salt to be excavated from sites for repository nuclear wastes.

Soils and Liner

Soil texture could be an effective parameter in determining the economic feasibility of a solar pond. Soil characteristics with respect to insulation, seepage, and infiltration of brine are particularly important in determining the cost of construction and operation of solar ponds. Generally, fine-textured soil areas have a greater number of large lakes on the High plains. Some of the larger playas are on the loessic-type soils. The sediments of the playas consist of thick smectitic and other expading clays that permit minimal infiltration into the underlying horizons of caliche and other strata. These characteristics will result in excellent heat insulation at the bottom and on the sides of the pond, and lack of seepage and infiltration below the lake. Consequently, the infrastructure costs could be reduced with minimal use of liners, insulating materials, and excavations that contribute to the major expenditures in construction and operation of solar ponds.

Concluding Remarks

The High Plains region of western Texas and eastern New Mexico is strongly favored for cost-effectiveness of solar ponds due to high direct solar beam averages in the area, the availability of naturally formed alkaline lake basins, salt and brine sources, and a high demand for energy at a moderately high temperature. Examination of the economic feasibility of solar ponds for small-scale electricity production, application in ranching, farming, oil production, and in a number of industrial processes, and over a wide range of assumptions indicate its attractiveness (Manning et al., 1983; Lambert et al., 1983). The development of a pond in an alkaline basin is possible in a cost-effective manner with available technology. Brine procurement from oil fields would enhance its cost effectiveness. Alternatively, solar ponds could be a good financial investment for many operators of oil-producing facilites.

A solar pond facility will have insignificant or no adverse effect on the environment considering land use compatibility, vegetation loss, climate and air quality, visual quality, noise, impact of construction phases, and so forth. The most serious potential environmental impact involves the quality of the groundwater resources of Ogallala Aquifer due to a possible brine leakage from ponds (1982). This concern is addressed by existing salt water disposal regulations of the Texas Railroad Commission.

This concept, I hope, will be of interest to local farmers, ranchers, oil and gas producers, utility companies, relevant industrialists, the Texas Railroad Commission, the Department of Energy, and other organizations.

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LITERATURE CITED

Beard, J. T., F. A. Iachetta, and L. U. Lilleleht. 1978. Annual collection and storage of solar energy for the heating of a building. Univ. Virginia Rept. UVA/532142/MAE78, 102 pp.

Bryant, H. C. 1981. Solar Energy—the salty solution. New Scientist, 17:734-735.

Cavalleri, G., and G. Folizno. 1977. Proposal for the production and seasonal storage of hot water to heat a city. Solar Energy, 19:677-683.

Davey, T. R. A. 1968. The Aspendale solar pond. Rept. CSIRO, Australia, R15:1-26.

Dickinson, W. C., A. F. Clark, J. A. Day, and L. F. Wouters. 1976. The shallow solar pond energy conversion system, Solar Energy, 18:3-10.

Edesses, M. 1982. On solar ponds: salty fare for the world's energy appetite. Technology Rev., 85:59-68.

Jayadev, T. S., M. Edesse, and J. Henderson. 1979. Solar pond concepts: old and new. Proc. 14th IECEC Conf., Amer. Chem. Soc., 1:45-48.

Kalecsinsky, A. O. 1902. Ungarische warme und heisse kochsalzeln, Ann. D. Physick, 7:408-416.

Lambert, B. K., J. E. Jonish, P. A. Chamberlain, L. V. Urban, and J. P. Craig. 1983. Energy availability and economic assessment of salt gradient solar pond, TENRAC Rept. 82-S-2-1: v + 100.

Lin, E. I. H. 1982. A review of salt gradient solar pond technology. JPL Publication, Pasadena, California, 81-116.

Lodhi, M. A. K., 1987*a*. Hydrogen production from renewable sources of energy, Internat. J. Hydrogen Energy, 12:461-467.

———. 1987*b*. Hydrogen City. Internat. J. Hydrogen Energy, 12:783-803.

———. 1987*c*. Thermal collection and storage of solar energies. Pp. J1-J56, *in* Workshop on Silicon Technology Development and its Role in the Sun Belt Countries. (A. Mulfi and T. N. Vezirogu, eds.), Nat. Inst. Silicon Tech., Islamabad, Pakiston.

Manning, R. A., T. P. Wisneski, and E. E. Clark. 1983. Conceptual study of a salt gradient solar pond in the crude oil production industry. TENRAC Rept. 82-S-3-3, EDF-086: vii + 76.

Margen, P. 1978. A central system for annual solar heat. Solar Age, 3:22-26.

Ortabasi, U., and H. Gurgenci. 1983. An overview of solar ponds for process heat and power. Pp. 87-137, *in* Lecture Book Intnat. Symp. Workshop on Renewable Energy Sources (M. K. Bhatti et al., ed.) PCSIR, Lahore, Pakistan, 449 pp.

Ortabasi, U., F. Dyksternhuis, and N. D. Kanshika. 1989. Honeycomb stabilized saltless solar pond. Solar Energy, in press.

Rabl, A., and C. E. Nielsen. 1975. Solar ponds for space heating. Solar Energy, 17:1-12.

Reeves, C. C. Jr. 1989. A proposal sequential development of lake basins, Southern High Plains, Texas and New Mexico. Proc. Symp. Quaternary Blackwater Draw and Tertiary Ogallala Formation, Bur. Econ. Geol., Austin, Texas, in press.

Tabor, H. 1963. Large-area solar collectors (solar ponds) for power production. Solar Energy, 7:189-194.

———. 1981. Solar ponds. Solar Energy, 27:181-194.

Weeks, D. D., S. M. Long, R. E. Emery, and H. C. Bryant. 1981. What happens when a solar pond boils? Proc. Southwest Regional Conf. Astronomy and Astrophysics, 8:540-545.

THE VEGETATION OF A PINE-OAK FOREST IN FRANKLIN COUNTY, TEXAS, AND ITS COMPARISON WITH A SIMILAR FOREST IN LAMAR COUNTY, TEXAS

Robert E. Wilson

Department of Biological Sciences, East Texas State University, Commerce, Texas 75428

Abstract.—A vegetational analysis was conducted on a mature forest in Franklin County, Texas. There were three distinct layers in the forest. Dominant canopy trees were *Pinus echinata* and *Quercus alba.* Dominant species in the understory were *Toxicodendron radicans* (shrub-seedling layer) and *Chasmanthium sessiliflorum* (herbaceous layer). *Liquidambar styraciflua* and several species of *Quercus* were reproducing successfully, but no seedlings or young saplings of *P. echinata* were found. The evidence indicated that this was a successional community in which pine was giving way to oaks and sweet gum. Data from this successional pine-oak forest were compared with that from a climax *P. echinata-Q. alba* stand in Lamar County, Texas. *Key words: Pinus*; *Quercus*; vegetational analysis; eastern Texas forests.

Wilson and Hacker (1986) reported that the pine-mixed hardwood forests in northeastern Texas have been poorly studied. The forest described here is in south-central Franklin County, Texas, and superficially resembles the relict community in Lamar County known locally as the Sanders Cove Pines (Wilson and Hacker, 1986). About 110 kilometers of forest and grassland separate the two communities. The study community is contiguous with the pine-oak forests that extend eastward into Arkansas and Louisiana, and lies within the area described by Tharp (1926, 1939) as oak-hickory forest. It was shown by McMahan et al. (1984) to be in an area of pine-oak forests. This study was conducted to determine the composition of the forest in the Franklin County area and to compare the structure of that community with the relict forest in Lamar County.

Study Area

The stand that was studied is on the southwestern shore of Lake Cypress Springs, about 15 kilometers northeast of Winnsboro, Texas, and is located within the Pine Valley lakeshore property development. Access to the site is from Farm Road 3007 near its intersection with Texas Highway 115. At the time of the study, streets on the site had been paved and lots had been surveyed. Clearing and construction had been started on two or three lots. Except for those lots and the streets and property lines, the forest was undisturbed.

The presence of numerous old sawed pine stumps on the site indicated that this was not a virgin stand. In the early part of the century, lumbering was important in the economy of Franklin County, but is a minor industry today (Kingston, 1985). The oldest short-leaf pine (*Pinus echinata* Mill.) was 47 years old, suggesting a timber harvest just prior to World War II.

Climatological data were obtained from Kingston (1985). The climate of the study area is temperate, with moderate winters and hot summers. The mean January low temperature is 2°C, and the mean July high is 35°C. The record high and low temperatures are 41°C and −12°C, respectively. The average annual rainfall is 113.7 centimeters, and the distribution is relatively uniform throughout the year, except for slightly increased precipitation during April and May, and reduced precipitation during August and September. The greatest monthly rainfall is in May, with an average of 13.3 centimeters. September is the driest month, with average precipitation of 7.4 centimeters. The average growing season is 234 frost-free days (March 23 to November 12).

The elevation varies from 116 to 131 meters above mean sea level. The terrain is rugged, with ridges and hills dissected by numerous deep, steep-sided, sandy-bottomed small streams. Many of these streams are spring fed with year-round flow; others carry water only in the winter and spring months. The streams drain into Lake Cypress Springs, in the Big Cypress Creek watershed. Area soils are fine sands or fine sandy loams of the Darco, Duffern, and Tenaha groups. They are described as acid and are well to excessively drained (personal communiation from United States Department of Agriculture, Agricultural Stabilization and Conservation Agency, Mt. Pleasant, Texas, July 1986).

METHODS

An existing survey line equidistant between two streets was selected for use as a transect. This line was approximately 850 meters in length and had been marked with stakes and flags at the corners of all lots. A belt of one to two meters in width had been cleared along the line. Fifty sets of nested quadrats, placed two meters from the transect, were established on alternate sides of the transect. These sets were spaced at 10-meter intervals. Trees and woody vines of 0.5 centimeter or more in diameter at approximately 1.4 meters above the soil surface—diameter breast high (dbh) $\geq$ 0.5 centimeter—were included in the canopy. Individuals of each canopy species were recorded by size and number from five-meter by five-meter (25 square meters) quadrats. Large canopy trees selected for age determinations were cored with a 1.0-centimeter by 90-centimeters increment borer. The ages of saplings were determined by sectioning with a bow saw about five centimeters from the soil surface. Annual rings were counted with the aid of a dissecting microscope. Heights of canopy trees were determined by use of a clinometer.

Shrubs, woody vines, and woody saplings of less than 0.5 centimeter dbh were counted in two-meter by two-meter (four square meters) quadrats located at the initial corners of each nest of quadrats. Coverage in square centimeters was estimated for each plant. Herbaceous species were counted in one-meter square quadrats located in the initial corners of each nest of quadrats. Coverage in square centimeters was estimated for each plant. Clumps of rhizomatous plants were treated as individual plants.

Correll and Johnston (1970), Gould (1975), and Vines (1960) were used for plant identification. The nomenclature used is that of Kartesz and Kartesz (1980).

Importance values (sums of relative density, relative dominance, and relative frequency) for all species were determined from the quadrat data. Relative dominance values were based on basal area for woody plants of 0.5-centimeter dbh or larger and on coverage for all others. Shannon-Weiner diversity indices for each of the three forest strata and for the community as a whole were calculated using the method given by Barbour et al. (1980).

A Hellige-Troug combination soil test kit was used to measure soil pH and nutrients. Soil texture was determined by means of the Bouyocos hydrometer method (Bouyocos, 1962). Elevations were measured with a hand-held Thommen aneroid altimeter calibrated at the normal water level of Lake Cypress Springs (114 meters above mean sea level).

RESULTS

Soils

Surface soil samples were collected from quadrats 1, 10, 20, 30, 40, and 50. The sample from quadrat 50 was a gray fine sand; all others were

TABLE 1. Analysis of surface soils from a Franklin County, Texas, pine-oak forest. Concentrations indicated by the symbol "<" are less than the lower limit of the Hellige-Troug soil test.

		Mineral nutrient (ppm)							Particle size distribution (%)		
Sample	pH	P	K	Ca	Mg	NO_3	NH_4	Sand	Silt	Clay	Texture
1	5.0	<15.0	126.1	<40.0	<150	3.0	<3.0	77	5	18	Sandy loam
2	5.5	25.2	50.5	<40.0	<150	<3.0	<3.0	67	15	18	Sandy loam
3	5.5	<15.0	37.8	378.4	<150	<3.0	<3.0	80	15	5	Sandy loam
4	6.0	<15.0	50.5	<40.0	<150	<3.0	<3.0	83	4	13	Sandy loam
5	37.5	<15.0	75.7	<40.0	<150	3.2	<3.0	73	5	22	Sandy loam
6	6.0	<15.0	138.7	378.4	<150	6.3	<3.0	87	5	8	Sand

cream- or tan-colored fine sandy loams. The soil pH ranged from 4.5 to 6.0. Mineral nutrient concentrations were low. Soil texture, pH, and mineral nutrient concentrations are shown in Table 1. Observed substrata were gray to red clays and fractured red or brown sandstone.

Canopy Species

Canopy trees were as tall as 23.5 meters in height (*Quercus alba* L.) and reached 74.7 centimeters in diameter (*Q. stellata* Wang.). Most of the mature trees were between 19 and 21 meters tall. Most of the older hardwoods were hollow, allowing only a few of the largest trees to be aged. The oldest tree found was 68 years of age (*Q. alba*). Most of the large *P. echinata* were from 40 to 45 years old (the oldest was 47). *Pinus echinata* saplings were 12 or 13 years old and ranged from 1.5 to 2.7 centimeters in diameter five centimeters above the soil surface.

The canopy (Table 2) was dominated by *P. echinata*. The next most important species in order were *Q. alba, Liquidambar styraciflua* L., *Q. falcata* Michx., and *Q. Stellata*. The relatively high importance value (11.21) for *Q. stellata* is misleading, as only four individuals were found. One of these had a diameter of 74.4 centimeters, causing post oak to have the fifth largest relative dominance in the entire community. *Ulmus alata* Michx. and *U. crassifolia* Nutt. were the most important lower canopy trees. Less common canopy trees were *Nyssa sylvatica* Marsh., *Q. marilandica* Muenchh., *Q. shumardii* Buckl., *Q. nigra* L., three species of *Carya*, and eight other species of small trees, each of which had importance values of less than 4.0. Among the seven species of woody vines, *Smilax laurifolia* L., *Toxicodendron radicans* (L.) Kuntze, and *Berchemia scandens* (Hill) K. Koch had the highest importance values. Twenty-seven species were identified in the canopy layer. The average density for all canopy species was 0.24 plants per square meter. Forty-nine of the fifty quadrats had woody plants large enough to be counted in the canopy.

The distribution by size classes is shown in Table 3. None of the trees was found in all size classes. *Pinus echinata* ranged in dbh between 1.0

TABLE 2. Relative density, relative dominance, relative frequency, and importance values of the canopy species of a pine-oak forest in Franklin County, Texas. Relative dominance is derived from basal area. Importance values represent the sums of relative density, relative dominance, and relative frequency.

Species	Relative density (percent)	Relative dominance (percent)	Relative frequency (percent)	Importance value
Pinus echinata	23.25	44.06	16.23	83.54
Ulmus alata	14.12	2.33	12.99	29.44
Quercus alba	7.97	12.12	9.10	29.19
Liquidambar styraciflua	9.96	11.66	7.14	28.76
Quercus falcata	4.31	14.70	7.14	21.27
Ulmus crassifolia	7.64	0.66	8.44	16.15
Quercus stellata	0.66	9.26	1.30	11.21
Smilax laurifolia	6.98	0.01	1.30	8.29
Toxicodenron radicans	2.66	0.08	3.90	6.64
Nyssa sylvatica	1.99	1.18	3.25	6.41
Quercus marilandica	2.99	0.78	3.25	6.31
Carya texana	2.33	0.06	3.90	6.29
Quercus shumardii	1.33	2.04	2.60	5.97
Vitis rotundifolia	2.99	0.08	2.60	5.67
Berchemia scandens	3.32	0.03	1.30	4.65
Juniperus virginiana	1.33	0.12	1.95	3.39
Quercus nigra	0.99	0.14	1.95	3.01
Ilex decidua	0.99	0.04	1.95	2.98
Carya tomentosa	0.99	0.02	1.95	2.96
Parthenocissus quinquifolia	0.99	0.01	1.95	2.94
Carya laciniosa	0.99	0.01	1.30	2.31
Crategus spathulata	0.66	0.11	0.65	2.07
Prunus serotina	0.66	0.07	1.30	2.03
Others[a]	1.98	0.46	2.60	4.73
Total	102.08	100.01	100.03	301.10

[a] Other species (in decreasing order of importance value): *Aralia spinosa, Meliz azedarach, Crataegus crus-galli, Cornus florida.*

and 35 centimeters. Within the quadrats, no evidence of recent reproduction in *P. echinata* was seen. *Quercus alba* and *L. styraciflua* were successfully reproducing, but none was larger than 20 centimeters in diameter. *Quercus falcata* was observed in more size classes (six of nine) than other canopy species, but ranked fifth in importance value and had only limited reproduction.

Shrubs and Seedlings

The shrub and seedling layer (Table 4) was dominated by *T. radicans*, which had an importance value of 61.26. *Ulmus alata, Q. nigra, L. styraciflua*, and *S. laurifolia* all had importance values of about 20. These five species and *Q. alba* represented almost half of the combined importance values for the shrub layer. Of the 23 canopy species with the

TABLE 3. Size classes and importance values for major trees in the canopy layer of a pine-oak forest in Franklin County, Texas. Number of individuals in the <0.5-centimeter class were counted in two-meter by two-meter quadrats; all other numbers of individuals and importance values were obtained from five-meter by five-meter quadrats.

Species	Importance value	Size class (dbh in cm)								
		<0.5	0.5-0.9	1-10	11-20	21-30	31-40	41-50	51-60	60+
Pinus echinata	83.54			31	15	16	6		2	
Ulmus alata	29.44	30	4	34	4					
Quercus alba	29.19	29		18	5					
Liquidambar styraciflua	28.76	21	6	18	4					
Quercus falcata	26.16	8		2	4	2	3	2		
Ulmus crassifolia	16.15	9	15	7						
Quercus stellata	11.21	2	1							1
Nyssa sylvatica	6.41	10		4		2				
Quercus marilandica	6.31	14	3	4	2					
Carya texana	6.29	7	4	3						
Quercus shumardii	5.95	4		3						
Others		170	34	74						
Total		304	66	167	34	20	10	2	2	1

highest importance values, only four were not recorded from the shrub-seedling quadrats (*P. echinata, Parthenocissus quinquifolia* (L.) Planch., *Carya laciniosa* (Michx. f.) Loud., and *Crataegus spathulata* Michx.). *Calicarpa americana* L., *Ilex decidua* Walt., and *Acer rubrum* L. also were found in the shurb quadrats. The average density for shrubs and seedlings was 1.92 plants per square meter. Only one quadrat had no plants of less than 0.5 centimeter dbh.

Herbaceous Vegetation

Data from the herbaceous quadrats are presented in Table 5. A total of 31 species was recorded in the herbaceous layer. The average density of this stratum was 3.22 plants per square meter. Four quadrats were found to have no herbaceous plants. The dominant herbaceous plant was the grass, *Chasmanthium sessiliflorum* (Poir.) Yates., with an importance value of 94.16. The two next most important were the grasses *Cynodon dactylon* (L.) Pers. and *Andropogon gerardi* Vitman. These three grasses had a total importance value of 155.05, more than half of the combined importance values for all herbaceous species.

Diversity

Shannon-Weiner diversity indices were calculated for all three strata and for the community as a whole (Table 6). Diversity was greatest in the shrub layer and least in the canopy. Diversity for the entire community was greater than the diversity for any single stratum.

TABLE 4. Relative density, relative dominance, relative frequency, and importance values for woody species in the shrub layer of a pine-oak forest in Franklin County, Texas. Relative dominance is derived from coverage. Importance values represent the sums of relative density, relative dominance, and relative frequency.

Species	Relative density (percent)	Relative dominance (percent)	Relative frequency (percent)	Importance value
Toxicodenron radicans	15.10	36.36	9.80	61.26
Ulmus alata	7.81	9.09	6.45	23.35
Quercus nigra	8.85	2.73	10.22	21.80
Liquidambar styraciflua	5.73	9.09	6.98	21.80
Smilax laurifolia	8.33	9.09	6.98	21.72
Quercus alba	7.81	4.55	5.91	18.27
Ulmus crassifolia	2.60	7.27	4.30	14.17
Quercus marilandica	3.65	2.73	6.45	12.83
Vitis rotundifolia	3.65	2.73	5.38	11.76
Parthenocissus quinquifolia	6.25	0.91	4.30	11.46
Carya texana	3.13	2.73	3.76	9.62
Smilax rotundifolia	3.13	0.91	5.38	9.42
Berchemia scandens	2.08	0.45	2.69	6.22
Nyssa sylvatica	2.60	0.91	2.69	6.20
Smilax bona-nox	3.65	0.18	2.15	5.98
Callicarpa americana	1.04	2.73	2.15	5.92
Quercus shumardii	1.04	3.64	0.54	5.22
Quercus falcata	1.56	0.09	2.15	3.80
Acer rubrum	1.04	0.91	1.61	3.56
Ilex decidua	2.60	0.27	0.54	3.41
Rubus sp.	1.04	0.29	1.08	2.41
Others[a]	5.72	1.95	5.94	13.61
Total	99.97	102.10	95.85	297.21

[a] Other species (in decreasing order of importance value): *Carya tomentosa, Gleditsia triacantha, Aesculus pavia, Quercus stellata, Morus rubra, Baptisia sphaerocarpa, Rhus copallina, Prunus serotina, Viburnum prunifolium, Juniperus virginiana.*

DISCUSSION

The Franklin County, Texas, study-community was a mature, but not virgin, stand. The pines had been harvested in about 1940. There was no evidence that hardwoods had been harvested. The highly leached, acidic soils were cream, tan, or gray fine sands or fine sandy loams, with low concentrations of mineral nutrients. The forest had distinct canopy, shrub and seedling, and herbaceous strata. A vine stratum was not designated, although there were seven species of woody climbers in the community, with large numbers of individuals in each species. For convenience, woody vines were treated as canopy or shrub species, depending upon the dbh of the individuals.

The canopy layer was dominated by *P. echinata. Quercus alba* had the second highest importance value in the canopy, followed by *Q. falcata*

TABLE 5. Relative density, relative dominance, relative frequency, and importance values of the herbaceous species of a pine-oak forest in Franklin County, Texas. Relative dominance is derived from coverage. Importance values represent the sums of relative density, relative dominance, and relative frequency.

Species	Relative density (percent)	Relative dominance (percent)	Relative frequency (percent)	Importance value
Chasmanthium sessiliflorum	13.66	55.50	25.00	94.16
Cynodon dactylon	12.42	5.55	10.23	28.20
Andropogon gerardi	1.24	18.18	2.27	21.69
Hypericum drummondii	8.69	3.09	5.69	16.24
Lindheimeria texana	7.45	1.82	6.82	16.09
Clitoria mariana	4.97	0.82	5.68	11.47
Valeriana woodsiana	6.83	0.27	2.27	9.37
Rudbeckia hirta	2.48	1.82	4.55	8.85
Monarda punctata	4.97	0.73	2.27	2.97
Commelina erecta	2.48	0.08	4.55	7.11
Rumex crispus	4.97	0.27	1.14	6.38
Eriogonum longifolium	4.35	0.55	1.14	6.04
Oxalis dillenii	2.48	0.05	3.41	5.94
Urtica chamaedryoides	0.62	3.64	1.14	5.40
Daucus carota	2.48	0.09	2.27	4.84
Chenopodium album	3.11	0.09	1.14	4.34
Panicum oligosanthes	1.86	0.91	1.14	3.91
Centrosema virginianum	1.24	0.36	2.27	3.87
Desmodium paniculatum	2.48	0.07	1.14	3.69
Hymenopappus artemesifolius	1.86	0.18	1.14	3.18
Cnidoscolus texanus	0.62	1.27	1.14	3.03
Desmodium glabellum	1.24	0.18	1.14	2.56
Erigeron philadelphicus	1.24	0.07	1.14	2.45
Physalis heterophylla	0.62	0.55	1.14	2.31
Carex sp.	0.62	0.36	1.14	2.12
Others[a]	4.96	4.08	9.12	18.16
Total	99.58	99.49	100.08	299.52

[a] Other species (in decreasing order of importance value): *Taraxacum officinale, Campsis radicans, Opuntia compressa, Rhynchosia latifolia, Baptisia sphaerocarpa, Aster subulatus.*

and *L. styraciflua.* Two other species of *Quercus* had lesser importance values. The elms, *U. alata* and *U. crassifolia*, were the most important among the smaller canopy species.

The shrub-seedling layer contained almost all of the species found in the canopy. Notably missing was *P. echinata.* The clearly dominant species in the shrub-seedling layer was *T. radicans.* Most other species were seedlings of canopy trees, except for woody vines, which included three species of *Smilax, Vitis rotundifolia* Michx., *P. quinquifolia, B. scandens*, and the shrubs *C. americana* and *I. decidua.* One tree species, *Acer rubrum*, was found only in the shrub and seedling layer.

Among the 31 species of herbaceous plants, *C. sessiliflorum* was dominant. This species, *C. dactylon*, and *A. gerardi* constituted more

TABLE 6. Shannon-Weiner diversity indices for canopy, shrub-seedling, and herbaceious layers and for the combined community in a pine-oak forest in Franklin County, Texas.

Layer	Diversity index	Number of species
Canopy	3.75	28
Shrub-seedling	4.23	31
Herbaceous	4.16	32
Combined	5.45	74

than half of the combined importance values of all of the herbaceous plants. Of the remaining herbaceous species, none was considered to be significant in the structure of the community.

The lack of reproduction in the dominant canopy tree, *P. echinata*, is noteworthy. No pines younger than 12 years of age were found in the quadrats or near the transect, and few cones were observed. There was no evidence of southern pine beetle infestation or other pine insects or diseases. Seedlings were observed only under two isolated pines in a field approximately 1.5 kilometers from the transect. No other pine seedlings were found in the entire stand. The lack of reproductive success over the past 11 years suggests that the pines are not being replaced as they die out. Of the 128 seedlings of the larger canopy trees, oaks (57) and *L. styraciflua* (21) accounted for 61 percent of the reproduction. Only seven seedlings of the three species of *Carya* were seen. This stand of shortleaf pine-white oak forest may be destined to become a mixed oak-sweet gum community.

In comparison, the relict Sanders Cove Pine community in Lamar County was found to be a climax forest (Wilson and Hacker, 1986), whereas the Franklin County stand was a successional community. Several tree species were found in the Sanders Cove Pines in Lamar County that were not seen in the Franklin County stand (Table 7), such

TABLE 7. Comparison of the numbers of species found in the various strata of the pine-oak forest study sites in Franklin and Lamar counties.

Strata	Franklin County	Franklin but not Lamar	Lamar County	Lamar but not Franklin	Both sites
Canopy[a]	27	12	27	12	15
Upper canopy	11	3	10	2	7
Lower canopy	16	5	17	7	6
Climbers	7	4	7	4	3
Shrub-seedling	31	14	34	17	17
Herbaceous	31	29	12	10	2
Combined totals	63	42	43	28	21

[a] Includes upper canopy, lower canopy, and woody vines of ≥0.5 centimeter in dbh.

as *Betula nigra* L., *Carya ovata* (Mill.) K. Koch, *Forestiera pubescens* Nutt., *Ilex vomitoria* Ait., and *Prunus mexicana* Wat. Found in Franklin County, but not in Lamar County were *Aralia spinosa* L., *L. styraciflua, Melia azedarach* L., *Nyssa sylvatica* Marsh., and *Prunus serotina* Ehrh. Seven species of woody climbers were found in both communities, although only three species were common to both. Importance values for all climbers combined was approximately 120 in the Franklin County community, but only about 45 at Sanders Cove.

In both communities, *T. radicans* was dominant in the shrub-seedling layer, and a grass was dominant in the herbaceous stratum (*C. sessiliflorum* in Franklin County and *C. dactylon* in Lamar County). Shannon-Weiner diversity indices were consistently higher in the Sanders Cove Pine community than in the Franklin County community, regardless of the number of species found in each stratum. Many species in the Franklin County stand were represented by only a few individuals, whereas, in the Lamar County stand, a larger number of individuals was found in most species. A total of 63 species was found in the Franklin County stand and 43 in the Lamar County stand. Only 21 of these were common to both communities. The difference in species present was most pronounced in the herbaceous layer, where only two species were common to both study areas.

A comparison of the evidence presented in this paper with that reported from Lamar County, Texas (Wilson and Hacker, 1986), suggests that the *P. echinata-Q. alba* forests in northeastern Texas are of two different types. Canopy species that might be indicative of the Franklin County community are sweet gum (*L. styraciflua*) and black gum (*N. sylvatica*). *Pinus echinata* is less important there than in the Lamar County stand. It is possible that the relict community in Lamar County more closely resembles the pine-oak forests in southeastern Oklahoma and southwestern Arkansas than those in the Franklin County area. Additional studies are planned to determine if these are two distinct forest types or represent variations within a gradient series of communities.

LITERATURE CITED

Barbour, M. D., J. H. Burk, and W. D. Pitts. 1980. Terrestrial plant ecology. Benjamin/Cummings Publ. Co., Inc., Menlo Park, California, 604 pp.

Bouyocos, G. J. 1962. Hydrometer method improved for making particle size analyses of soil. Agron. J., 54:464-465.

Correll, D. S., and M. C. Johnston. 1970. Manual of the vascular plants of Texas. Texas Res. Foundation, Renner, Texas, 1881 pp.

Gould, F. W. 1975. The grasses of Texas. Texas A&M Univ. Press, College Station, 653 pp.

Kartesz, J. T. and R. Kartesz. 1980. Synonymized checklist of the vascular flora of the United States, Canada and Greenland. Univ. North Carolina Press, Chapel Hill, 494 pp.

Kingston, M. (ed.). 1985. The Texas almanac. 1986-1987 ed., The Dallas Morning News, Dallas, 768 pp.

McMahan, C. A., R. G. Frye, and K. L. Brown. 1984. The vegetation types of Texas. Texas Parks and Wildlife Dept., Austin, 40 pp. + map.

Tharp, B. C. 1926. Structure of Texas vegetation east of the 98th meridian. Univ. Texas Bull., 2606:1-96.

———. 1939. The vegetation of Texas. Texas Acad. Sci., Nontech. Publ. Ser., The Anson Jones Press, Houston, 74 pp.

Vines, R. A. 1960. Trees, shrubs and woody vines of the Southwest. Univ. Texas Press, Austin, 1104 pp.

Wilson, R. E. and D. Hacker. 1986. The Sanders Cove pines: vegetational analysis of a *Pinus echinata-Quercus alba* community in northern Lamar County, Texas. Texas J. Sci., 38:183-190.

THE MAMMAL FAUNA OF COKE COUNTY, TEXAS

Lynn A. Simpson and Terry C. Maxwell
Department of Biology, Angelo State University, San Angelo, Texas 76909

Abstract.—Specific distributional records of mammals in much of central Texas are lacking. This survey describes the mammalian fauna of Coke County and is the first for this region of Texas. *Key words:* mammals; fauna; Texas.

Knowledge of the distribution of mammals in central Texas is incomplete; in-depth surveys are lacking. Hall (1981) and Davis (1974) provided the only available distribution maps for the state as a whole, but many local areas, including Coke County, never have been adequately sampled for mammalian species. This study provides the first description of the mammalian fauna of Coke County and western Edwards Plateau of Texas.

Mammal records from Coke County previously were represented only by a few incidental collections. Davis' (1974) distributional maps indicate that specimens of some species (*Sylvilagus floridanus, Cynomys ludovicianus, Peromyscus leucopus, Vulpes vulpes, Urocyon cinereoargenteus*, and *Felis rufus*) have been taken in the county, but we were able to verify only one of these in a Texas collection. A few specimens, evidently unknown to Davis (1974), were found in collections at Angelo State University (*Geomys bursarius* and *Conepatus mesoleucus* and Midwestern State University (*Antilocapra americana*) prior to this study. To our knowledge, there are no additional scientific records or accounts known for Coke County mammals.

Coke County (Fig. 1) is located in west-central Texas, in the northwestern part of the Edwards Plateau, lying between 31° 42′ and 32° 05′ north latitude and between 100° 14′ and 100° 49′ west longitude (King, 1975). It covers an area of 585,000 acres (911 square miles) in a rectangular shape of approximately 34 miles east to west and 30 miles north to south.

Elevations range from about 1800 feet in the Colorado River valley to 2250 feet in the surrounding hills (Barnhill, 1974). The county has a mean January temperature minimum of 29°F and a mean July temperature maximum of 97°F. Mean annual precipitation is 20.48 inches (Anon., 1988) with much lost to runoff (Wilson, 1973).

Topography varies from the gentle slope of the Colorado River to steep hills running on both sides parallel to the river. Between the hills and river lies a gently sloping plain that averages 14 miles wide and 35 miles long (Brnovak, 1975). Numerous tributaries caused by runoff from nearby hills have worn deep, narrow courses across the valley (Barnhill, 1974). Major bodies of water are Oak Creek Reservoir, located in the

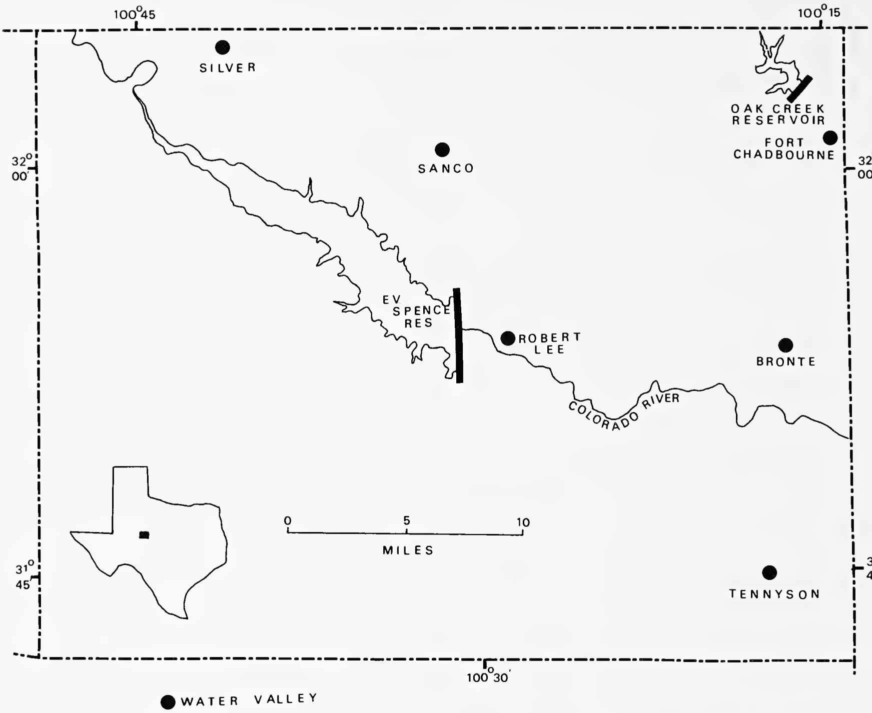


FIGURE 1. Map depicting the upper Colorado River drainages. Vertical lines at right angles to the rivers indicate the places Concho watersnakes were found. See text for details.

extreme northeastern corner of the county, and E. V. Spence Reservoir, located one mile west of Robert Lee. Spence Reservoir, when full, extends northwesterly approximately 18 miles (Brnovak, 1975), covering 2.2 percent of Coke County land area.

Ninety percent of the county is used for production of domestic livestock and deer or other wildlife (Barnhill, 1974). Overutilization has allowed for the invasion of mesquite (*Prosopis glandulosa*) and subsequent erosion of soil throughout. Mesquite and associated brush species are of such density today on the plains soils that the appearance is of a brushland. Historical accounts from the nineteenth century indicate that formerly these plains were often fairly open grasslands. Ormsby (1854), while a passenger on the Butterfield Overland Mail Route, described the area of the Colorado River Valley as a boundless prairie without trees or shrubs. Bailey (1899) described the Water Valley area, above the North Concho River in the southwestern corner of the county, as a mesquite plain with short grass and scattered shrubs.

Using vegetation, soil type, and topographic features (Barnhill, 1974), five basic mammalian habitats were recognized in this study. Limestone ledges, located at various places in the county, cover nine percent of the land area. Soils are shallow, clayey and calcareous on steep limestone ridges. Vegetation includes live oak (*Quercus fusiformis*), scrub oak (*Quercus mohriana*) and red-berry juniper (*Juniperus pinchotii*) along with a variety of grasses and forbs. Deep sands, located in the northwestern corner, cover five percent of the county's land area. Soils are characterized by gently undulating deep sand. Vegetation includes shin oak (*Quercus havardii*) and side-oats grama (*Bouteloua curtipendula*), with mesquite a common invader. Riparian habitat, along streams, covers four percent of the land area. Soils are fine sandy loams and silt loams adjacent to streams, with hackberry (*Celtis reticulata*), pecan (*Carya illinoiensis*), and mesquite the most common trees. Side-oats grama and silver bluestem (*Bothriochloa saccharoides*) are the dominant groundcover. Stony hills cover 18 percent of the county's land area. Topography and soils are gently to strongly sloping sandy loams with rock outcrops usually of sandstone or limestone. The sparse vegetation includes gramas (*Bouteloua* sp.) and bluebonnet (*Lupinus texensis*), with red-berry juniper and mesquite as invaders. Mesquite grassland, located throughout much of the county, covers 62 percent of the land area. Soils are a clay loam with little or no slope. The vegetation includes numerous grass species, with most areas heavily invaded by mesquite.

Collecting of specimens and observational records began on 22 April 1986 and continued to 20 December 1987. Mammals were collected with Museum Special snap traps, Sherman live traps, Havahart traps, Victor nos. 2 and 3 steel traps, Macbee-type gopher traps, pit fall traps, and mist nets. Additional specimens were salvaged from mammals killed along the road ways and obtained from professional trappers who capture furbearers and predators. Each specimen included the skull and, when possible, a museum skin, prepared following techniques described by Hall (1962). These specimens were deposited in the Angelo State University Natural History Collection.

Forty-eight locations were trapped for a total of 8190 trap nights (one trap per night equals one trap night). Trapping efforts in each habitat type were as follows: limestone ledges—1450 trap-nights; deep sands—1900; riparian—1000; stony hills—1625; and mesquite grassland—2215. Mist nets were operated on 24 nights in riparian habitats, with an average of eight nets set each night.

SPECIES ACCOUNTS

During the study, 474 specimens and numerous sightings were recorded representing 34 genera and 42 species. Thirty-four of these species are first records for Coke County. Three additional species are represented by old or unverifiable records. Species accounts include scientific and vernacular names, distribution in Coke County, number of specimens captured and specific locality data, ordered first from north to south and second from east to west. A summary of reproductive information and a specimen list in telegraphic style including dates of collection, habitat association, and individual specimen data (personal catalog number, reproductive data, measurements in millimeters of total length, tail length, length of hind foot, height of ear from notch, and in bats the lengths of the tragus and forearm), and type of specimen preparation may be found in Simpson (1988).

Didelphis virginiana Kerr, 1792 (Virginia opossum).—Opossums were taken from stony hill, limestone ledge, and mesquite grassland habitats. Additional sightings within the county indicate that the animal is common throughout.

Specimens (4).—9.9 mi. S Silver, 1; 2.6 mi. N, 1.3 mi W Robert Lee, 1; 5.4 mi. S, 7.5 mi. W Robert Lee, 1; 10.5 mi. S, 3.1 mi. E Robert Lee, 1.

Notiosorex crawfordi Coues, 1877 (desert shrew).—The single specimen taken in this study is the first Coke County record of this shrew, but the species was expected based on Davis' (1974) mapped distribution. Its apparent rarity may not reflect its true status, because few pit fall traps were utilized.

Specimens (1).—4.5 mi. S, 13.8 mi. W Robert Lee, 1.

Myotis velifer (J. A. Allen, 1890) (cave myotis).—Manning et al. (1987) reported two specimens from adjacent Sterling County. Cave bats in Texas are believed to be nonmigratory; large populations of permanent residents occupy gypsum caves in the Panhandle, north of Coke County, and limestone caves in the central part of the Edwards Plateau, southeast of Coke County (Barbour and Davis, 1969). Caverns are present in the study area, but their abundance and suitability for bat occupation are unknown. Because only two specimens were netted, one on the North Concho River, in the southwestern corner, and the other on Grape Creek, in the south-central part of the county, it seems likely that the population of this species is low in the area.

Specimens (2).—11.4 mi. S, 7.9 mi. W Robert Lee, 1; 13.8 mi. S, 18.5 mi. W Robert Lee, 1.

Pipistrellus hesperus (H. Allen, 1864) (western pipistrelle).—Known county records for this species are few between Val Verde County, in the southern Edwards Plateau, and Knox County, near the Red River to the north. Manning et al. (1987) reported a specimen from Upton County, southwest of Coke County. The single specimen taken in this study was netted over a small pool in an otherwise dry canyon. Rock canyons and cliffs, preferred daytime roosts for this species, are common in the county and this bat may prove to be more numerous than existing evidence indicates.

Specimens (1).—2.3 mi. N, 13.0 mi. W Robert Lee, 1.

Lasiurus borealis (Müller, 1776) (eastern red bat).—The red bat was the most frequently netted chiropteran—five were taken on three dates at two locations in northern Coke County. They are the first reported for the county but the species was expected (Davis, 1974), and Manning et al. (1987) reported it from adjacent Sterling County. It probably should be regarded as uncommon in Coke County.

Specimens (5).—4.2 mi. N, 0.6 mi. W Robert Lee, 4; 10.3 mi. N, 1.9 mi. E Bronte, 1.

Lasiurus cinereus (Palisot de Beauvois, 1776) (hoary bat).—Two specimens of this migratory species were taken over water and beneath overhanging deciduous trees on 15 August and 11 September 1987.

Specimens (2).—0.4 mi. S, 3.8 mi. W Silver, 1; 13.8 mi. S, 18.5 mi. W Robert Lee, 1.

Tadarida brasiliensis (I. Geoffroy St.-Hilaire, 1824) (Brazilian free-tailed bat).—This species is common and was expected because it is widespread in the state (Davis, 1974; Hall, 1981); it has been reported from adjacent Sterling (Manning et al., 1987) and Tom Green (Davis, 1974) counties. Specimens were taken from buildings and bridges, but only two were netted over water.

Specimens (16).—2.3 mi. N, 13.0 mi. W Robert Lee, 2; 16.0 mi. W Robert Lee, 3; 14.5 mi. W Robert Lee, 6; Bronte High School, 5.

Dasypus novemcinctus Linnaeus, 1758 (nine-banded armadillo).—In the western Edwards Plateau region, published records of the armadillo exist only for Val Verde and Kimble counties (Davis, 1974). Specimens taken in this study confirm its presence in Coke County and extend the known distribution approximately 90 miles to the northwest of Kimble County. Sightings indicate that this species is common in all habitats except limestone ledge.

Specimens (5).—9.6 mi. N Bronte, 1; Robert Lee, 1; 2.2 mi. S, 0.5 mi. W Robert Lee, 1; 5.7 mi. S Robert Lee, 1; 9.8 mi. S, 14.5 mi. W Robert Lee, 1.

Sylvilagus floridanus (J. A. Allen, 1890) (eastern cottontail).—This cottontail previously has been reported from Coke County (Davis, 1974), but no specimens were located. Numerous sightings of *Sylvilagus* occurred throughout the county, but sight separation of *S. floridanus* and *S. audubonii* was not possible. *S. floridaus* appears to be the more abundant of the two species.

Specimens (5).—JCT 2059 and 1672 at Silver, 1; 0.4 mi. S, 0.9 mi. W Silver, 1; 5.5 mi. SSE Silver, 1; 4.2 mi. N, 4.6 mi. W Robert Lee, 1; 7.6 mi. E Robert Lee, 1.

Sylvilagus audubonii (Baird, 1857) (desert cottontail).—The single specimen taken in this study was obtained in the sandy northwestern part of the study area.

Specimens (1).—5.5 mi. SSW Silver, 1.

Lepus californicus Gray, 1837 (black-tailed jackrabbit).—The species is common throughout the county, in sandy, mesquite grassland, and stony hill habitats.

Specimens (5).—2.3 mi. SW Silver, 1; 5.5 mi. S Silver, 3; 2.7 mi. N, 1.3 mi. E Robert Lee, 1.

Spermophilus mexicanus (Erxleben, 1777) (Mexican graound squirrel).—This species was expected in Coke County because confirmed records surround the county (Davis, 1974). The species is uncommon in sandy and stony hill sites in the northwest, and additional sightings place it in mesquite grassland throughout the county.

Specimens (4).—11.4 mi. N, 8.5 mi. W Robert Lee, 1; 5.5 mi. S Silver, 1; 5.0 mi. S Silver, 2.

Spermophilus variegatus (Erxleben, 1777) (rock squirrel).—Rock squirrels are rare in riparian, stony hill, and limestone ledge habitats. The one specimen taken in this study is from a riparian site in the northeastern corner of the county.

Specimens (1).—1.5 mi. S Fort Chadbourne's ruins, 1.

Cynomys ludovicianus (Ord, 1815) (black-tailed prairie dog).—Coolidge (1856) and Bailey (1899, 1918) wrote of populations of prairie dogs in the Fort McKavett, Fort Phantom Hill, and Concho Valley areas near Coke County. Davis (1974) reported the species from Coke County, we were unable to locate a specimen on which that report was based. None was taken during this study and the species may be extirpated.

Sciurus niger Linnaeus, 1758 (fox squirrel).—Fox squirrels were rarely seen in the city of Robert Lee and in large pecan trees surrounding the Glass Ranch headquarters in the southwestern corner of the county. No specimens were obtained. This animal should occur in riparian habitats throughout Coke County (Davis, 1974).

Geomys bursarius (Shaw, 1800) (plains pocket gopher).—Despite considerable efforts, no pocket gophers were collected in the county during this study period. This species was collected in sand in the northwestern part of the county in 1971 (Thornton and Creel, 1975). Apparently, if still present, it is rare.

Specimens (2).—10.0 mi. NW Robert Lee, 2.

Perognathus flavus Baird, 1855 (silky pocket mouse).—This pocket mouse is abundant in all habitats except limestone ledge, but is most commonly found on deep sand and in mesquite grassland.

Specimens (35).—0.3 mi. S, 3.6 mi. W Silver, 2; 4.2 mi. N, 0.4 mi. W Sanco, 1; 0.4 mi. S, 0.9 mi. W Silver, 2; 1.0 mi. S Fort Chadbourne's ruins, 1; 5.5 mi. S Silver, 1; 5.5 mi. SSE Silver, 3; 5.0 mi. S Silver, 6; 7.0 mi. N, 10.9 mi. W Robert Lee, 4; 7.0 mi. N, 5.8 mi. W

Robert Lee, 3; 2.3 mi. N, 13.0 W Robert Lee, 1; 1.8 mi. NW Robert Lee, 4; 1.7 mi. NW Robert Lee, 1; 7.2 mi. S, 2.4 mi. E Robert Lee, 2; 13.9 mi. S, 17.2 mi. W Robert Lee, 1; 13.7 mi. S, 18.4 mi. W Robert Lee, 2; 13.8 mi. S, 18.5 mi. W Robert Lee, 1.

Chaetodipus hispidus (Baird, 1858) (hispid pocket mouse).—The hispid pocket mouse is found, in all five habitats, but is rare in limestone ledges.

Specimens (62).—0.3 mi. S, 3.6 mi. W Silver, 3; 0.4 mi. S, 0.9 mi. W Silver, 7; 4.2 mi. N, 0.5 mi. W Sanco, 2; 4.1 mi. N, 0.4 mi. W Sanco, 1; 1.5 mi. S, 1.4 mi. W Silver, 1; 1.8 mi. S, 1.1 mi. W Silver, 2; 1.9 mi. S, 1.3 mi. W Silver, 1; 0.6 mi. S Fort Chadbourne's ruins, 2; 1.0 mi. S Fort Chadbourne's ruins, 1; 0.2 km E Sanco, 3; 5.5 mi. SSE Silver, 1; 5.0 mi. S Silver, 4; 7.0 mi. N, 10.9 mi. W Robert Lee, 5; 7.0 mi. N, 5.8 mi. W Robert Lee, 2; 3.8 mi. N, 4.8 mi. E Robert Lee, 1; 1.8 mi. NW Robert Lee, 4; 1.7 mi. NW Robert Lee, 2; 16.9 mi. W. Robert Lee, 1; 1.1 mi. S Bronte, 1; 2.8 mi. S Bronte, 1; 3.5 mi. S, 1.1 mi. E Robert Lee, 1; 4.5 mi. S, 13.8 mi. W Robert Lee, 2; 7.2 mi. S, 2.4 mi. E Robert Lee, 2; 7.2 mi. S, 9.8 mi. E Robert Lee, 1; 9.6 mi. S, 9.0 mi. W. Robert Lee, 1; 12.5 mi. S, 17.8 mi. W Robert Lee, 1; 13.4 mi. S, 18.1 mi. W Robert Lee, 3; 13.7 mi. S, 18.4 mi. W Robert Lee, 4; 13.8 mi. S, 18.5 mi. W Robert Lee, 2.

Dipodomys ordii Woodhouse, 1853 (Ord's kangaroo rat).—The species was found only in sand in the northwest corner of the county, where it is uncommon.

Specimens (8).—0.3 mi. S, 3.6 mi. W Silver, 1; 0.4 mi. S, 0.9 mi. W Silver, 1; 5.5 mi. SSE Silver, 5; 7.0 mi. N, 10.9 W Robert Lee, 1.

Castor canadensis Kuhl, 1820 (beaver).—Beavers are known to occur in the Colorado River upstream to Mitchell County, bordering Coke County to the north (Hall, 1981), so their presence in Coke County was not unexpected. Nevertheless, the specimen obtained in this study, from Oak Creek Reservoir, is the first county record. Additional, unconfirmed sightings are from the Colorado River, but potential confusion with nutria (*Myocastor coypus*) prevents assessment of the status of this species.

Specimens (1).—11.4 mi N, 0.7 mi. E Bronte, 1.

Reithrodontomys montanus (Baird, 1855), (plains harvest mouse).—This harvest mouse was expected (Davis, 1974) but is uncommon. The majority of captures were in mesquite grasslands in a large central part of the county. One specimen was taken in stony hill habitat.

Specimens (7).—7.0 mi. N, 5.8 mi. W Robert Lee, 2; 3.4 mi. S, 1.9 mi. E Robert Lee, 4; 4.5 mi. S, 13.8 mi. W Robert Lee, 1.

Peromyscus attwateri J. A. Allen, 1895 (Texas mouse).—Texas mice are common. They were taken throughout the county, most frequently in stony hill and less frequently in riparian and limestone ledge habitats.

Specimens (17).—4.1 mi. N, 0.4 mi. W Sanco, 1; 0.7 mi. S Fort Chadbourne's ruins, 2; 1.8 mi. NW Robert Lee, 1; 4.5 mi. S, 13.8 mi. W Robert Lee, 3; 9.8 mi. SW Robert Lee, 1; 9.6 mi. S, 9.0 mi. W Robert Lee, 1; 11.4 mi. S, 7.9 mi. W Robert Lee, 1; 12.6 mi. S, 3.0 mi. E Robert Lee, 1; 13.8 mi. S, 3.0 mi. E Robert Lee, 3; 14.2 mi. S Robert Lee, 3.

Peromyscus leucopus (Rafinesque, 1818) (white-footed mouse).—The white-footed mouse is the most abundant species of *Peromyscus* in Coke County. It was taken in all habitat types except limestone ledge. Davis (1974) reported a previous record, but it was not located.

Specimens (51).—0.3 mi. S, 3.6 mi. W Silver, 1; 0.4 mi. S, 0.9 mi. W Silver, 3; 4.2 mi. N, 0.5 mi. W Sanco, 2; 4.2 mi. N, 0.4 mi. W Sanco, 1; 4.1 mi. N, 0.5 mi. W Sanco, 1; 1.3 mi. S, 1.1 mi. W Silver, 1; 1.5 mi. S, 1.4 mi. W Silver, 2; 1.9 mi. S, 1.3 mi. W Silver, 2; 0.6 mi. S Fort Chadbourne's ruins, 1; 1.5 mi. S Fort Chadbourne's ruins, 1; 9.5 mi. N, 1.4 mi. W Bronte, 1; 7.0 mi. N, 10.9 W Robert Lee, 1; 3.8 mi. N, 4.8 mi. E Robert Lee, 5; 1.8 mi. NW Robert Lee, 4; 6.0 mi. N, 3.7 mi. W Robert Lee, 2; 4.5 mi. S, 13.8 mi. W Robert Lee, 1; 5.7 mi. S, 1.9 mi. E Robert Lee, 3; 7.2 mi. S, 9.8 mi. E Robert Lee, 2; 9.6 mi. S, 9.0 mi. W Robert Lee, 4; 11.4 mi. S, 7.9 mi. W Robert Lee, 1; 1.6 mi. S, 0.4 mi. E Tennyson, 1; 3.7 km S, 1.8 km W Tennyson, 5; 13.4 mi. S, 18.1 mi. W Robert Lee, 1; 13.7 mi. S, 18.4 mi. W Robert Lee, 3; 13.8 mi. S, 18.5 mi. W Robert Lee, 2.

Peromyscus maniculatus (Wagner, 1845) (deer mouse).—The deer mouse is widespread in Texas and was an expected resident in Coke County (Davis, 1974). Although common throughout, this is the least abundant species of *Peromyscus* in the area. It favors stony hill and mesquite grassland in the southeast and sand in the northwest. None was trapped in riparian sites, the only species of *Peromyscus* absent from this habitat.

Specimens (15).—0.4 mi. S, 0.9 mi. W Silver, 3; 1.3 mi. S, 1.1 mi. W Silver, 3; 1.5 mi. S, 1.4 mi. W Silver, 2; 1.9 mi. S, 1.3 mi. W Silver, 2; 4.5 mi. S, 13.8 mi W Robert Lee, 2; 3.7 km S, 1.8 km W Tennyson, 2; 5.7 mi. S, 1.9 mi. E Robert Lee, 1.

Peromyscus pectoralis Osgood, 1904 (white-ankled mouse).—This mouse was reported from Coke County by Davis (1974), but no specimen was located. In this study, the species was found to be abundant, taken in all habitats types except sand. Individuals frequently were trapped on limestone ledges.

Specimens (35).—4.1 mi. N, 0.4 mi. W Sanco, 1; 9.5 mi. N, 1.4 mi. W Bronte, 1; 10.1 km N, 4.9 km E Bronte, 6; 10.1 km N, 4.7 km E Bronte, 5; 3.7 mi. N, 11.7 mi. W Robert Lee, 2; 16.9 mi. W Robert Lee, 3; 5.1 mi. S, 8.3 mi. W Robert Lee, 1; 9.4 mi SW Robert Lee, 2; 8.0 km N Water Valley, 3; 12.6 mi. S, 3.0 mi. E Robert Lee, 4; 13.4 mi. S, 17.7 mi. W Robert Lee, 1; 14.2 mi. S Robert Lee, 6.

Baiomys taylori (Thomas, 1887) (northern pygmy mouse).—Davis (1974) mapped Coke County as at the western edge of the distribution of *Baiomys taylori* in central Texas, although he recorded no specimens from the northwestern Edwards Plateau. Hollander et al. (1987) reported five specimens from Schleicher County, approximately 60 miles to the south. Specimens obtained in this study revealed the species to be common in sand and mesquite grassland and less frequent in stony hill sites throughout the county.

Specimens (19).—0.3 mi. S, 3.6 mi. W Silver, 1; 0.4 mi. S, 0.9 mi. W Silver, 4; 7.0 mi. N, 10.9 mi. W Robert Lee, 2; 6.7 mi. N, 2.0 mi. E Robert Lee, 4; 4.5 mi. N, 1.1 mi. E Bronte, 1; 1.1 mi. S Bronte, 1; 4.7 mi. S, 13.8 mi. W Robert Lee, 1; 3.7 km S, 1.8 km W Tennyson, 1; 13.4 mi. S, 17.7 mi. W Robert Lee, 2; 13.9 mi. S, 17.2 mi. W Robert Lee, 2.

Sigmodon hispidus Say and Ord, 1825 (hispid cotton rat).—Hispid cotton rats are common throughout much of Texas. Cotton rats were found to be abundant in all habitat types and were the most frequently trapped species in this study. They were taken least frequently on limestone ledges.

Specimens (69).—0.3 mi. S, 3.6 mi. W Silver, 1; 4.2 mi. N, 0.5 mi. W Sanco, 3; 0.4 mi. S, 0.9 mi. W Silver, 5; 4.2 mi. N, 0.4 mi. W Sanco, 1; 1.5 mi. S, 1.4 mi. W Silver, 3; 1.8 mi. S, 1.1 mi. W Silver, 2; 1.9 mi. S, 1.3 mi. W Silver, 5; 1.5 mi. S Fort Chadbourne's ruins, 1; 7.0 mi. N, 10.9, mi. W Robert Lee, 6; 6.7 mi. N, 2.0 mi. E Robert Lee, 3; 4.5 mi. N, 1.1 mi. E Bronte, 4; 3.8 mi. N, 4.8 mi. W Robert Lee, 2; 2.3 mi. N, 13.0 mi. W Robert Lee, 2; 4.9 mi. S, 5.3 mi. W Silver, 1; 0.2 km E Sanco, 4; 7.0 mi. N, 5.8 mi. W Robert Lee, 3; 0.4 mi. N, 7.7 mi. W Robert Lee, 7; 16.9 mi. W Robert Lee, 3; 1.1 mi. S Bronte, 3; 9.6 mi. S, 9.0 mi. W Robert Lee, 6; 11.4 mi. S, 7.9 mi. W Robert Lee, 1; 3.7 km S, 1.8 km W Tennyson, 1; 13.7 mi. S, 18.4 mi. W Robert Lee, 1; 13.8 mi. S, 18.5 mi. W Robert Lee, 1.

Neotoma albigula Hartley, 1984 (white-throated wood rat).—No specimens are reported from the western half of the Edwards Plateau region (Davis, 1974; Hall, 1981); the specimens reported here are not only the first for Coke County, but also the first for the region. The species is uncommon in the county, although found throughout in all habitat types except mesquite grassland. Stony hills seem to be the preferred habitat.

Specimens (10).—4.2 mi. N, 0.5 mi. W Sanco, 1; 4.1 mi. N, 0.5 mi. W Sanco, 1; 5.5 mi. S Silver, 1; 1.8 mi. NW Robert Lee, 2; 16.9 mi. W Robert Lee, 1; 11.4 mi. S, 7.9 mi. W Robert Lee, 1; 12.6 mi. S, 3.0 mi. E Robert Lee, 3.

Neotoma micropus Baird, 1855, (southern plains wood rat).—This wood rat has been reported from three bordering counties (Davis, 1974), but the specimens reported here are the first from Coke County. The species is common in the northern half and southeastern corner of the county. It is most frequently encountered in sand and less frequently in mesquite grassland.

Specimens (18).—0.4 mi. S, 0.9 mi. W Silver, 2; 1.3 mi. S, 1.1 mi. W Silver, 1; 1.5 mi. S, 1.4 mi W Silver, 1; 1.8 mi. S, 1.1 mi. W Silver, 2; 1.9 mi. S, 1.3 mi. W Silver, 1; 0.2 km E Sanco, 3; 5.5 mi. S Silver, 1; 7.0 mi. N, 10.9 mi. W Robert Lee, 5; 6.7 mi. N, 2.0 mi. E Robert Lee, 1; 3.7 mi. S, 1.8 mi. W Tennyson, 1.

Mus musculus Linnaeus, 1766 (house mouse).—This introduced species is particularly common in and around human dwellings (Davis, 1974).

We took specimens of the house mouse at a riparian site in the north-central part of the county and at a mesquite site in the southeastern corner. The species probably is found throughout the county.

Specimens (4).—4.2 mi. N, 0.5 mi. W Sanco, 1; 3.7 km S, 1.8 km W Tennyson, 3.

Erethizon dorsatum (Linnaeus, 1758) (porcupine).—Porcupines taken in this study are the first on record for the western half of the Edwards Plateau other than from Terrell County (Davis, 1974). The species is rare; we took one specimen each from limestone ledge and stony hill habitats in the southern part of the county.

Specimens (2).—9.4 mi. SW Robert Lee, 1; 13.1 mi. S, 2.1 mi. E Robert Lee, 1.

Myocastor coypus (Molina, 1782) (nutria).—Nutria, which are introduced in North America, are uncommon in Coke County. The few specimens and sightings obtained were in riparian habitats with permanent water.

Specimens (5).—11.8 mi. N, 1.5 mi. W Bronte, 1; 2.2 mi. S, 1.2 mi. E Blackwell, 1; 5.1 mi. N, 4.8 mi. W Robert Lee, 1; 0.8 mi. N, 7.2 mi. W Robert Lee, 1; 3.4 mi. S, 2.0 mi. W Bronte, 1.

Canis latrans Say, 1823 (coyote).—Coyotes were found uncommonly throughout the county in all habitats except riparian, where they probably also occur. Stony hill and mesquite grassland seem to be preferred. Most of the specimens reported here were obtained from trappers. These are the first specimens reported for Coke County.

Specimens (8).—5.5 mi. S Silver, 1; 6.6 mi. NNW Bronte, 1; 4.9 mi. E Robert Lee, 1; 2.4 mi. S, 3.0 W Bronte, 1; 8.4 mi. ESE Robert Lee, 1; 8.0 km N Water Valley, 1; 10.0 mi. S, 9.0 mi. W Robert Lee, 2.

Vulpes vulpes (Linnaeus, 1758) (red fox).— The red fox is uncommon in Coke County, but fairly widespread in the south in stony hill, mesquite grassland, and riparian habitats. The only record from the northern part of the county was one seen near Oak Creek Reservoir. A specimen, presumably ASUNHC 1018, was reported by Davis (1974). This is a target species of local trappers, who apparently take it regularly.

Specimens (5).—3.0 mi. S Robert Lee, 1; 10.3 mi. S, 14.1 mi. W Robert Lee, 2; 2.0 mi. S, 2.0 mi. E Tennyson, 1; 23.2 mi. SW Robert Lee, 1.

Urocyon cinereoargenteus (Schreber, 1775) (gray fox).—This species also is uncommon in Coke County. It occurs in the south and west in stony hill and mesquite grassland habitats, where trappers consider it a target species. A record mapped by Davis (1974) was not located.

Specimens (8).—4.2 mi. N, 8.3 mi. W Robert Lee, 5; 9.0 mi. S, 13.4 mi. W Robert Lee, 1; 10.4 mi. S Bronte, 1; 2.0 mi. S, 2.0 mi. E Tennyson, 1.

Bassariscus astutus (Lichtenstein, 1830) (ringtail).—Only seven specimens, from stony hill and limestone ledge habitats, were obtained, but the species is likely common.

Specimens (7).—5.8 mi. N, 5.4 mi. W Robert Lee, 3; 4.2 mi. N, 8.3 mi. W Robert Lee, 3; 9.4 mi. SW Robert Lee, 1.

Procyon lotor (Linnaeus, 1758) (raccoon).—Raccoons were taken throughout the county from limestone ledge and stony hill habitats. Additional sightings confirm that the raccoon is common and occurs in all habitats.

Specimens (8).—6.6 mi. NNW Bronte, 1; 4.2 mi. N, 8.3 mi. W Robert Lee, 2; 9.4 mi. SW Robert Lee, 1; 10.6 mi. S, 3.1 mi. E Robert Lee, 1; 14.2 mi. S Robert Lee, 1; 3.4 mi. S Tennyson, 1; 13.1 mi. S, 2.1 mi. E Robert Lee, 1.

Taxidea taxus (Schreber, 1778) (badger).—One badger was taken in this study. Additional sightings of individuals killed among roadways establish the species as a rare resident in stony hill habitats in the south-central and northwestern areas of the county.

Specimens (1).—12.1 mi. S, 2.3 mi. E Robert Lee, 1.

Mephitis mephitis (Schreber, 1776) (striped skunk).—Striped skunks were taken mostly from the north-central part of the county in sandy and stony hill habitats. Additional sightings, however, revealed the species to be common throughout the county in all habitats.

Specimens (6).—13.1 mi. NNW Robert Lee, 1; 7.0 mi. N, 10.9 mi. W Robert Lee, 1; 9.8 mi. SE Silver, 1; 5.8 mi. N, 5.4 mi. W Robert Lee, 1; 5.0 mi. N, 4.8 mi. W Robert Lee, 1; 1.3 mi. S, 3.0 mi. W Robert Lee, 1.

Conepatus mesoleucus (Lichtenstein, 1832), (hog-nosed skunk).—Specimens in the Angelo State University collection are from central Coke County in stony hill and mesquite grassland habitats. Additional, nonsalvageable animals killed on roads revealed that the hog-nosed skunk also occupies mesquite grasslands. A specimen in the Texas Tech University Museum was reported from Coke County (Manning et al., 1986), but specific location milage places (17 mi. WNW Ballinger) the collection site in adjacent Runnels County to the east.

Specimens (2).—8 mi. S Robert Lee on US 208, 1; 2.2 mi. N Robert Lee, 1.

Felis concolor Linnaeus, 1771 (mountain lion).—In Texas, the range of the mountain lion is primarily confined to the Rio Grande border area (Davis, 1974), with the largest population believed to occupy remote areas of the Trans Pecos (Schmidly, 1977). These large cats prefer rocky, deep canyons with rimrock and dense brush (Davis, 1974), a physiographic feature found commonly in Coke County.

There are no specimens from Coke County; however, there are two reliable records that establish the likelihood of the presence of *F. concolor*. A mountain lion reportedly was killed on the Blanks Estate, west of Robert Lee, by a deer hunter in 1976. In January 1987, Coke County Game Warden Sparks Burdett reported observing a mountain lion six miles north and six miles east of Robert Lee (Maxwell and Burdett, personal communication). Several records confirm the presence of this cat on the northwestern Edwards Plateau, the most recent of which is a confirmed kill of a lion in nearby Irion County (Engstrom and Maxwell, 1988).

Felis rufus (Linnaeus, 1758) (bobcat).—The bobcat has been reported previously from Coke County (Davis, 1974), but no specimen has been located. During this study, bobcats were found to be uncommon in the county, with specimens from riparian, stony hill, and mesquite grassland habitats in the western half. It probably occurs as well in limestone ledge areas (Schmidly, 1977). It is a target species of local trappers and is trapped regularly.

Specimens (9).—5.5 mi. S Silver, 3; 4.2 mi. N, 8.3 mi. W Robert Lee, 2; 23.2 mi. SW Robert Lee, 1; 11.2 mi. SSW Silver, 2; 10.3 mi. S, 14.1 mi. W Robert Lee, 1.

Tayassu tajacu (Linnaeus, 1758) (collared peccary).—Davis (1974) considered the peccary to be extirpated from the northern portion of its historical distribution in Texas and to be "restricted to western Texas and the Brush Country south of San Antonio." Accordingly, Hollander et al. (1987) regarded their sightings from Upton County as establishing the current range north "at least to the northwestern edge of the Edwards Plateau." The specimens taken in this study are not only the first for Coke County, but extend the known current distribution to the northern limit of the western Edwards Plateau. Our four specimens were taken in limestone ledge areas. The species evidently is rare in the county.

Specimens (4).—9.4 mi. SW Robert Lee, 1; 5.0 mi. S, 7.6 mi. W Robert Lee, 3.

Odocoileus virginianus (Zimmermann, 1780) (white-tailed deer).—White-tailed deer taken in this study were collected in mesquite grassland and stony hill habitats. Abundant sightings confirm the presence of the white-tail deer throughout the county in all habitats.

Specimens (3).—0.5 mi, S, 3.8 mi. W Silver, 1; 2.0 mi. S, 0.3 mi. W Robert Lee, 1; 9.6 mi. S, 9.0 mi. W Robert Lee, 1.

Antilocapra americana (Ord, 1818) (pronghorn).—The one specimen reported from Coke County is located in Midwestern State University and is of an unknown date. Coolidge (1856) and Bailey (1899, 1918) wrote of the pronghorn in the Fort McKavett, Fort Phantom Hill, and Concho Valley areas but not Fort Chadbourne or Coke County in general. Sightings of pronghorns during this study were made in Mitchell County, approximately five miles from the northeastern corner of Coke County. Pronghorn have been reintroduced to portions of the Edwards Plateau in recent years.

Specimens (1).—"Near Robert Lee," 1 (Midwestern State University).

UNREPORTED SPECIES

Four species are not known certainly to occur in Coke County today, although in some way have been reported previously from the county. A specimen of least shrew, *Cryptotis parva*, reportedly taken on 10 March 1974 in Bronte, was cataloged as ASUNHC 1044 but cannot now be located. Considering that the specimen would represent the first record of this species from central Texas, the fact that it cannot now be found renders it suspect, and *C. parva* should not be included in the Coke County fauna. The mountain lion (*Felis concolor*) probably does occur, based on verbal accounts of a kill and sightings by a trained wildlife professional, but its presence is not otherwise confirmed. Black-tailed prairie dogs (*Cynomys ludovicianus*) and pronghorns (*Antilocapra americana*) undoubtedly occurred within historic time, and specimens have been reported, but we know of no evidence that they occur today in Coke County.

Eleven additional species, listed below, may occur in Coke County. Their possible presence is inferred by their known occurrence near the county borders and the availability of suitable habitat.

Eptesicus fuscus (Palisot de Beauvois, 1796).—The big brown bat, a nonmigratory species, has not been reported from central Texas (Barber and Davis, 1969) but may occur at least as far south as Coke County (Davis, 1974). But see Manning et al. (1989).

Plecotus townsendii Cooper, 1837.—Davis (1974) included Coke County within the distribution of Townsend's big-eared bat, a nonmigratory, cave-dwelling species. Actual specimen records from east of the Trans-Pecos exist only from the Panhandle and limestone caves in the southern Edwards Plateau (Barbour and Davis, 1969).

Antrozous pallidus (Le Conte, 1856).—The pallid bat is a southwestern species that favors rock outcrops with tight crevices for night roosts (Barbour and Davis, 1969). Davis (1974) included Coke County within its distribution, but the nearest specimen records are from Kimble (Martin and Schmidly, 1982), Crockett (Manning et al., 1987), and Haskell (Davis, 1974) counties.

Spilogale gracilis (Merriam, 1890).—Local trappers claimed that spotted skunks are occasionally caught in traplines within the county. Hollander et al. (1987) reported *S. gracilis* in Howard County to the northwest.

Vulpes macrotis Merriam, 1888.—Davis (1974) included part of Coke County in his distribution of the desert fox, but the nearest specimens are from Glasscock and Reagan counties to the west (Davis, 1974).

Spermophilus spilosoma Bennett, 1833.—The spotted ground squirrel has been taken in adjacent Mitchell County, and Davis (1974) included western Coke County within its distribution. The sands around Silver should be good habitat for this species.

Thomomys bottae (Eydoux and Gervais, 1836).—Thornton and Creel (1975) trapped Botta pocket gophers near Water Valley, Tom Green County, in 1971. Identical soil and vegetation exists in adjacent Coke County.

Cratogeomys castanops (Baird, 1852).—Davis (1974) believed the yellow-faced pocket gopher did not occur as far east as Coke County; Thornton and Creel (1975) collected the species 4 mi. W Sterling City, Sterling County, adjacent to the west.

Onychomys leucogaster (Wied, 1841).—The northern grasshopper mouse has been taken in Tom Green County and Davis (1974) included Coke County in its proposed distribution. In this study, numerous attempts were made to trap it in sands around Silver but without success.

Rattus rattus (Linnaeus, 1758).—Roof rats are widespread commensals of man in Texas, and may well occur in Robert Lee, Bronte, or elsewhere in Coke County.

Rattus norvegicus (Berkenhout, 1769).—Norway rats also are widespread commensals in Texas.

DISCUSSION

The mammalian fauna of Coke County currently is known to contain 42 species representing 35 genera and eight orders. Some evidence exists supporting the presence of three additional species (*Felis concolor,* *Cynomys ludovicianus* and *Antilocapra americana*), but their presence was not confirmed in this study.

Thirty-four of the species found (81 percent of the total confirmed species) are first records for Coke County, not a surprising result considering the paucity of studies of mammals in this region. More significantly, seven species represented significant additions to the known mammalian fauna of the northwestern Edwards Plateau region. *Lasiurus cinereus, Neotoma albigula, Erethizon dorsatum*, and *Dasypus novemcinctus* are first reported for the region. Specimens of *Pipistrellus hesperus* and *Baiomys taylori* constitute the second reports for the region. Specimens of *Tayassu tajacu* confirm the continued survival of this species in a region from which it had been reported extirpated.

The only marsupial in the United States, *Didelphis virginiana*, is common today in Coke County but probably has been there only during this century (Hoffmann and Jones, 1970). Only one species of Insectivora, *Notiosorex crawfordi*, is certainly present. Inasmuch as pitfall traps were not used extensively in our study, the abundance of this shrew and its distribution in the county are not known.

Five species of bats were documented as occurring in Coke County. Only *Tadarida braziliensis* and *Lasiurus borealis* are known to be more than rare and part of the regular summer fauna. *Myotis velifer* and *Pipistrellus hesperus* were taken in August 1987 but are represented by only two specimens and one specimen, respectively. *P. hesperus* is a slow-flying bat and difficult to capture in nets (Barbour and Davis, 1969). *Lasiurus cinereus* almost certainly is a rare, but perhaps regular, migrant through the county.

Nine species of carnivores are known to occur in the county and *Felis concolor* probably occurs there occasionally. Predator trappers regularly take carnivores in this ranching county and eight species seem to be common there, whereas *Taxidea taxus* apparently is rare. All nine species occupy the expansive stony hills and mesquite grassland habitats (80 percent of land area) at lower elevations. Only three carnivores (*Procyon lotor, Bassariscus astutus*, and *Mephitis mephitis*) regularly occupy rocky canyon sites.

The most diverse order in Coke County is Rodentia, with 20 species (46 percent of the mammalian fauna). Among the 18 terrestrial species, *Sigmodon hispidus* is the most abundant, and together with *Chaetodipus hispidus* occurs in all major habitat types in the county. Limestone ledges had the least diverse rodent fauna, with only seven species. Although *Chaetodipus hispidus* and *Sigmodon hispidus* were taken there, these abundant rodents were rarely encountered on bare rock sites and probably utilized them only peripherally. Among the terrestrial rodents, the most restricted is *Dipodomys ordii*, which is confirmed to the sands in the northwestern corner of the county. The two seim-aquatic rodents, *Castor canadensis* and the introduced *Myocastor coypus*, apparently are near the western limits of their distributions of Texas.

The order lagomorpha is represented by three species. The relative abundance of the two species of *Sylvilagus* is unknown because they cannot be identified on sight; probably *S. audubonii*, known from one specimen, is more common than available evidence supports. All three species are typically found in level terrain of lower elevations.

Only one species of the order Artiodactyla is more than rare in the county. *Odocoileus virginianus* is abundant and widespread. *Tayassu tajacu* continues to survive in the county, contrary to published accounts. *Antilocapra americana* may well occur in the northwestern corner of the county, with extant populations only five miles from Coke County, in Mitchell County, but their presence has not been confirmed.

The only species of edentate in the United States, *Dasypus novemcinctus*, is a common resident of all but the highest elevations in Coke County. This is probably a fairly recent colonization, dating no earlier than 1930 (see review in McBee and Baker, 1982), and constitutes a range extension to the northwest in the Edwards Plateau.

LITERATURE CITED

Anonymous. 1988. Texas almanac. Dallas Morning News, Dallas, Texas, 640 pp.

Bailey, V. 1899. Personal notes from San Angelo to Big Spring from 19 May to 23 May 1899. Smithsonian Archives, Washington, D.C.

———. 1918. Personal notes from San Angelo region from 18 March to 30 March 1918. Smithsonian Archives, Washington, D.C.

Barbour, R. W., and W. H. Davis. 1969. Bats of America. Univ. Press Kentucky, Lexington, 286 pp.

Barnhill, L. J. 1974. Soil survey of Coke County, Texas. U.S. Dept. Agric., Soil Conserv. Serv., Texas Agric. Exp. Sta., 49 pp.

Brnovak, G. J. 1975. An ecological survey of the reptiles and amphibians of Coke Co., Texas. Unpublished M.S. thesis, Angelo St. Univ., San Angelo, Texas. 48 pp.

Coolidge, R. H. 1856. Statistical report on the sickness and mortality in the Army of the United States, compiled from the records of the surgeons general's office; embracing a period of sixteen years from January 1839 to January 1855. A.O.P. Nicholson Printer, Washington, D.C., issued as Senate Ex. Doc. 96, 34th Cong., 1st Sess.

Davis, W. B. 1974. The Mammals of Texas. Bull. Texas Parks Wildlife Dept., Austin, 41:1-244.

Engstrom, M. D., and T. C. Maxwell. 1988. Records of mountain lion (*Felis concolor*) from the western Edwards Plateau of Texas. Texas J. Sci., 40:450-452.

Hall, E. R., 1962. Collecting and preparing study specimens of vertebrates. Misc. Publ. Mus. Nat. Hist., Univ. Kansas, 30:1-46.

———. 1981. The mammals of North America. John Wiley and Sons, New York, 2nd ed. 1:xv + 1-600 + *90* and 2:vi + 601-1181 + *90*.

Hoffmann, R. S., and J. K. Jones, Jr. 1970. Influence of late-glacial and post-glacial events on the distribution of Recent mammals on the northern Gerat Plains. Pp. 355-394, *in* Pleistocene and Recent environments of the central Great Plains (W. Dort, Jr. and J. K. Jones, Jr., eds), Univ. Press Kansas, Lawrence, (x) + 433 pp.

Hollander, R. R., C. Jones, R. W. Manning, and J. K. Jones, Jr. 1987. Distributional notes on some mammals from the Edwards Plateau and adjacent areas of the south-central Texas. Occa. Papers Mus., Texas Tech Univ., 110:1-10.

King, W. W. 1975. The vascular flora of Coke County, Texas. Unpublished M.S. thesis, Angelo St. Univ., San Angelo, Texas.

Manning, R. W., J. K. Jones, Jr., and R. R. Hollander. 1986. Northern limits of distribution of the hog-nosed skunk, *Conepatus mesoleucus*, in Texas. Texas J. Sci., 38:289-291.

Manning, R. W., J. K. Jones, Jr., R. R. Hollander, and C. Jones. 1987. Notes on distribution and natural history of some bats on the Edwards Plateau and in adjacent areas of Texas. Texas J. Sci., 39:279-285.

Manning, R. W., J. K. Jones, Jr., and C. Jones. 1989. Comments on the distribution and variation in the big brown bat, *Eptesicus fuscus*, in Texas. Texas J. Sci., 41:95-101.

Martin, C. O., and D. J. Schmidly. 1982. Taxonomic review of the pallid bat, *Antrozous pallidus* (Le Conte). Spec. Publ. Mus., Texas Tech Univ., 18:1-48.

McBee, K., and R. J. Baker. 1982. Dasypus novemcinctus. Mamm. Species, 162:1-9.

Ormsby, W. L. 1854. The Butterfield Overland Mail (L. H. Wright and J. M. Bynam, eds.), The Huntington Library. San Morino, California, 179 pp.

Schmidly, D. J. 1977. The mammals of Trans Pecos Texas.—Texas A&M Univ. Press, College Station, 225 pp.

Simpson, L. A. 1988. The mammal fauna of Coke Co. Texas. Unpublished M.S. thesis, Angelo St. Univ., San Angelo, Texas, 75 pp.

Thornton, W. A., and G. C. Creel. 1975. Distribution of gophers (Geomyidae) in western Texas. Southwestern Nat., 20:272-275.

Wilson, C. A. 1973. Ground resources of Coke County, Texas. Rept. Texas Water Develop. Board, Austin, 166:1-87.

CLASSIFICATION OF STONE PROJECTILE POINTS BY A SMALL TEXAN FOLK COMMUNITY: A CASE STUDY

LeRoy Johnson, Jr.
Texas Historical Commission, P.O. Box 12276, Austin, Texas 78711

Abstract.—The classificatory practices of a small Texan "community," which tries to type stone projectile heads, are found to mirror primitive folk semantics. Although constituted as a category of professional archaeologists, when classifying stone tools the Texas community functions as a *Volksgemeinschaft* in the grips of erroneous Artistotelian logic. Salvation can best be found by embracing and using Korzybskian non-Aristotelian semantics. A practical application of such mental formulations is to employ multivariate procedures in analyzing projectile points, to discover quantifiable trends (rather than tool types) in aboriginal behavior. This philosophical justification of mathematical approaches has generally been overlooked by archaeologists. *Key words:* archaeology; artifact classification; projectile points; philosophy of science; Texas.

Today, an association of people exists within the borders of the state of Texas that actively practices the typing and classification of stone projectile heads. That group and their semantically governed behaviors are the subject of the present case study. The Texan "typologists" function, in their classificatory endeavors, much as a typical *Volksgemeinschaft* or folk community—this in spite of their stated aim of practicing "scientific" methods and techniques. Here the term *Gemeinschaft* is employed partly in the sense in which it was put forward by Ferdinand Tönnies, to mean a society, or segment of a society, that operates mostly with folk concepts. The well-informed reader will at once recall that somewhat similar behaviors have recently been studied among the San Bushmen (Wiessner, 1983, 1984), who are reputedly able to recognize distinctive arrowhead styles among their regional social divisions. The Texan group, in contrast, concerns itself with labeling the projectile styles of other, aboriginal and usually prehistoric, groups; thus one can say that the Texan *Gemeinschaft* studies alien styles.

It is as interesting to examine the folk behavior of the Texan as it is the San society—not just to reveal the folk semantics of the former, but to determine how and to what extent the Texan community fails to achieve its scholarly classificatory objectives on account of its shared folk psychology. Indeed, the present essay suggests helpful attitudes and mental-semantic formulations that, once embraced, can cause a beneficial change in the way the members of the Texan *Volksgemeinschaft* classify stone projectile points. A certain freedom from the shackles of faulty, folkish psychological and mental formulations is the desired end. In the following lines, it is shown that the folk-typological approach of the social group in question is often ineffective, through it is capable of mirroring a certain kind of reality in cases that will be indicated.

Regrettably, the actual and practical substitution of healthy alternatives for the Texan folk system of idea formulation and semantics will be an extraordinarily difficult matter. This is so because the would-be substitutions depend, for their success, upon modes of expression that are mostly foreign to the cognitive system of the community being examined.

Practicing archaeologists working within the state of Texas, whether professional people or amateurs, constitute the *Volk* or community in which I am interested. My view is hardly unique; Kuhn (1970:6, 209), for example, also has referred to the community nature of scholarly and artistic professions. Yet I believe this is the first time the largely folkish cast of an American archaeological group has been underscored. Nevertheless, the reader may at once take umbrage at my definition, and reply that Texan archaeologists are, instead, a group or association of professional scientists, in no way to be thought of as a folk community.

I reply by admitting that archaeologists also do exist, of course, as a quasi-*Gesellschaft*—a society of professionals *sensu lato*. They claim to function according to mutually accepted professional analytic procedures and scientific methods during their reconstructions of the past. But speaking philosophically, archaeologists and archaeology are only quasi-scientific; by this I mean that the profession calls into play true sciences in its various analytic endeavors (for example, radiocarbon dating and chemical studies), although in its final generalizations archaeology cannot hope to offer nomothetic (lawlike) scientific statements about prehistoric behaviors any more than history or ethnology can (for a discussion of this conclusion, see Johnson, 1972). This necessary, but nonscientific, side of archaeology makes the discipline all the more susceptible to a dependence on the general beliefs and semantics of the ethnic society in which it exists—and those mental formulations constitute a primitive, nonscientific, and philosophically unsound *Völkerpsychologie* (usage after Wilhelm Wundt).

The Texas approach is a regional expression of the impressionistic definition of types or kinds of stone projectile heads that characterizes North American archaeology generally. The named types are fairly inflexible mental formulations established by selecting as diagnostic only a few of the variables of the classified specimens—often stem shapes—without recourse to multivariate approaches. The Texan system is not only reflected in the now elderly typological manuals of Suhm et al. (1954) and Suhm and Jelks (1962), but continues to be used in almost every new description of stone points (for example, Turner and Hester, 1985; Black, 1986). We shall see that the folk beliefs of Texan and other Occidental archaeologists are part and parcel of an Aristotelian system of logic—a system which is highly inaccurate, but for which there is a remedy. First, however, the philosophic antibiotic for the semantic disease needs to be set in historical perspective. Non-Aristotelian systems share certain features with other philosophies that have attempted to affect archaeology.

Maverick Philosophies

Maverick philosophic currents sometimes splash forth into archaeology before their waters are contained by the dikes of conservatism. In the early 1970s, it was pointed out (Johnson, 1972) that the detectivistic philosophy of Michael Scriven (1959, 1963) could be used to evaluate clues to past behaviors and arrange proofs for their explanation more accurately than was being done using the fashionable positivist philosophy of the day. Scriven's detectivism, in the matter of arguing proof, is known as "analytical narrative" (see comments by Kelley and Hanen, 1988). It permits one to add together pieces of evidence and quantify their sum when making an interpretative argument, whereas positivism can deal with quantification of proof only insofar as it repeats experimental instances designed to produce proof (which is itself of a yea or nay sort, and not quantifiable). Because it has never been faddish, detectivism has been almost completely ignored by the archaeological community.

Nowadays, a philosophical current known as hermeneutics and experience is calling attention to itself. Hermeneutics, as a word, is a ghastly neologism once used in theology to refer to the systematic study of methodological principles of interpretation, as of the Bible. The label is now used to mean an interpretative bridging of certain misleading semantic dichotomies, such as inductive-deductive, theory-data, and present-past (see Shanks and Tilley, 1987), in order to establish a critical perspective in whatever discipline. Hermeneutics recognizes the cultural and political nature of the formulations used by western analysts and recommends that they be transcended. One of its future paths may lead in the direction of personal experiential understanding, whereby the analyst who embraces the new credo is freed somewhat from the contemporary ideologies in which his research is carried out (Chaney, 1988).

The Non-Aristotelian Remedy for Cultural Blindness

A third maverick philosophy can be of even greater aid to Texan archaeologists than the two mentioned above—non-Aristotelianism. Although detectivism and hermeneutics are non-Aristotelian in several of their particulars, it is the general, total, non-Aristotelian view of reality, nature, relationships, and so on, that is wanted most urgently. Once the diagnosis of the archaeological sickness is agreed upon, the best restorative is a massive *dosis* of non-Aristotelian semantics figuratively taken as a purgative. After all, if the symptoms of an erroneous folk psychology are to be treated, the medicine must reach the infected part of the patient. And more than anything else, a *Völkerpsychologie* involves gut-level thinking and reactions of the crude, culturally dependent sort. First, however, what exactly is Aristotelian logic, and how does it cause problems in archaeological typologies? Aristotelian thought sees things as kinds or types, and does not readily permit of degree of similarity in describing items. For example, in Texan archaeology there are the Marcos, Williams, and other related dart-point types (Suhm et al., 1954:pls. 100, 128), but no satisfactory systematics for showing their close relation to each other and their vague resemblance to other kinds of points.

Aristotelianism has an elementalistic conception of reality wherein everything is composed of concrete entities that do not intergrade. It semantically employs the "is of identity" in doing classifications, so that when one says that a specimen "is" a member of such-and-such type, the psychology of the semantic usage causes the classifier to think of all members of that type as equal, including the specimen to which he has just referred. Even when he knows better. As Korzybski has remarked, "The 'is' of identity underlies the two-varied, too primitive, too restricted, and structurally fallacious Aristotelian logic" (1958:202). If one remembers the words kinds, identity, and elementalism, as well as their meanings, he already has a firm grasp on what Aristotelianism is.

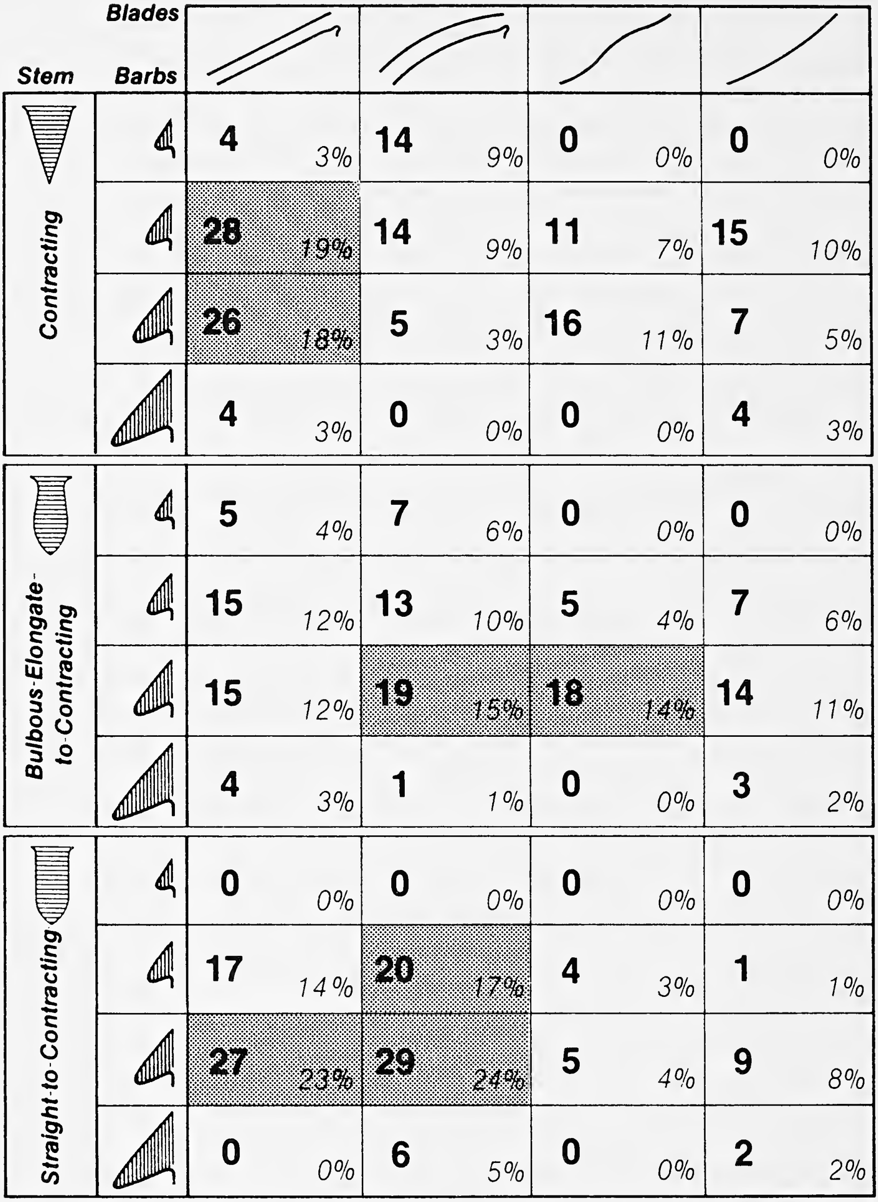
Scriven's analytical narrative and hermeneutics, both outlined above, partake of several non-Aristotelian elements. Detectivism avoids a dischotomizing "yes" or "no" evaluation of proofs for hypotheses, whereas hermeneutics overrides false dichotomies of several sorts: past-present, inductive-deductive, and so forth. Both enter into the philosophic fray on the side of the angels. Yet the conflict between Aristotelian and non-Aristotelian systems of thinking is nothing new. Its first historical expression is in the schism between Aristotle, the biologist, and Plato, the founder of mathematical philosophy. In principle, mathematics is non-aristotelian, and promises a way to view and record archaeological observations in a semantically sound manner. Non-Aristotelian thought sees reality, when appropriate, as being best expressed as continua and in terms of degree of resemblance. Mathematics provides the easiest way to express degree, although its application does not have to be fancy.

If the archaeologist places types within named series (for example, Jelks, 1978), or defines varieties of types (for example, Johnson, 1962), a small step in the direction of the non-Aristotelian approach has been made. But a much more detailed description of variation is demanded. Consider the Perdiz arrowhead type of Texas (Suhm et al., 1954), which name has been in use a long time. Because the type concept semantically allows for little variation within the Perdiz idea, the variation that has been seen among collections of Perdiz points becomes the *casus belli* in disputes about what the type should properly be. Thus, in conversations I have had, some archaeologists would class a few of the arrow points from a burial found at the Early Caddo Davis site (Shafer, 1973:fig. 17, r1, s1, t1) as Perdiz points, whereas the pertinent Davis specimens appear to intergrade with other arrow points from the selfsame burial that are said to be of the Alba type. A multivariate analysis might well decide whether the variation in that artifact lot occurs evenly along one or more trait continua, or whether a dichotomous clustering of traits can be perceived that bespeaks two different stylistic modes. Such a study has not been done.

An utterly simple technique can be used by anyone describing the form of aboriginal tools, which is to show the co-occurrence of metric variables in a correlation matrix, or display nonmetric traits in a multivariate contingency table. A rare but slightly flawed example from, or near, Texas is that published by Robert J. Mallouf (1987), who described Perdiz arrowheads discovered as a cairn cache in the state of Chihuahua. Figure 1 repeats a trait contingency count based on that collection, and shows the association of various forms of margins of arrow-point blades (here treated as an independent variable) with other variables expressed as simple ordinal, but almost nominal, scales (from Mallouf, 1987:fig. 101). The shaded cells are the major trends in the data set, and can be thought of as reflections of human behavioral tendencies. The most common trends are 1) for individual straight-sided blade edges to be associated with contracting stems and medium to medium-long barbs; 2) for straight or convex edges to be associated with straight to contracting stems and medium to medium-long barbs, and 3) for convex and recurved blade margins to occur with bulbous stems and medium-long barbs. The more minor trends in the data set are also interesting: for instance, the mild tendency of concave blade edges to be associated with bulbous stems and moderately long barbs.

The ability of trends like the above to reveal behavior should be obvious. In the case of the Chihuahuan arrowheads, the tendencies of variable characters to co-occur, strongly or weakly, mainly reflects modes of stylistic expression on the part of the knappers—modes that are best recorded as "degree" along several variable dimensions. But other factors can enter into the picture. The shape of the foreshaft of the arrow, as well as its size, may have imposed limitations on the dimensions and form of the stem of an arrow point; these limiting conditions can vary from one individual to another or among different human groups. Whatever the explanation, behavioral differences emerge, whether mirroring separate stylistic traditions or inter-group differences of a technological sort.

The trouble with Figure 1 is that the items being counted are single blade margins, not arrowheads, and specimens with both edges intact



Stem	Blades / Barbs				
Contracting		4 3%	14 9%	0 0%	0 0%
		28 19%	14 9%	11 7%	15 10%
		26 18%	5 3%	16 11%	7 5%
		4 3%	0 0%	0 0%	4 3%
Bulbous-Elongate-to-Contracting		5 4%	7 6%	0 0%	0 0%
		15 12%	13 10%	5 4%	7 6%
		15 12%	19 15%	18 14%	14 11%
		4 3%	1 1%	0 0%	3 2%
Straight-to-Contracting		0 0%	0 0%	0 0%	0 0%
		17 14%	20 17%	4 3%	1 1%
		27 23%	29 24%	5 4%	9 8%
		0 0%	6 5%	0 0%	2 2%

FIGURE 1. Example contingency table for three associated variables (blade shape, barb length, and stem form) among Perdiz arrow points from Las Haciendas, Chihuahua (adapted from Mallouf, 1987:fig. 101). Cells with high frequencies are shaded.

enter twice into the table. Consequently, not all of the blade shapes are independent of each other because each arrowhead has two. In contrast to the above procedure, the usual interest is in counting individual arrowheads, so that the archaeologist can discover what traits occur on them and in what kind of combinations. And, although Figure 1 illustrates adequately the ability of a contingency table to reflect data trends, statistical measures of association would have helped considerably in doing this job. On the other hand, when tool groups are defined only impressionistically, the archaeologist's own folkish cultural background comes to the fore and causes him to imagine fairly discrete kinds of artifacts and to ignore much gradation between them, simply because his folk semantics shields his eyes in blinders.

In certain cases, however, the Texan typology, as it is encapsulated in *An introductory handbook of Texas archeology* (Suhm et al., 1954), may work fairly efficiently and allow the scholar to accomplish his goals. After all, the *Handbook* was "one giant step forward for Texankind" in its day. For instance, Folsom people were rigid conformists when it came to making dart points, and the Folsom type (named elsewhere before the days of the *Handbook*) expresses that conformity nicely. Even in this instance, however, at least two trends have been discerned by simple mathematics that express slightly different behaviors involved in producing the Folsom style (Wilmsen and Roberts, 1984:101-112). And in Middle Archaic times, the Pedernales dart-point type appears to be a useful "kind" or group, probably because its specimens were made almost exclusively for many centuries throughout the central part of Texas. Nevertheless, the type is mostly a stemming style, and occurs with different blade forms. Some Pedernales blades (that are probably quite late) are wide, thin, and billet flaked (Suhm et al., 1954:pl. 113, u), and resemble blades of the later Castroville and Montell dart-point types (Suhm et al., 1954:pls. 83, 105). There is regrettably no way, given the current folk typology, to express this similarity. Multivariate analyses like Mallouf's, or others that employ measures of correlation and association, are called for.

When dealing with some time periods, the Texan typology breaks down almost completely. In late Archaic and early Ceramic days, the so-termed Gary dart-point type was popular in the woodlands of eastern Texas and nearby areas, but the amount of variation in that form is enormous, with the result that the name has little meaning as a summary of human behavior. It is too broad. Others and I discovered this fact long ago (Baerreis et al., 1958; Johnson, 1962; Story, 1965), and a host of Gary varieties were named in a primitive effort to express some of this variability. For another example, in Early Archaic times a confusing stylistic melding seems to have existed among dart points in central Texas and the Lower Pecos region. In the case of specimens from the Devil's Mouth site (Johnson, 1964), I was unable to recognize or perceive Texan types or define new types and simply named a quite variable Early

Barbed form. Since that day, other Texan archaeologists have wrestled with the same problem in classifying Early Archaic dart heads and have taken a path similar to mine in proposing Early Corner-Notched (Hester, 1971) and other general groupings.

Finally, a large number of extremely late Paleo-Indian dart points are presently coming to light that have great variability and are difficult to type. They have been uncovered in the so-called Plainview zone at the Wilson-Leonard site of the Edwards Plateau (W. C. Young, unpublished data), at the Quince site of Atoka County, Oklahoma (T. K. Perttula, unpublished data), and throughout eastern Oklahoma and Texas (files of D. A. Story; Johnson, 1989). The reader should realize that the reference to Oklahoma data is entirely appropriate, because Oklahoma archaeologists form a sister *Volksgemeinschaft* closely allied to the folk community of their Texan colleagues. In fact, this close cultural relationship is sometimes expressed semantically by minimizing the geopolitical difference between Texas and Oklahoma, through labeling the first entity Baja Oklahoma (for example, Jenkins, 1981), though some resistance to this nomenclature has been discerned in Texas.

The tendency among many Texan archaeologists with whom I have discussed this material is to force most of the late Paleo-Indian lanceolate styles into the Plainview type (for example, Perttula, 1985), when in fact the specimens do not fit it except in the most general way. So the folk typology may work moderately well when the aborigines obligingly kept their variation to a minimum, but it mostly fails when they did not, or when styles changed rapidly or were themselves only points along a continuum of form. Only a multivariate description allowing of degree will express this variation.

To summarize, Texan and other archaeologists can benefit considerably by contemplating the differences between Aristotelian and non-Aristotelian semantics, and by digesting Alfred Korzybski's *Science and sanity* (1958), a ponderous but entertaining tome that best sets forth the latter philosophy. It is surely helpful to be aware of the way in which our thinking is culturally bound, and to recognize the primitiveness of the older approach which always sees the world as discrete kinds of things. Certainly, archaeological mathematics and multivariate approaches have been around a long time and include sophisticated factor analyses, iterative clustering studies, and so forth (for a list of early studies of the sort see Johnson, 1972:373-374). But archaeologists always have felt a bit cast down to find that their multivariate approaches did not let them discover types.

The inappropriateness of the type notion, itself, quite obviously never has been appreciated fully in Texas (as well as many other regions), but for an enlightened example of an improvement on the idea elsewhere see

Wilmsen and Robert's (1984:25) substitute concept involving less idealized and less uniform "categories." Other alternatives also have been proposed. In only one publication (Hughes and Willey, 1978), however, have any Texan archaeologists ever mentioned, to my knowledge, the dangers inherent in Aristotelian techniques of description. Finally, it is good to remember that all of the variation that occurs in types, and in behavioral trends revealed by non-Aristotelian techniques, does not merely reflect style *per se*. Variations caused by differing manufacturing techniques, or by resharpening and reworking attempts, also affect the final form of a stone tool.

The task of implementing non-Aristotelianism will be difficult, and archaeologists may suffer apoplectic fits as they confront data trends that are tedious to compile and hard to compare from one site to another. The most reasonable approach is not to abandon all at once the folkish Aristotelian system now in use, but to modify it slowly and surely by perceiving degrees of relationship and by expressing traits, when it is appropriate, in terms of continua or near-continua (such as ordinal scales). The result will be frustratingly hard to grasp mentally. But at last Texan archaeologists will no longer be one group of primitives trying to study the tools of other groups of primitives.

As an afterword, I beg leave to address another but related matter: the faddish trend in certain circles to criticize archaeologists of the Texan state (usually only by word of mouth) for placing so much emphasis on the study of projectile points. That is a piece of unfounded humbuggery. Archaeologists may be criticized validly for excluding various sorts of tools and paleoenvironmental information from their principal analyses, but surely not for studying and emphasizing the tools they have seen fit to treat. As it turns out, projectile points are a special medium for the expression of ethnic style, and are consequently helpful regional markers and period fossils. They deserve considerable attention.

Sometimes it takes an outsider to see this fact. For that reason I value the opinion concerning this matter published by C. Garth Sampson, a Cambridge-trained Paleolithic specialist who analyzed a major archaeological site in northern California. In his report on Nightfire Island of Siskiyou County, Sampson (1985) concluded that local prehistoric aboriginal flint knappers were limited in their inventiveness and artistic expression, by tradition, mainly to the fashioning of projectile heads. The change in their styles from period to period may have been slow, but it tended to exceed that among other classes of chipped-stone tools. The same safely may be said for Texan aborigines of most periods. What is interesting is that it takes an Old World prehistorian familiar with many ancient cultures to have sufficient comparative knowledge to appreciate the New World aboriginal interest in stone projectile points.

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LITERATURE CITED

Baerreis, D. A., J. E. Freeman, and J. V. Wright. 1958. The contracting stem projectile point in eastern Oklahoma. Bull. Oklahoma Anthropol. Soc., 6:61-82.

Black, S. L. 1986. The Clemente and Herminia Hinojosa site, 41 JW 8: a Toyah horizon campsite in southern Texas. Center Archaeol. Res., Spec. Rept. 18, Univ. Texas at San Antonio, vii+302 pp.

Chaney, R. 1988. Cultural plurality and human potential. Paper presented at the Northwest Anthropology Conference, Tacoma, Washington, March 10-13, 8 pp.

Hester, T. R. 1971. Archeological investigations at the La Jita site, Uvalde county, Texas. Bull. Texas Archeol. Soc., 42:51-148.

Hughes, J. T., and P. S. Willey. 1978. Archeology at Mackenzie Reservoir. Archeol. Surv. Rept. 24, Texas Hist. Comm., Austin, xiii+294 pp.

Jelks, E. B. 1978. Diablo range. Pp. 71-111, *in* Chronologies in New World archaeology (R. E. Taylor and C. W. Meighan, eds.). Academic Press, New York, xiii+587 pp.

Jenkins, D. 1981. Baja Oklahoma. Atheneum, New York, 299 pp.

Johnson, L., Jr. 1962. The Yarbrough and Miller sites of northeastern Texas, with a preliminary definition of the La Harpe aspect. Bull. Texas Archeol. Soc., 32:141-284.

———. 1964. The Devil's Mouth site: a stratified campsite at Amistad reservoir, Val Verde County, Texas. Archaeol. Ser., Dept. Anthropol., Univ. Texas at Austin, 6:1-115.

———. 1972. Problems in "avant-garde" archaeology. Amer. Anthropol., 74:366-377.

———. 1989. Great Plains interlopers in the Eastern Woodlands during late Paleo-Indian times: the evidence from Oklahoma, Texas, and areas close by. Texas Hist. Comm., Austin, in press.

Kelley, J. H., and M. P. Hanen. 1988. Archaeology and the methodology of science. Univ. New Mexico Press, Albuquerque, xiii+437 pp.

Korzybski, A. 1958. Science and sanity, an introduction to non-Aristotelian systems and general semantics. Inst. General Semantics, Lakeville, Connecticut, 4th ed., xc+806 pp.

Kuhn, T. S. 1970. The structure of scientific revolutions. University of Chicago Press, Chicago, 2nd ed., xii+210 pp.

Mallouf, R. J. 1987. Las Haciendas, a cairn-burial assemblage from northeastern Chihuahua, Mexico. Rept. Office State Archeologist 6, Texas Hist. Comm., Austin, xiii+108 pp.

Perttula, T. K. 1985. The Quince site: a stratified Paleoindian to Woodland occupation in the Ouachita Mountains of southeast Oklahoma. Current Res. Pleistocene, 2:25-26.

Sampson, C. G. 1985. Nightfire Island: later Holocene lakemarsh adaptation on the western edge of the Great Basin. Univ. Oregon Anthropol. Papers, 33:xx+1-553.

Scriven, M. 1959. The covering law position: a critique and an alternative analysis. Pp. 443-471, *in* Theories of history (P. Gardiner, ed.), The Free Press, Glencoe, Illinois, ix+549 pp.

———. 1963. Critical study: the structure of science (E. Nagel, 1961). Rev. Metaphysics, 17:403-424.

Shanks, M., and C. Tilley. 1987. Re-constructing archaeology, theory and practice. Cambridge Univ. Press, Cambridge, xvi+267 pp.

Shafer, H. J. 1973. Lithic technology at the George C. Davis site, Cherokee County, Texas. Ph.D. dissertation, Univ. Texas (as reprinted by H. J. Shafer, 1978), Austin, xvi+369 pp.

Story, D. A. 1965. The archeology of Cedar Creek Reservoir, Henderson and Kaufman counties, Texas. Bull. Texas Archeol. Soc., 36:163-258.

Suhm (Story), D. A., and E. B. Jelks. 1962. Handbook of Texas archeology: type descriptions. Spec. Publ. Texas Archeol. Soc. 1 and Bull. Texas Mem. Mus., 4:ix+1-299.

Suhm (Story), D. A., A. D. Krieger, and E. B. Jelks. 1954. An introductory handbook of Texas archeology. Bull. Texas Archeol. Soc., 25:viii+1-582.

Turner, E. S., and T. R. Hester. 1985. A field guide to stone artifacts of Texas Indians. Texas Monthly Press, Austin, 308 pp.

Wiessner, P. 1983. Style and social information in Kalahari San projectile points. Amer. Antiquity, 48:253-276.

———. 1984. Reconsidering the behavioral basis for style: a case study among the Kalahari San. J. Anthropol. Archaeol., 3:190-234.

Wilmsen, E. N., and F. H. H. Roberts, Jr. 1984. Lindenmeier, 1934-1974, concluding report on investigations. Smithsonian Contrib. Anthropol., 24:xvi+1-187.

MAMMALIAN FAUNAS OF A LATE PLEISTOCENE-HOLOCENE TERRACE OF THE RED RIVER, TILLMAN COUNTY, OKLAHOMA

Jim R. Goetze

Department of Biology, Midwestern State University, Wichita Falls, Texas 76308

Abstract.—The stratigraphy and paleontology of Cooper Creek (18.5 km. WSW Grandfield, Tillman Co., Oklahoma) was studied in an attempt to date and identify a terrace complex and possible Pleistocene-age strata containing fossil mammalian faunas. The majority of the small mammals recovered were from a stratum radiocarbon dated at 2000±80 years before present. The faunas suggest a prairie environment since the end of the Pleistocene. *Mammuthus columbia, Canis lupus*, and *Equus* sp. remains were recovered. *Bison antiquus* remains were found in a younger stratum. *Key words:* vertebrate paleontology; Pleistocene; Oklahoma; Cooper Creek; paleoecology.

The Red River, from the southwestern corner of Oklahoma eastward to the Arkansas border, forms the boundary between Oklahoma and Texas. The 645-kilometer length of the river west of Lake Texhoma is a braided stream with a broad valley and wide, shallow bed of sand and silt with gravel or cobbles exposed. Banks are mostly low, rarely more than a few meters high, but complicated systems of terraces are visible in aerial views, including some of late Pleistocene sands and gravels.

Bones of large mammals often are washed from nearby terraces into the river channel. Species represented usually include modern horses and cattle, the plains bison, and Pleistocene mammoths, horses, and bisons. Such bones, however, are not typically found in place in the sediments.

In 1984, Mr. Luett McMahon noted numerous bones of large mammals while searching for Indian artifacts along Cooper Creek, a short (7.3 kilometers), narrow tributary entering the north side of the Red River 18.5 km W Grandfield, Oklahoma. Some were subsequently identified by Dr. W. W. Dalquest as mammoth, extinct horse, and modern bison. The lower jaw of a black bear (*Ursus americanus*) was added to the list of species by Stangl and Dalquest (1986).

In 1987, the landowner, Mr. Jack Varner, granted permission to work the site. A study area was chosen and matrix from different sites along the creek was tested by screen-washings.

The stratigraphy exposed along Cooper Creek is extremely complicated with an extensive pattern of sandy terraces and channels. The extent of the terrace complex was not determined but must be great because, after heavy rains, Cooper Creek remains flooded for days after the water elsewhere has receded.

A thin soil covers thick, sandy loam that is loose and yellowish in color, and is presumably of late pre-Columbian age. Remains of the modern bison, *Bison bison*, are common in the sandy loam and

TABLE 1. Statigraphic levels of Cooper Creek and associated mammals.

Yellowish loam (less than 2000 years)
Cynomys ludovicianus (Ord)
Bison bison (Linnaeus)
Gray, sandy clay (2000±80 years BP)
Cynomys ludovicianus (Ord)
Geomys bursarius (Shaw)
Chaetodipus hispidus (Baird)
Sigmodon hispidus Say and Ord
Microtus cf. *pinetorum* (Le Conte)
Sylvilagus cf. *floridanus* (J. A. Allen)
Odocoileus virginianus (Zimmermann)
Black, viscous clay (earliest Holocene)
Cynomys ludovicianus (Ord)
Taxidea taxus (Schreber)
Bison antiquus Leidy
Bison sp.
Pleistocene sands (dispersed specimens)
Canis lupus Linnaeus
Equus sp.
Mammuthus columbi (Falconer)

numerous bones (including articulated partial legs and a complete skull) were found.

Beneath the yellowish sandy material is a 1.49-meter thick layer of gray to brownish gray clay containing a sparse fauna of mollusk shells and small vertebrates. Shells from this layer yielded a radiocarbon date of 2000±80 years before present (Beta Analytic, Inc.; sample number 25803). Less than 100 meters distant and at approximately the same level, remains of white-tailed deer and modern bison were found.

Beneath the gray clay level is a layer of extremely viscous (when wet) clay. Ledges of this erosion-resistant material are prominent in the creek bed. Surfaces exposed are almost jet-black, concealing the dark gray interior. Samples of this clay were dried but did not break down when placed in either cold or warm water, and could not be screen-washed. Fossils from this clay are mostly or completely black in color, sometimes fading to dark gray when dried. Other bones are shining black, hard and mineralized. A frontal with horn core of *Bison antiquus* from one such clay bed suggests late Wisconsin to early Recent age.

Just upstream from the study site, the creek cuts through a ridge or hill of yellowish, calcareous sand and gravel of unknown depth. Unfortunately, this site was barren of fossils. Just downstream from the study area, a similar ridge of almost pure sand yielded a fragment of a limb bone from a large mammal. This probable proboscidian establishes the age of this sand deposit as Pleistocene.

No Pleistocene-age mammals were found in place along Cooper Creek. However, the lower molar of a mammoth, two cheekteeth of a species of extinct horse, and the ulna of a wolf were recovered from the creek bed. Upstream from the ridge of calcareous gray clay, the valley becomes shallow; only late Holocene sediments containing bison remains are present. The remains of the large Pleistocene mammals probably originated from either the calcareous gray ridge or the sandy ridge where the proboscidian bone fragment was found.

The following is postulated. The original Pleistocene terrace was channeled through the study area, perhaps by the ancestral Cooper Creek or the Red River. The channel was subsequently filled with the viscous black clay. Still other sediments may lie beneath the black clay, not exposed. Because the black, viscous clay contains fossils no older than latest Pleistocene (and probably early Holocene) age, the erosion must have occurred late in the Pleistocene. The viscous clay was covered with the gray sandy clay some 2000 years ago. The sandy, yellow loam was deposited less than 2000 years ago.

Accounts of Selected Species

Taxidea taxus (Schreber), badger.—Badger remains consist of the preserved distal half of a humerus (MWSU 12483) with the complete ectepicondyle and entepicondylar foramen. The specimen was compared to a badger in the Midwestern State University (MWSU) Collection of Recent Mammals and found to be correspond closely in measurements.

Canis lupus Linnaeus, gray wolf.—Material consists of the proximal end of an ulna (MWSU 12469). Assignment to *Canis lupus* was made upon comparison with a Recent individual. Measurements for the fossil and the Recent specimen are respectively: transverse width across the olecranon process, 27.15 and 27.90 mm; length across the semiulnar notch 27.20 and 25.10 mm; preserved length of the specimen, 165.00 mm.

Cynomys ludovicianus (Ord), black-tailed prairie dog.—A right mandible (MWSU 12482) and partial skull (MWSU 12487) of the black-tailed prairie dog were obtained from the study area. Assignment of the specimens to *Cynomys ludovicianus* is based upon the size and morphology of the material when compared to recent specimens. The length of the lower toothrow and length of the diastema fall within the range of variation given by Lundelius (1972). Dimensions of the palate, such as length from the anterior margin of the incisor to the posterior margin of M3, and width across the lingual side of the palate at P3, agreed closely with a Recent specimen (MWSU 8194) with teeth in a similar stage of wear.

Microtus cf. *pinetorum* (Le Conte), pine vole.—Only fragmentary lower first molars and a single lower m2 (MWSU 12493) of *Microtus* were obtained. Species identification can only be tentative and is based upon the geographic distribution of *M. pinetorum* and *M. ochrogaster* as presented in Hall (1981).

Equus sp., Pleistocene horse.—Horse material consists of the distal end of a metapodial (MWSU 12470), an upper P2 (MWSU 12471), and a lower m1 (MWSU 12472). The premolar and molar were sectioned with a diamond saw to better ascertain the enamel patterns. The ectoflexid of the lower molar is blunt and does not reach the molar isthmus, whereas the linguaflexid is broad and U-shaped (Dalquest, 1988). Premolars of horses are, for the most part, undiagnostic.

The molar, premolar, and metapodial fragment were compared to specimens in the Midwestern State University Collection of Fossil Vertebrates and were found to be larger than those of *Equus conversidens*. The material is close in size to *E. excelsus*, and possibly could represent that species.

Bison antiquus Leidy, extinct bison.—Remains consist of a partial frontal with horn core (MWSU 12476). Species identification was made on the basis of the horn core's orientation to the saggital plane of the skull. According to McDonald (1981) and Lundelius (1972), *Bison antiquus* horns make nearly a 90-degree angle with the midline of the skull. *Bison bison* horn cores make an angle of 65 to 70 degrees to the saggital plane of the skull (McDonald, 1981).

Mammuthus columbi (Falconer), Columbian mammoth.—A partial thoracic vertebra (MWSU 12473), tusk fragment (MWSU 12474), and isolated enamel fragments (MWSU 12475) represent *M. columbi* in the Pleistocene fauna. Enamel fragments were referred to the genus *Mammuthus* on the basis of thickness, and measurements compared favorably with those given for *M. columbi* by Kurtén and Anderson (1980). The partial thoracic vertebra was compared to a specimen in the Collection of Fossil Vertebrates and was found to match closely.

CONCLUSION

The stratigraphy of the terrace system on the north bank of the Red River at Cooper Creek is complicated and extensive. The occurrece of *Cynomys ludovicianus* in each stratum indicates a prairie environment since the end of the Pleistocene. *Geomys bursarius, Chaetodipus hispidus* and *Sigmodon hispidus* from the dated gray, sandy clay stratum are also predominantly prairie forms. *Equus* sp. and *Taxidea taxus* suggest a grassland habitat.

The major faunal change indicated is extinction of the bison, *Bison antiquus*, in the early Holocene followed by replacement with the plains bison, *Bison bison*, and local extirpation (based upon trapping data) of the pine vole in the last 2000 years.

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LITERATURE CITED

Dalquest, W. W. 1988. Astrohippus and the origin of Blancan and Pleistocene horses. Occas. Papers Mus., Texas Tech Univ., 116:1-23.

Hall, E. R. 1981. The Mammals of North America. John Wiley and Sons, New York, 2:vi+601-1181 + *90*.

Kurtén, B., and E. Anderson. 1980. Pleistocene Mammals of North America. Columbia Univ. Press, New York, 442 pp.

Lundelius, E. L., Jr. 1972. Fossil vertebrates from the late Pleistocene Ingleside Fauna, San Patricio County, Texas. Univ. Texas Bur. Econ. Geol. Invest., 77:1-74.

McDonald, J. N. 1981. North American bison: their classification and evolution. Univ. California Press, 316 pp.

Stangl, F. B., Jr., and W. W. Dalquest. 1986. Two noteworthy records of Oklahoma mammals. Southwestern Nat., 31:123-124.

METALLOCENE SYNTHESIS WITH PHASE TRANSFER CATALYSTS

FREDERICK R. LEMKE, BRUCE JACOBSON, JOHN W. HILL,
AND RICHARD H. LANGLEY

Department of Chemistry University of Wisconsin, River Falls, Wisconsin (FRL, BJ, JWH) 54022, and Department of Chemistry, Stephen F. Austin State University, Nacogdoches, Texas 75962

ABSTRACT.—Ferrocene, $Fe(C_5H_5)_2$, was synthesized from cyclopentadiene and $FeCl_2 \cdot 4H_2O$ in the presence of solid KOH and a phase transfer catalyst (tetra-n-butyl ammonium hydrogen sulfate, $[(n\text{-Bu})_4N]\ HSO_4$, dibenzo-18-crown-6, or dicyclohexano-18-crown-6). Nickelocene was prepared under the same conditions as ferrocene using dicyclohexano-18-crown-6. The results from these syntheses indicate that metallocenes, other than ferrocene, can be prepared using phase transfer catalysis, and they indicate that crown ethers work well in catalytic amounts. *Key words:* metallocene; phase-transfer; catalysts; synthesis.

Ferrocene has been synthesized through a wide variety of methods. These methods range from the use of metal derivatives such as cyclopentadienylmagnesium bromide to acid-base reactions such as cyclopentadiene with potassium hydroxide (Jolly, 1970; Pauson, 1955; Rausch et al., 1957). The use of phase transfer catalysts in the synthesis of ferrocene is a modified acid-base reaction.

The use of phase transfer catalysts requires a two-phase system. In this work, a solid-liquid system was used; however, two immiscible liquids also could have been used. Common phase transfer catalysts include quaternary ammonium salts and crown ethers. The preparation and action of these catalysts is reviewed elsewhere (Gokel and Weber, 1978; Hill and Corredor, 1980; Varughese, 1977; Weber and Gokel, 1978).

Salisōvȧ and Alper (1979) reported the synthesis of ferrocene and several of its derivatives using 18-crown-6 as the catalyst. Zhou and Li (1983) used polyethylene glycol as the catalyst to synthesize ferrocene. In this paper, we describe an extension to other solvent systems, other catalysts, and to the synthesis of nickelocene.

EXPERIMENTAL

NMR spectra were obtained on a Perkin-Elmer Model R32 90 MHz; ^1H NMR spectrometer. UV-VIS spectra were obtained on a Cary 118 spectrometer over the range 800-250 nonometers. IR spectra were recorded on a Perkin Elmer 293B spectrometer over the range 4000-200 cm^{-1} using KBr pellets.

Ferrocene Synthesis

To 60 grams (1.07 mole) of finely ground KOH (Baker) was added 2.3 grams (0.07 mole) of $[(n\text{-BU})_4]HSO_4$ (Aldrich), 120 milliliters of 1,2-

dimethoxyethane (Eastman), and five milliliters of water. The system was then purged with argon or nitrogen and 11 milliliters (0.13 mole) of freshly prepared cyclopentadiene (from the thermal cracking of bicyclopentadiene (Aldrich—Jolly, 1970) was added. (An inert atmosphere is not essential for this or the following steps due to the stability of ferrocene to air oxidation). After the wine red color of the cyclopentadienide ion appeared, 13 grams (0.07 mole) of $FeCl_2 \cdot 4H_2O$ (Alfa) in 75 milliliters of dimethylsulfoxide (Alfa) was added slowly over a period of 0.75-1.0 hours. When addition was complete, stirring was continued for an additional 0.25 hours. The reaction mixture then was added to 180 milliliters of 6-molar HCl containing 200 grams of ice and stirred for 0.25 hours. The product was collected on a sintered-glass funnel, washed with 30-milliliter portions of water, air-dried, and sublimed at 100°C/760 millimeters (Jolly, 1970). The yield was 52 percent based on cyclopentadiene. ^1H NMR: 4.2, s; UV-VIS: 325 nanometers (ϵ = 50) and 440 nanometers (ϵ = 87) (Armstrong et al., 1967; Johnson and Rayner-Ganham, 1972).

The above procedure was repeated using 0.1 grams (0.0003 mole) of dicyclohexano-18-crown-6 (Alfa) instead of $[(n\text{-Bu})_4N]HSO_4$ and no water. Yield was 53 percent based on cyclopentadiene. This procedure was repeated using toluene in place of the 1,2-dimethoxyethane and dibenzo-18-crown-6 (Aldrich) as the phase transfer catalyst. All reaction times were increased by 0.5 hour in this solvent. The yield was nearly quantitative based on cyclopentadiene.

Nickelocene Synthesis

The ferrocene-crown ether method may be adapted for the synthesis of nickelocene by making a few modifications. In the nickelocene synthesis, 11.0 grams (0.05 mole) of $NiCl_2O$ (Alfa) and 8.5 milliliters (0.10 mole) of cyclopentadiene were used. The phase transfer catalyst was dicyclohexano-18-crown-6. Because nickelocene is more air-sensitive than ferrocene the acid-ice mixture was deaerated by bubbling a stream of argon through the mixture for 0.5 hour. All manipulations must be done under argon or nitrogen. A vacuum sublimation (100°/10 millimeters) was carried out to purify the product. The yield was about 40 percent based on cyclopentadiene. The bright green product gave an IR spectrum with peaks at: 3105, 3088, 1428, 1112, 1004, 838, 800 and 355 cm_{-1} (Lit. 3109, 3096, 1423, 1109, 1002, 838, 802, 355 cm_{-1}, Wilkinson et al., 1954).

RESULTS AND DISCUSSION

The yields (experimental) of ferrocene obtained with either dicyclohexano-18-crown-6 or tetrabutylammonium hydrogen sulfate were comparable to those reported earlier (Salisōvá and Alper, 1979). The quaternary ammonium salt was used in approximately the same mole ratio (catalyst:cyclopentadiene) as in the work of Salisōvà with about the same results. Thus, quaternary ammonium salts work just as well as crown ethers though they are not truly catalytic because such a large amount was used. Crown ethers were used in catalytic amounts instead of a 1:2 (catalyst:cyclopentadiene) ratio as reported by previous workers.

Using either catalyst has its advantages. The quaternary ammonium salt was easier to use and less toxic that the crown ethers. But, the crown ethers can be used in catalytic amounts so they are cheaper to use. Also, either catalyst could be used in the presence of water thus eliminating the need for rigorously anhydrous solvents. In fact, the quaternary ammonium salt worked better in the presence of added water.

Crown ethers do have an advantage over quaternary ammonium salts in that they do not form tightly bound ion-pairs. This permits the crown ether to work in a truly catalytic sense. Also, crown ethers have the proper geometric arrangement of heteroatoms to aid in the removal of the cation from the solid base in a solid-liquid system.

This investigation showed that it is possible to extend the synthesis to nonpolar solvents. In this study, it was shown that in the presence of a dibenzo-18-crown-6 the reaction of KOH with cyclopentadiene could be carried out in toluene as well as 1,2-dimethoxyethane.

Nickelocene was synthesized by an analogous reaction using nickel (II) chloride with dicyclohexano-18-crown-6 as the catalyst. The nickelocene is much more air-sensitive than the ferrocene so additional precautions are necessary. The yield is also lower.

The method used for ferrocene and nickelocene is applicable, in general, to syntheses employing carbanions of acids with pK_a's as great as 22. These results demonstrate that quaternary ammonium salts can be used instead of crown ethers and that crown ethers can be used catalytically.

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LITERATURE CITED

Armstrong, A. T., F. Smith, E. Elder and S. P. McGlynn. 1967. Electronic absorption spectrum of ferrocene. J. Chem. Phys., 46:4321-4328.

Gokel, G. W., and W. P. Weber. 1978. Phase transfer catalysis part 1: general principles. J. Chem. Ed., 55:350-354.

Hill, J. W., and J. Corredor. 1980. An ether synthesis using phase transfer catalysis. J. Chem. Educ., 57:822.

Johnson, D. W., and G. W. Rayner-Ganham. 1972. Ferricinium picrate. J. Chem. Ed., 49:211.

Jolly, W. L. 1970. The synthesis and characterization of inorganic compounds. Prentice-Hall, Englewood Cliffs, New Jersey, xi+590 pp.

Pauson, P. L. 1955. Ferrocene and related compounds. Quart. Revs., 9:391-414.

Rausch, M., M. Voge, and H. Rosenberg. 1957. Ferrocene: a novel organometallic compound. J. Chem. Ed., 34:268-292.

Salisōvá, M., and H. Alper. 1979. Phase transfer catalyzed synthesis of ferrocene derivatives. Agnew. Chem. Int. Ed. Engl., 18:792.

Varughese, P. 1977. Quaternary ammonium salts. J. Chem. Ed., 54:666-669.

Weber, W. P., and G. W. Gokel. 1978. Phase transfer catalysis part II: synthetic applications. J. Chem. Ed., 55:429-433.

Wilkinson, G., P. L. Pauson, and F. A. Cotton. 1954. Bis-cyclopentadienyl compounds of nickel and cobalt. J. Am. Chem. Soc., 76:1970-1974.

Zhou, J., and G. Li. 1983. Improvement in the synthesis of ferrocene. Youji Huaxue, 1:54.

ESTIMATING DIGESTIBILITIES FOR WHITE-TAILED DEER IN SOUTH TEXAS

Otto F. Strey III and Robert D. Brown

Caesar Kleberg Wildlife Research Institute, Texas A&I University, Kingsville, Texas 78363, and Department of Wildlife and Fishies, Mississippi State University, Mississippi State, Mississippi 39762

Abstract.—*In vivo* and *in vitro* digestible dry matter (DDM), digestible organic matter (DOM), and digestible protein (DP) were determined for white-tailed deer fed alfalfa hay, mesquite beans and alfalfa hay, and a commercial low protein-low energy (LPLE) ration. Regression of *in vivo* and *in vitro* digestibilities resulted in significant linear relationships ($P = 0.0001$, $R^2 = 0.88$, $N = 9$) for DDM, DOM ($P = 0.044$, $R^2 = 0.91$, $N = 4$), and DP ($P = 0.037$, $R^2 = 0.88$, $N = 5$). Regression equations developed from the *in vivo-in vitro* digestibility comparisons for DDM, DOM, and DP provided estimates of *in vivo* digestibilities for 21 deer forages in South Texas. *Key words:* digestibility; forage, *in vivo; in vitro; Odocoileus virginianus.*

Nutrient availability limits the productivity of white-tailed deer (*Odocoileus virginianus*) inhabiting rangelands in southern Texas. Nutrient digestibilities of preferred deer forages, along with nutritional requirements and forage production, is essential to estimate carrying capacity for deer habitats.

Because it would be cumbersome to determine the *in vivo* digestibilities of all natural deer forages, *in vitro* digestion procedures are used to estimate digestibility, incorporating deer forage standards of known *in vivo* digestibilities. The source of rumen inoculum has been the principal obstacle in establishment of a standardized *in vitro* digestion procedure for deer. Several studies (Ward, 1971; Blankenship et al., 1982; Campa et al., 1984; Priebe et al., 1987) have revealed differences in digestibility estimates due to inoculum source. Other investigators (Robbins et al., 1975; Palmer et al., 1976; Palmer and Cowan, 1980; Crawford and Hankinson, 1984) have reported little or no difference between deer and bovine inoculum. The animal species used as an inoculum source is not a factor provided *in vitro* digestibility values obtained from the donor species correlate well with *in vivo* digestibilities of the study species (Milchunas and Baker, 1982).

Comparative *in vivo-in vitro* digestibilities of feed standards for deer yield regression equations providing estimates of *in vivo* digestibilities for natural deer foods. The purpose of our study was to: (1) provide a range of *in vivo* feed standards for white-tailed deer; (2) develop regression equations from comparisons of deer *in vivo* and *in vitro* digestibilities of these standards using cow inoculum; (3) use these equations to estimate *in vivo* digestibilities of a variety of South Texas range plants selected by deer.

METHODS

In Vivo Trials

The *in vivo* digestion trials were conducted using four metabolism chambers at the Texas A&I University Wildlife Research Facility, Kingsville, Texas (Wheaton and Brown, 1983). Six pen-raised does were selected for each trial. Three diets were evaluated: alfalfa (ALF), alfalfa mixed with (20 percent) honey mesquite pods (*Prosopis glandulosa*) (MBALF), and a commercial low protein-low energy (LPLE) ration. Trial periods were 21 days in length, allowing animals 14 days for adjustment to feed and confinement and seven days for fecal collection. Aliquots of five percent of the total fecal output were taken daily during the final week of each trial. Fecal samples were placed in polypropylene bags and frozen until analysis. Grab samples of feed were collected daily for nutrient composition analysis. Feed and water were offered *ad libitum* during the first three days of the adjustment phase, after which feed was decreased until all was consumed in a 24-hour period. This amount was then offered to deer for the remainder of the digestion trial (Harris, 1970). Deer were allowed a minimum of 14 days rest between each trial. During this period, animals were maintained on a pelleted wildlife ration (P&M Products, San Antonio, Texas).

Duplicate samples of feed and fecal material from each trial were air dried at 40°C and ground in a Wiley mill to pass a one millimeter screen. Dry matter (DM), organic matter (OM), and crude protein (CP) were determined by proximate analysis (AOAC, 1980). Apparent digestible dry matter (DDM), organic matter (DOM), and protein (DP) coefficients were determined (Schneider and Flatt, 1975).

In Vitro Trials Inoculum for the *in vitro* samples was collected from a fistulated, non-lactating Jersey cow maintained on coastal bermuda (*Cynodon dactylon*) hay and provided with Purina Forage Balancer Block 3-HL and Purina Cattle Mineral 12:12 (Ralston Purina Co., St. Louis, Missouri) *ad libitum*. The *in vitro* procedure used was a modified version of the two-stage technique of Tilley and Terry (1963), see Harris (1970).

Percent *in vitro* digestible dry matter (IVDDM), *in vitro* digestible organic matter (IVDOM), and *in vitro* digestible protein (IVDP) were determined for each *in vivo* feed. *In vitro* digestible protein percent (IVDP) of standards was calculated from a procedure established for domestic animals (Knight and Harris, 1966) and is presented by Schneider and Flatt (1975): $y = 0.725x - 1.46$; (where: x = crude protein percent of forage sample, and y = estimated or *in vitro* digestible protein).

Evaluation of South Texas Deer Forages

Twenty-one forage species were identified (Table 1) by bite-counts (Graham, 1982) and collected from 25 February to 31 March 1985 in a 22-hectare enclosure located five kilometers south of Kingsville, Texas. Emergent forbs were collected whole. Only spring regrowth of herbaceous plants was sampled, and the terminal three to five centimeters of new growth from browse species was analyzed. Forage samples were weighed, dried, and analyzed *in vitro* along with samples of *in vivo* feed standards to minimize trial variability.

Seven additional feed standards were included in these calcuations. Northern white-cedar (*Thuja occidentalis*) (CEDAR), a deer ration (DEERFD), redclover hay (REDCLO), early- and late-cut alfalfa (ECALF and LCALF, respectively) (Palmer and Cowan, 1980) were used in the DDM regression. A pelleted deer ration (ANTLER+) (Wheaton and Brown, 1983) was added to the regression for DP, and a pelleted deer feed (DEERPLT) used at the TAIU Wildlife Research Facilities, was added to regressions for DDM, DOM, and DP.

Linear regressions from *in vivo* and *in vitro* digestibility comparisons were used to adjust *in vitro* digestibilities (Palmer and Cowan, 1980; Brooks and Urness, 1984; Crawford and Hankinson, 1984) to estimate *in vivo* digestibility of these natural forages for white-tailed deer.

TABLE 1. Plant species most important in white-tailed deer diets as determined by bite-counts on the Texas A&I University Range and Wildlife Research Area, 1 March 1980-31 August 1981 Graham (1982).

Forage species	Percent of diet
Shrubs	
Celtis pallida (Granjeno)	12.0
Condalia obovata (Brazil)	6.4
Acacia rigidula (Blackbrush)	5.5
Zanthoxylum fagara (Colima)	5.0
Acacia farnesiana (Huisache)	4.2
Ziziphus lobtusifolia (Lotebush)	2.0
Diospyros texana (Texas persimmon)	1.5
Prosopis glandulosa (Honey mesquite)	0.3
Forbs	
Parthenium hysterophorus (False ragweed)	4.4
Eupatorium odoratum (Mistflower)	4.3
Parietaria floridana (Pellitory)	3.7
Clematis drummondii (Old-man's beard)	2.1
Ericameria austrotexana (False broomweed)	1.3
Helenium amarum (Bitterweed)	0.2
Grasses	
Dichanthelium annulatum (Kleberg bluestem)	7.5
Cenchrus ciliaris (Buffelgrass)	3.5
Setaria texana (Texas bristlegrass)	2.2
Erichloa contracta (Prairie cupgrass)	1.5
Sorghum halepense (Johnsongrass)	1.1
Chloris pluriflora (Trichloris)	0.9
Aristida purpurea (Purple threeawn)	0.1
Bothriochloa saccharoides (Silver bluestem)	0.1
Cynodon dactylon (Common bermuda)	0.1

RESULTS

In vivo digestibility values (Table 2) were highest for the MBALF diet, whereas DDM (51.6 percent) was similar to values reported by Palmer and Cowan (1980) (52.2 percent DDM) and Mould and Robbins (1982) (55.2 percent DMD).

A linear relationship ($Y = 1.56+0.93x$, $P = 0.0001$, $R^2 = 0.88$, $N = 9$) was found between *in vivo* and *in vitro* DDM. The regression of *in vivo* with *in vitro* DOM also was linear ($Y = 9.05 + 0.8x$, $P = 0.044$, $R^2 = 0.91$, $N = 4$). Only four standards were used in the DOM comparison because *in vivo* DOM values were unavailable for five of the standards used. When *in vivo* DP was regressed against IVDP a linear association ($Y = 0.009 + 0.95x$, $P = 0.037$, $R^2 = 0.88$) was obtained as well. An additional standard ($N = 5$) was used for the *in vivo* DP regression.

Estimated *in vivo* and *in vitro* DDM of spring range plants for deer (Table 3) were similar; *in vivo* estimates ranging from 36.38 percent

TABLE 2. Mean apparent *in vivo* and *in vitro* digestibilities of feed standards for white-tailed deer.

	In vivo (%)			*In vitro* (%)		
Standard	DDM	DOM	DP	DDM	DOM	DP
ALF[1]	51.60	51.21	10.67	57.18	52.88	11.69
MBALF[1]	61.19	61.84	11.49	63.14	61.27	9.96
LPLE[1]	47.19	46.91	2.63	48.17	47.39	3.64
DEERPLT[2]	63.03	61.77	11.49	70.56	67.58	10.88
CEDAR[3]	37.0	*	*	41.59	*	*
DEERFD[3]	74.10	*	*	75.28	*	*
ECALF[3]	62.10	*	*	57.55	*	*
LCALF[3]	52.20	*	*	54.46	*	*
REDCLO[3]	58.90	*	*	61.18	*	*
ANTLER+[4]	*	*	12.02	*	*	13.91

[1] Six deer used for each *in vivo* trial. Trial periods were 21 days.
[2] Seven deer used in *in vivo* trial. Trial period was 21 days.
[3] Palmer and Cowan (1980).
[4] Wheaton and Brown (1983).
*Digestibilities not available.

DDM for silver bluestem (*Bothriochloa saccharoides*) to 71.28 percent *in vivo* DDM for granjeno (*Celtis pallida*).

Estimates of *in vivo* DOM for range plants were slightly less than those obtained for DDM, as is usually found when *in vitro* DDM and DOM are determined; higher soluble ash content in some range forages tend to elevate estimates of *in vitro* DDM while supressing *in vitro* DOM (Meyer and Brown, 1985).

Percent *in vivo* DP estimates for deer (Table 3) ranged from 2.63 to 11.81 percent for prickly pear (*Opuntia lindheimeri*) and buffelgrass (*Cenchrus ciliaris*), respectively. Estimated *in vivo* DP (10.77 percent) for buffelgrass and colima (*Zanthoxylum fagara*) were considerably higher than that of Kleberg bluestem (*Dichanthelium annulatum*) (6.09), following the trend of varying seasonal crude protein levels estimated for these forages (Meyer et al. 1984) in South Texas.

DISCUSSIONS AND CONCLUSIONS

Regression of *in vivo* and *in vitro* DDM using ALF, MBALF, and LPLE feed standards provided a highly significant ($P = 0.0001$) equation for estimating *in vivo* DDM (Urness et al., 1977) when augmented with additional *in vivo* feed standards (Palmer and Cowan, 1980; Wheaton and Brown, 1983). These results were anticipated because the predictive value for estimates of *in vivo* digestibility are generally enhanced through increased sample size (Crawford and Hankinson, 1984). Moreover, selecting standards with a wide range of *in vivo* digestibilities (37 to 74.1 percent DDM), provides digestibility estimates for a greater variety of

TABLE 3. *In vitro* and estimated *in vivo* digestibilities of spring range plants for white-tailed deer.

	In vitro			Estimated *in vivo* (%)		
Forage	DDM	DOM	DP	DDM[2]	DOM[3]	DP[4]
Shrubs						
Granjeno	74.41	66.46	21.30	71.28	62.86	*
Brazil	61.07	55.14	11.60	58.78	53.70	*
Colima	71.69	67.61	11.29	68.73	*	10.77
Huisache	57.86	56.15	22.23	55.77	54.52	*
Mesquite pod	57.86	57.08	6.33	55.77	55.27	6.03
Persimmon	66.33	61.59	15.57	63.71	58.92	*
Lotebush	54.82	51.59	19.47	52.54	50.82	*
Mesquite foliage	59.10	57.61	6.24	56.93	55.70	5.94
Forbs						
Mistflower	65.26	55.93	22.78	62.70	52.72	*
Pellitory	64.89	47.32	17.24	61.90	46.90	*
Bitterweed	58.22	50.07	10.32	56.11	49.59	9.84
Old-man's beard	71.17	66.94	20.53	68.24	63.25	*
False broomweed	55.72	49.53	14.18	53.77	49.16	*
Grasses						
Buffelgrass	64.33	57.85	12.38	61.83	55.90	11.81
Trichloris	58.34	53.70	10.16	56.22	52.54	9.69
Johnsongrass	67.69	61.91	11.62	64.98	59.18	11.08
Bermuda	59.05	51.67	9.29	56.47	50.89	8.82
Kleberg bluestem	52.26	46.18	6.39	50.52	*	6.09
Silver bluestem	37.44	35.78	4.07	36.38	*	3.87
Purple threeawn	42.05	39.97	5.71	39.11	*	5.43
Cacti						
Prickly pear	78.84	64.14	2.87	*	51.10	2.63

[1] Determined from two feed replicates using inoculum from a cow.

[2] $Y=1.56+0.93x$ ($P=0.0001$, $R^2=0.88$, $N=9$) with Y=*in vivo* DDM and X=*in vitro* DDM.

[3] $Y=9.05+0.80x$ ($P=0.044$, $R^2=0.91$, $N=4$) with Y=*in vivo* DOM and X=*in vitro* DOM.

[4] $Y=0.009+0.95x$ ($P=0.037$, $R^2=0.88$, $N=5$) with Y=*in vivo* DP and X=*in vitro* DP.

*Estimates were beyond the range of *in vivo* digestibilities for feed standards and are statistically invalid.

forages utilized by deer (Palmer and Cowan, 1980). Linear regression of DOM standards also were significant ($R^2 = 0.91$, $P = 0.044$), although prior attempts to develop estimators for *in vivo* DOM in elk (*Cervus elaphus*) (Brooks and Urness, 1984) met with limited success ($R^2 = 0.37$, $P < 0.05$).

In vitro techniques have been used to estimate dietary crude protein of deer diets (Meyer et al., 1984), as well as physiological indices to estimate nitrogen intake of deer diets (Kopf et al., 1984). However, application is limited to the relative ranking of diet quality and animal condition, whereas our equation for estimating *in vivo* DP of deer foods provides a means of detemining digestibility. This is especially important during periods of protein stress for deer such as the rut period for bucks (Wheaton and Brown, 1983), and for pre- and postpartum does (Murphy and Coates, 1966).

Estimated *in vivo* digestibilities of South Texas range plants for deer (Table 3) were generally proportional to their selection (Table 1). Highly digestible browse species such as granjeno, brazil (*Condalia obovata*), and colima were among the most highly selected. Mistflower (*Eupatorium odoratum*) and false ragweed (*Parthenium hysterophorus*) were forbs highly selected by deer, and estimated *in vivo* DDM and DOM were highest for mistflower (62.70 percent DDM, 52.72 percent DOM) and false ragweed (58.47 DOM) among forbs tested. However, whereas Kleberg bluestem represented the highest percent of deer diets (Table 1) among grasses (7.50), estimated *in vivo* digestibilities (50.52 percent DDM, 6.09 percent DP) were lower than those of less-selected grass species such as buffelgrass (61.83 percent DDM, 11.81 percent DP) and trichloris (*Chloris pluriflora*) (56.22 percent DDM, 9.69 percent DP).

The practical applications for using regression equations to estimate *in vivo* digestibilities for deer are apparent. The nutritive value of natural deer forages that are impractical to feed in conventional *in vivo* digestion trials can be determined simply by running an *in vitro* digestibility trial and adjusting the values with these equations. Inasmuch as the feed standards for DDM represent a wide range of *in vivo* digestibilities, and the regression equation obtained is highly significant ($P = 0.0001$), reliable estimates of *in vivo* DDM for deer are possible. Additionally, digestible energy (DE) can be calculated from IVDDM (Rittenhouse et al., 1971) or IVDOM (Meyer et al., 1984) using Swift's (1957) constant of 4.4 kilocalories DE per gram total digestible nutrients (TDN) (Palmer and Cowan, 1980; Blankenship et al., 1982), because both nutrients are numerically equivalent to TDN. The estimated maintenance level of TDN for deer (Silver et al., 1969; Blankenship et al., 1982) ranges from 52 to 60 percent. Calculated DE estimates of the spring range plants collected met or exceeded these levels for all but a few forages, such as Kleberg bluestem, common bermuda (*Cynodon dactylon*), and false broomweed (*Ericameria austrotexana*). Estimates of DE or TDN for deer forages coupled with forage production data can provide managers with estimates of rangeland carrying capacity for deer (Palmer and Cowan, 1980; Blankenship et al., 1982).

Despite the small number of *in vivo* standards for *in vivo* and *in vitro* DOM and DP comparisons, estimates of *in vivo* digestible nutrients for the spring deer forages are believed to be representative. Additional feed standards for DOM and DP linear regressions may help improve the dependability of estimates for these nutrients.

High deer densities coupled with revenues to landowners from sport hunting suggests that white-tailed deer may influence land use patterns in Texas (Everitt and Gonzales, 1979; Blankenship et al., 1982). Managers concerned with maintaining quality rangeland forages can utilize this technique to estimate *in vivo* digestibilities of foods for free-ranging deer.

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LITERATURE CITED

Association of Official Agricultural Chemists (AOAC). 1980. Official methods of analysis. 12th ed., Washington, D.C., 1015 pp.

Blankenship, L. H., L. W. Varner, and G. W. Lynch. 1982. In vitro digestibility of South Texas range plants using inoculum from four ruminant species. J. Range Manag., 35:664-666.

Brooks, J., III, and P. J. Urness. 1984. Comparison of in vivo and in vitro digestibility of forages by elk. J. Anim. Sci., 58:963-970.

Campa, H., III, D. K. Woodyard, and J. B. Haufler. 1984. Reliability of captive deer and cow in vitro digestion values in predicting wild deer digestion levels. J. Range Manag., 34:468-470.

Crawford, H. S., and D. H. Hankinson. 1984. White-tailed deer vs. bovine inocula for in vitro digestibilities. J. Wildlife Manag., 48:649-652.

Everitt, J. H., and C. L. Gonzales. 1979. Botanical composition and nutrient content of fall and early winter diets of white-tailed deer in South Texas. Southwestern Nat., 24:297-310.

Graham, M. W. 1982. Diets of white-tailed deer and nilgai antelope in South Texas. Unpublished M.S. thesis, Texas A&I Univ., Kingsville, 122 pp.

Harris, L. E. 1970. Nutrition research techniques for domestic and wild animals. Utah State Univ., Logan, 124 pp.

Knight, A. D., and L. E. Harris. 1966. Digestible protein estimation for NRC feed composition tables. J. Anim. Sci., 25:593.

Kopf, V., R. D. Brown, and D. L. Drawe. 1984. Prediction of protein intake in white-tailed deer in South Texas. J. Wildlife Manag., 48:518-526.

Meyer, M. W., R. D. Brown, and M. W. Graham. 1984. Protein and energy content of white-tailed deer diets in the Texas Coastal Bend. J. Wildlife Manag., 48:527-534.

Micchunas, D. G., and D. L. Baker. 1982. In vitro digestion—sources of within-and between-trial variability. J. Range Manag., 35:199-203.

Mould, E. D., and C. T. Robbins. 1982. Digestive capabilities of elk compared to white-tailed deer. J. Wildlife Manag., 46:22-29.

Murphy, D. A., and J. A. Coates. 1966. Effects of dietary protein on deer. Trans. N. Amer. Wildlife Nat. Res. Conf., 31:129-139.

Palmer, W. L., R. L. Cowan, and A. P. Ammann. 1976. Effect of inoculum source on in vitro digestion of deer foods. J. Wildlife Manag., 40:301-307.

———. 1980. Estimating digestibility of deer foods by an in vitro technique. J. Wildlife Manag., 44:469-472.

Priebe, J. C., R. D. Brown, and D. Swakon. 1987. Comparative in vitro digestive efficiency of cattle, goats, nilgai antelope, and white-tailed deer. Texas J. Sci., 39:341-348.

Rittenhouse, L. R., C. L. Streeter, and D. C. Clanton. 1971. Estimating digestible energy from digestible dry and organic matter in diets of grazing cattle. J. Range Manag., 24:73-75.

Robbins, C. T., P. J. Van Soest, W. W. Mautz, and A. N. Moen. 1975. Feed analyses and digestion with reference to white-tailed deer. J. Wildlife Manag., 39:67-79.

Schneider, B. H., and W. P. Flatt. 1975. The evaluation of feeds through digestibility experiments. Univ. Georgia Press, Athens, 423 pp.

Silver, H., N. F. Colovos, J. B. Holter, and H. H. Hayes. 1969. Fasting metabolism of white-tailed deer. J. Wildlife Manag., 33:490-498.

Swift, R. W. 1957. The nutritive evaluation of forages. Penn State Univ. Agric. Exp. Sta. Bull., 615:1-34.

Tilley, J. M. A., and R. A. Terry. 1963. A two-stage technique for the in vitro digestion of forage crops. J. British Grassland Soc., 18:104-111.

Urness, P. J., A. D. Smith, and R. K. Watkins. 1977. Comparison of in vivo and in vitro dry matter digestibility of mule deer forages. J. Range Manag., 30:119-121.

Ward, A. L. 1971. In vitro digestibility of elk winter forage in southern Wyoming. J. Wildlife Manag., 30:119-121.

Wheaton, C., and R. D. Brown. 1983. Feed intake and digestive efficiency of South Texas white-tailed deer. J. Wildlife Manag., 47:442-450.

Present address of Strey: Texas Agricultural Experiment Station, Department of Entomology, Texas A&M University, College Station, Texas 77843.

GENERAL NOTES

OBSERVATIONS OF PREDATION BY RED IMPORTED FIRE ANTS ON LIVE-TRAPPED WILD COTTON RATS

EDWARD L. FLICKINGER
U.S. Fish and Wildlife Service, Patuxent Wildlife Research Center, Laurel, Maryland 20708

Red imported fire ants (*Solenopsis invicta*) from South America were introduced into the United States in Alabama in the 1940s. They reached eastern Texas by 1953 and moved west and south across the state (Hung and Vinson, 1978). These ants are aggressive, bite furiously, and inflict a painful sting of powerful necrotizing poison (Metcalf et al., 1962). Although omnivorous, fire ants prefer protein food (Metcalf et al., 1962) that is located by scent detectors on their antennae (B. Van Eimeren, University of Texas, personal communication).

In studies involving live-trapping of small mammals in southern states, mortality of animals in traps frequently was inferred to be due to predation by various species of ants (Coleman, 1950; McFarlane, 1985), including fire ants (Masser and Grant, 1986), because ants were present on carcasses. However, ants were not observed killing live animals. Consequently, there was uncertainty as to whether ants actually preyed on live animals in traps or ants were scavenging carcasses of animals that had died from other causes. During studies of the effects of hazardous industrial waste on wildlife, information was recorded on losses of small mammals in live traps. In this paper, I report observations of fire ants preying on live hispid cotton rats (*Sigmodon hispidus*) in traps.

Cotton rats were captured in Sherman live traps (7.6 by 7.6 by 25.4 centimeters) near Houston in Harris and Galveston counties, southeastern Texas, from May through July 1984 (seven sites), in February 1985 (three sites), and in February 1986 (one site). Steps taken to reduce attraction of fire ants to traps and attacks on small mammals in traps included: 1) use of apple slices instead of conventional small mammal baits; 2) checking traps at midnight and at first daylight; 3) moving traps away from areas where ant attacks occurred; 4) removing ant swarms from bodies of mobile rats; and 5) trapping in winter the second and third years of the studies.

Of 225 captures of cotton rats, 43 involved fire ants. Twenty rats were dead and covered with fire ants. Thirteen live rats were covered with fire ant swarms and had their bodies partly eaten by the ants. Fire ants were removed from 10 rats that seemed to be at risk but showed no obvious effects. In the period May through July, 34 of 126 (27 percent) cotton rats captured had fire ants; 27 were partly eaten (10 alive, 17 dead). In February, only nine of 99 (nine percent) of cotton rats caught had attracted fire ants. Six were partly eaten (three alive, three dead). Temperatures were lower and ants were not as active as in the May-July period.

Ants in swarms were observed biting, stinging, and removing and transporting tissue from live rats (frequently as the rats moved about in the traps). Some cotton rats were already mutilated by fire ants by midnight. Masser and Grant (1986) found that checking traps every three hours in September did not reduce small mammal mortality. Mortality of cotton rats from fire ant predation in the present studies probably would have been much greater if steps had not been taken to reduce losses.

Other species of small mammals in traps also are affected by fire ants. In the present studies, a live fulvous harvest mouse (*Reithrodontomys fulvescens*), a dead adult eastern woodrat (*Neotoma floridana*), and a dead house mouse (*Mus musculus*) were covered with fire ants. Masser and Grant (1986) caught 37 small mammals of four species. None of 12 cotton rats captured was affected by fire ants, but six pygmy mice (*Baiomys taylori*) and a white-footed mouse (*Peromyscus leucopus*) were dead and covered with ants. They concluded that fire ants were the probable cause of death of these mice. They suggested that: 1) mortality was dependent on the body size of small mammals, at least for shorter periods of confinement in traps; 2) mortality was not as great in cooler weather when fire ants usually were not especially actve; and 3) small mammals in areas heavily infested with fire ants might have been eliminated by the presence of ants.

This study suggests that the effects of red imported fire ants on young wild mammals confined to nests might be substantial, but remain unknown. Some effects of fire ants on young birds have been reported. Mrazek (1974) observed fire ants killing nestling black skimmers (*Rynchops niger*) and gull-billed terns (*Sterna nilotica*), and adult birds abandoning nests invaded by fire ants. Sikes and Arnold (1986) observed red imported fire ants attack live cliff swallow (*Hirundo pyrrhonota*) nestlings in 212 of 357 nests.

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LITERATURE CITED

Coleman, R. H. 1950. DDT protects bait from ants. J. Mamm., 31:199.

Hung, A. C. F., and S. B. Vinson. 1978. Factors affecting the distribution of fire ants in Texas (Myrmicinae: Formicidae). Southwestern Nat., 23:205-215.

Masser, M. P., and W. E. Grant. 1986. Fire ant-induced trap mortality of small mammals in east-central Texas. Southwestern. Nat., 31:540-542.

McFarlane, R. W. 1985. A small mammal survey of the Brio site and environs. Contract study for Resource Engineering, Inc., McFarlane and Associates, Houston, Texas, 14 pp.

Metcalf, C. L., W. P. Flint, and R. L. Metcalf. 1962. Destructive and useful insects, their habits and control. McGraw-Hill Book Co., New York, 1087 pp.

Mrazek, R. W. 1974. The relationship of the fire ant (*Solenopsis geminate* Fabricus) to the young of birds nesting on two spoil islands in the Laguna Madre. Unpublished M.S. thesis, Texas A&I Univ., Kingsville, 122 pp.

Sikes, P. J., and K. A. Arnold. 1986. Red imported fire ant (*Solenopsis invicta*) predation on cliff swallow (*Hirundo pyrrhonota*) nestlings in east-central Texas. Southwestern Nat., 31:105-106.

Current address of author: Gulf Coast Research Station, P.O. Box 2506, Victoria, Texas 77902

NOTES ON THE THERMAL BIOLOGY OF THE LAREDO WHIPTAIL *CNEMIDOPHORUS* "LAREDOENSIS" (TEIIDAE)

MARK A. PAULISSEN, JAMES E. CORDES AND JAMES M. WALKER
Division of Natural Science, Westark Community College, PO Box 3649, Fort Smith, Arkansas 72913, and Department of Zoology, University of Arkansas, Fayetteville, Arkansas 72701 (JEC, JMW)

The Laredo whiptail, *Cnemidophorus* "laredoensis", is comprised of two clonal morphotypes, designated LAR-A (=*C. laredoensis* in the sense of McKinney et al., 1973) and LAR-B (Walker, 1986), that presumably were generated from separate hybridization events between two gonochoristic whiptail species (Bickham et al., 1976; Wright et al., 1983;

Parker et al., 1989). LAR-A occurs in a narrow band along either side of the Rio Grande from Laredo and Nuevo Laredo southeastward to Bentsen-Rio Grande Valley State Park in Texas and Nuevo Progreso in México and in a few areas away from the river in Dimmit, LaSalle, and Starr counties (Walker, 1987*a*). LAR-B occurs within eight kilometers of the Rio Grande from Del Rio/Ciudad Acuna south to within 96 kilometers N Laredo and then, after a distributional hiatus, from 7.2 kilometers E Rio Grande City east to within 16 kilometers west of the Gulf of Mexico (Walker, 1987*b*). The two clones co-occur in many sites in a small zone from south-central Starr County to south-central Hidalgo County and adjacent México (Walker, 1987*b*; Paulissen et al., 1988). The gonochoristic species *Cnemidophorus gularis* (which is the maternal progenitor of LAR-A and presumably also of LAR-B) occurs at a majority of sites where one or both clones have been found (Walker, 1987*a*; 1987*b*). Recent study by Walker and colleagues has revealed much about the distribution, systematics, karyotypes, and ecology of the *C.* "laredoensis" clones (Walker, et al., 1986*a*; 1986*b*; Walker, 1987*a*; 1987*b*; 1987*c*; Walker and Cordes, 1989; Paulissen et al., 1988; Parker et al., 1989). However, no data on the thermal biology have been published. This report presents body temperature data of field-captured LAR-A and LAR-B (and of *C. gularis* for comparison), and a preliminary assessment of their relationship to the thermal environment.

Lizards were shot with BB pistols and body temperatures were taken immediately by inserting a Schultheis quick-reading thermometer into the lizard's cloaca. All temperature readings were taken within 10 seconds after the animal was shot. Records taken from animals that were handled for longer than 10 seconds or that were extensively damaged were discarded. Body temperatures were measured from lizards collected at several sites in August and October 1987 and May 1988. There was no significant difference within a form in the mean body temperature among sites or among months (Kruskall-Wallis test, $P > 0.05$) so data for each form were pooled. The mean of these pooled body temperatures is defined as the mean activity temperature (Pough and Gans, 1982). Comparisons of mean activity temperature between the two clones and between each clone and *C. gularis* were statistically evaluated with Mann-Whitney U tests. Tests were made using the data taken from adult lizards, young-of-the year, and the combined sample. The mean activity temperature of adult and young-of-the-year of each form were also compared with Mann-Whitney U tests.

We also studied the relationship between activity of the two clones and environmental temperature at Los Ebanos, between the town and the Rio Grande, Hidalgo County, Texas (H-2 in Walker, 1987*a*; 1987*b*). The time each lizard was captured was recorded during collecting trips on 25-26 May 1986, 18 July 1986, and 10-11 August 1987; each trip represented the equivalent of one full day of lizard activity. (These daily activity pattern data are presented in Paulissen et al., 1988, and in Parker et al., 1989.) The temperature of unshaded ground, shaded ground, and shaded air 1.5 meters above the ground were recorded every 15 minutes throughout each collecting period using a YSI portable teletherometer. This distribution of environmental temperatures was compared to the time of day in which the majority of animals of each clone was collected in order to derive an estimate of the environmental temperatures in which each clone is most active.

The mean activity temperature of the two *C.* "laredoensis" clones and *C. gularis* are similar, about 38 to 39° C (Table 1). These results follow the general pattern for *Cnemidophorus* species, all of which maintain a high mean activity temperature at or just above 38° C (Avery, 1982). There were no significant differences in mean activity temperature between LAR-A and LAR-B for adults, young-of-the-year, or the pooled data set (although given the small sample size of LAR-A these results must be considered preliminary). There were also no significant differences between LAR-A and *C. gularis*. Young-of-the-year LAR-B have a significantly higher mean activity temperature than young-of-the-year *C. gularis*; this outcome also occurs for the total sample (Table 1). This probably is due to a seasonal sample bias. Most LAR-B activity temperatures were taken in

TABLE 1. Mean activity temperature, boundaries of central 50 percent of activity temperature distribution and sample size (N) for LAR-A, LAR-B, and *C. gularis*. Significant differences (Mann-Whitney tests) are indicated by asterisks. All temperatures are in degrees Celsius.

	LAR-A	LAR-B		*C. gularis*	
Adult					
Mean	40.8	39.6		39.7	
Central 50%	38.1–43.0	38.0–41.4		38.3–41.0	
N	(5)	(20)		(12)	*
Young-of-the-year					
Mean	38.8	39.3	*	37.9	
Central 50%	38.0–39.6	38.3–41.0		36.5–39.3	
N	(10)	(53)		(35)	
Total					
Mean	39.4	39.4	*	38.4	
Central 50%	38.1–42.0	38.3–41.2		37.5–39.8	
N	(15)	(73)		(47)	

August, whereas the majority of *C. gularis* activity temperatures were taken in October. Activity temperatures of all forms were lower in October than in August although this trend was not statistically significant. Therefore, the difference between LAR-B and *C. gularis* is probably more a consequence of the time activity temperatures were taken rather than of a fundamental difference in thermal biology.

There was no significant difference between adult and young-of-the-year mean activity temperature for either clone; however, *C. gularis* adults showed significantly higher mean activity temperatures than did young-of-the-year (Table 1). Though such an ontogenetic trend has been noted in other studies (for example, Middendorf, 1979; Stevens, 1982), it probably represents seasonal bias in this case. Most of the activity temperatures, of adult *C. gularis* were taken in August, whereas activity temperatures of most young-of-the-year *C. gularis* were taken in October.

Data from Los Ebanos show that lizards can be active at unshaded ground temperatures ranging from 28.7° to more than 50° C and air temperatures ranging from 24.0 to 39.0° C. Despite encountering such wide variation in environmental thermal conditions, both clones and *C. gularis* maintain their activity temperatures within a narrow range. The central 50 percent of the activity temperature distribution for all forms is less than 4.0° C (Table 1). This suggests (though does not prove) that all employ some type of thermoregulation to maintain their activity temperatures relatively stable despite dramatic daily changes in the thermal environment. Other cnemidophorines are known to rely on basking, adjustment of body position, and alteration of microhabitat usage to control their activity temperatures (Asplund 1971; 1974; Paulissen, 1986). Those discussed here probably also exhibit such thermoregulatory behaviors.

The two clones did not show pronounced differences in the range of environmental temperatures over which they were most active at Los Ebanos (Table 2). This is despite the fact LAR-A and LAR-B often have different daily activity cycles (Paulissen et al., 1988; Parker et al., 1989). Both clones are active at higher environmental temperatures in late summer than in early summer. This may represent seasonal acclimation to changing environmental conditions.

This report presents the first data on the thermal biology of the Laredo whiptail. These data suggest that the thermal biologies of the two clones are similar to each other and to the thermal biology of their maternal progenitor, *C. gularis* (at least where the ranges of *C.*

Table 2. Range of environmental temperatures in which the majority of LAR-A and LAR-B were captured at Los Ebanos on each of the three collecting trips. The top number gives the lower bound, the bottom gives the upper bound. All temperatures are in degrees Celsius. Shaded ground temperature was not taken in August 1987. The LAR-B data for August 1987 reflects two activity periods, morning and afternoon.

	May 1986		July 1986		August 1987	
	LAR-A	LAR-B	LAR-A	LAR-B	LAR-A	LAR-B
Open Ground	41.5-50+	41.5-50+	50+	36.5-50+	50.0-50.6	38.0-50+ 43.8-50+
Shaded Ground	31.0-35.0	31.0-35.0	37.0-37.5	36.0-38.0	—	—
Shaded Air	31.0-36.0	31.0-35.0	34.0-35.0	32.0-34.0	36.3-37.4	31.5-36.2 35.3-37.2

gularis and *C.* "laredoensis" overlap). These results, however, are only an initial step in the study of the thermal biology of the Laredo whiptail. Further field studies should seek to determine what active and passive thermoregulation these animals employ and to what degree. Controlled laboratory studies of body temperature selection in a thermal gradient, critical thermal maximum and critical thermal minimum also represent fertile ground for research. Comparison of LAR-A and LAR-B by these methods, while worthwhile in and of itself, can be applied to a general understanding of the relationship between genetic composition and thermal biology in parthenogenetic clonal complexes.

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Literature Cited

Asplund, K. K. 1971. Behavior of lizards in an artificial shade mosaic. Herpetol. Rev., 3:97-98.

———. 1974. Body size and habitat utilization in whiptail lizards (*Cnemidophorus*). Copeia, 1974:695-703.

Avery, R. A. 1982. Field studies of body temperatures and thermoregulation. Pp. 93-166, *in* Biology of the Reptilia (C. Gans and F. H. Pough, eds.), Academic Press, New York, 12:xiv+1-586.

Bickham, J. M., C. O. McKinney, and M. F. Mathews. 1976. Karyotypes of the parthenogenetic whiptail lizard *Cnemidophorus laredoensis* and its presumed parental species (Sauria: Teiidae). Herpetologica, 32:395-399.

McKinney, C. O., F. R. Kay, and R. A. Anderson. 1973. A new all-female species of the genus *Cnemidophorus*. Herpetologica, 29:361-366.

Middendorf, G. A. 1979. Resource partitioning by an iguanid lizard: thermal and density influences. Unpublished Ph.D. dissertation, Univ. Tennessee, Knoxville, 97 pp.

Parker, E. D., J. M. Walker, and M. A. Paulissen. 1989. Clonal diversity in *Cnemidophorus*: ecological and morphological consequences. ASIH Symposium, in press.

Paulissen, M. A. 1986. Ontogenetic changes in the ecology of the six-lined racerunner, *Cnemidophorus sexlineatus* (Sauria: Teiidae). Unpublished Ph.D. dissertation, Univ. Oklahoma, Norman, 129 pp.

Paulissen, M. A., J. M. Walker, and J. E. Cordes. 1988. Ecology of syntopic clones of the parthenogenetic whiptail lizard *Cnemidophorus* 'laredoensis.' J. Herpetol., 22:329-340.

Pough, F. H. and C. Gans. 1982. The vocabulary of reptilian thermoregulation. Pp. 17-23, *in* Biology of the Reptilia (C. Gans and F. H. Pough, eds.), Academic Press, New York, 12:xiv+1-586.

Stevens, T. P. 1982. Body temperatures of montane *Cnemidophorus inornatus* (Reptilia: Teiidae). Southwestern Nat., 27:232-243.

Walker, J. M. 1986. The taxonomy of parthenogenetic species of hybrid origin: cloned hybrid populations of *Cnemidophorus* (Sauria: Teiidae). Syst. Zool., 35:427-440.

———. 1987*a*. Distribution and habitat of the parthenogenetic whiptail lizard, *Cnemidophorus laredoensis* (Sauria: Teiidae). Amer. Midland Nat., 117:319-332.

———. 1987*b*. Distribution habitat of a new major clone of parthenogenetic whiptail lizard (genus *Cnemidophorus*) in Texas and Mexico. Texas J. Sci., 39:313-334.

———. 1987*c*. Habitat and population destruction and recovery in the parthenogenetic whiptail lizard, *Cnemidophorus laredoensis* (Sauria: Teiidae), in southern Texas. Texas J. Sci., 39:81-88.

Walker, J. M., and Cordes. 1989. Whiptail lizards on artificial substrates in southern Texas. Southwestern Nat., 33: in press.

Walker, J. M., S. E. Trauth, J. E. Cordes, and J. M. Britton. 1986*a*. *Cnemidophorus laredoensis* (Laredo striped whiptail). Distribution. Herpetol. Rev., 17:26-27.

Walker, J. M., S. E. Trauth, J. M. Britton, and J. E. Cordes. 1986*b*. Burrows of the parthenogenetic whiptail lizard *Cnemidophorus laredoensis* (Teiidae) in Webb Co., Texas. Southwestern Nat., 31:408-410.

Wright, J. W., C. Spolsky, and W. M. Brown. 1983. The origin of the parthenogenetic lizard *Cnemidophorus laredoensis* inferred from mitochondrial DNA analysis. Herpetologica, 39:410-416.

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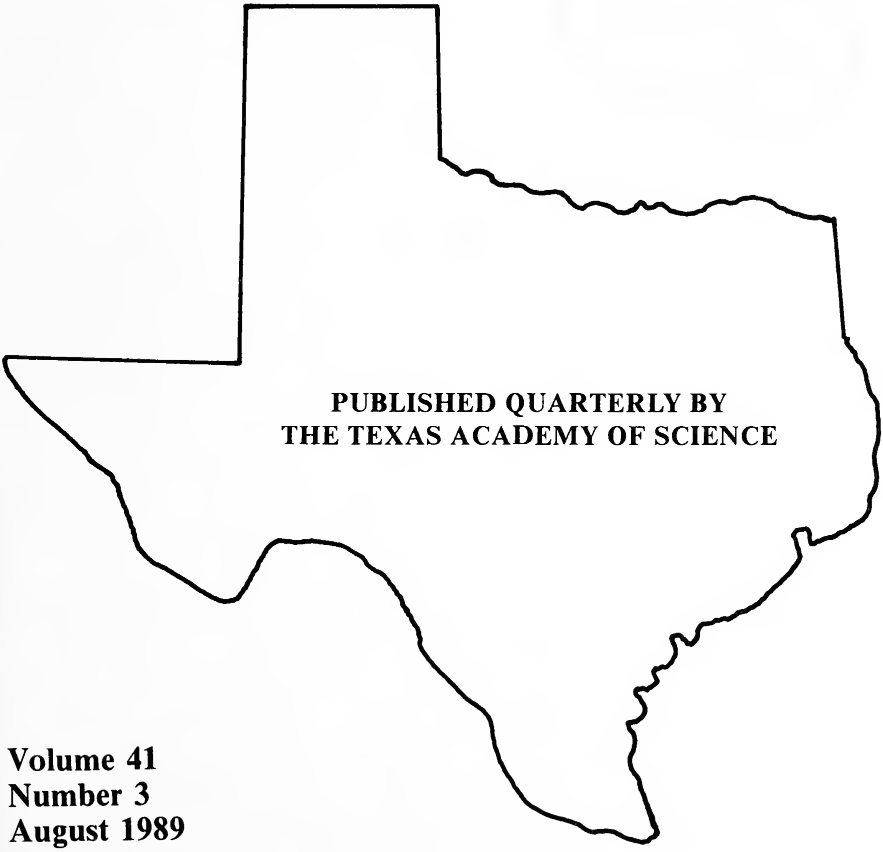

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A CLASSIFICATION OF TEXAS AQUATIC COMMUNITIES WITH SPECIAL CONSIDERATION TOWARD THE CONSERVATION OF ENDANGERED AND THREATENED TAXA

Robert J. Edwards, Glenn Longley, Randy Moss, John Ward,
Ray Matthews, and Bruce Stewart

Department of Biology, Pan American University, Edinburg, Texas 78539, Department of Biology, Southwest Texas State University, San Marcos, Texas 78666, Texas Parks and Wildlife Department, Austin, Texas 78744, Texas Water Commission, 16010 Buccaneer, Houston, Texas 77062, Freshwater Systems Unit, Texas Water Development Board, Austin, Texas 78711, and Department of Biology, Murray State College, Tishomingo, Oklahoma 73460.

Abstract.—A classification of Texas aquatic habitats was developed. Seven biotic provinces and 11 primary aquatic habitat types are recognized. The distribution of endangered and threatened vertebrates of Texas among habitats and provinces was considered. We found that habitats associated with spring systems (aquifers, springs, and spring-runs) contained a majority of the endangered fauna in the central and western part of the state, whereas large rivers and streams contained the greatest number of endangered taxa in the eastern part of the state. Only through wise conservation of a wide variety of water resources throughout the state will the state's aquatic resources be maintained at their current levels of abundance. *Key words*: aquatic habitats; Texas aquatic organisms; endangered and threatened species; aquatic communities classification.

The state of Texas has an inventoried total of more than 3500 streams and tributaries within the state's boundaries consisting of nearly 128,000 kilometers (80,000 miles) of streambed. In addition, more than half of the state is underlain by seven major and 17 minor aquifers that provide approximately 70 percent of the total water used for human activities (Texas Department of Water Resources, 1982). At the interface of aquifers and streams are springs and their outflows. Texas had more than 280 major springs originally; of these, only two (of four originally) remain as large springs and more than 60 have failed completely (Brune, 1975, 1981). In all but the easternmost part of Texas, existing water supplies are insufficient to supply all demand (TDWR, 1981, 1982). Because of this limited supply of water and an ever increasing use of this water by human activities, many aquatic organisms have become threatened with extinction. The Texas Organization for Endangered Species, the Texas Parks and Wildlife Department, and the U.S. Fish and Wildlife Service are concerned with the status of threatened and endangered organisms throughout the state and maintain a listing of these. Each of the above groups recognizes that in order to preserve species, their habitats and associated communities also must be preserved. The purpose of this report is to develop a classification of aquatic community associations found within the boundaries of the state in order to facilitate the conservation efforts toward the officially recognized endangered and threatened taxa. We have further correlated the distribution of endangered and threatened aquatic vertebrates with community associations in order to provide insight into those aquatic communities most in need of conservation or protection.

The following represents a preliminary classification of the primary aquatic communities of Texas. It has drawn upon the early analyses of Blair (1950) and Hubbs (1954, 1957) in which the high degree of correlation between "biotic provinces" for terrestrial and aquatic vertebrates was initially developed. We have further refined this concept for use with respect to the aquatic communities of Texas by more recent studies into the distribution, biogeography and ecology of aquatic organisms inhabiting Texas waters. All the authors are members of the Aquatic Associations Subcommittee of the Texas Organization for Endangered Species.

METHODS

The aquatic associations of Texas have been broken down into a hierarchical framework that incorporates two basic components. First is a general descriptor of aquatic habitat types, based in part upon the general longitudinal pattern (upstream to downstream) of natural unmodified streams in Texas. Whereas the concept of stream order is sometimes used to describe such longitudinal zonation in lotic systems, we felt that as much information is present in our more broadly based qualitative terminology and is more closely applicable to the aquatic systems in the state. Other miscellaneous aquatic habitats were added to these. Some temporary aquatic habitats, such as dry arroyos or washes, which may contain water only periodically following precipitation, have been excluded from this classification. Our analysis also, except for a categorization, excludes organisms and their communities from the Texas coast.

The second community association component stems from the concept of biotic provinces as applied by Blair (1950), Hubbs (1954, 1957) and more recently expanded by Conner and Suttkus (1986), Smith and Miller (1986), and Diamond, et al. (1987). These works, when taken together, add considerable insight into the biogeographical affinities of Texas aquatic organisms.

Endangered and threatened vertebrates were taken from the compiled list prepared by TOES (1988). An effort was made to include only taxa that were primarily members of aquatic communities (Appendix A). In some cases, especially with respect to birds and mammals, difficulties arose as to the inclusion of a given taxon as a member of an aquatic as opposed to a terrestrial community. In many instances, these organisms justifiably belong to both. For our analysis, organisms that required aquatic environments for even a portion of their life cycle were included as aquatic organisms. Taxa that, although not obligatory members of aquatic communities, nonetheless used aquatic resources (such as predation on fishes by birds, and so forth) also were included as members of the various aquatic communities. In order to assess the influence of the inclusion of the chosen birds and mammals on the distribution of threatened species among the various aquatic communities, we performed two analyses, one using all threatened aquatic species and the other using only species of fishes, amphibians, and reptiles that were unquestionably members of aquatic communities.

In order to more clearly elucidate the nature of the distribution of threatened taxa across biotic provinces, and to correct for the fact that there is considerable variation in the species richness (that is, the pool of species that potentially could be threatened with extinction)

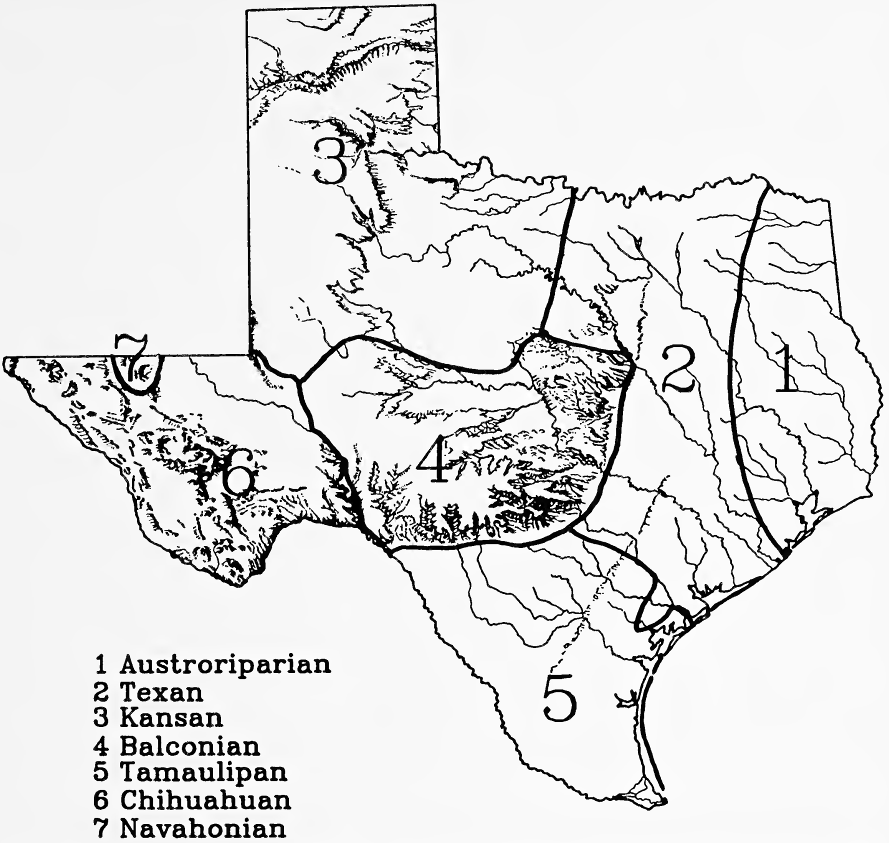

Figure 1. Approximate boundaries of the biotic provinces of Texas, (modified from Blair, 1950).

among the biotic provinces of Texas, fishes were chosen to illustrate the relative degree of endangerment among the different provinces. The number of endangered fishes from the TOES listing of vertebrates was compared with the total number of fishes recorded from each biotic province as outlined by Hubbs (1982). Introduced species were excluded from this analysis and the number of species inhabiting this study's "Texan" Biotic Province was derived from a combination of species inhabiting the "Blackland Prairie" and the "East and West Crosstimbers" provinces used by Hubbs (1982) minus the few southernmost species of these two biotic provinces that were included as rightful members of the Balconian Province species grouping. The number of native fishes inhabiting the Navahonian Province as used by us and Blair (1950) is uncertain. A reasonable estimate for this region in Texas would be fewer than 10 fish species, hence, this number was used for the analysis.

Results and Discussion

The classification of Texas aquatic habitats is shown in Table 1. Ten primary habitats are distinguished, although two categories each include two subdivisions. Both headwater creeks and streams were separated into

TABLE 1.—Classification of Texas aquatic environments with definitions of primary habitat types and biotic provinces.

Primary Aquatic Habitat Types

1. Headwaters/Creeks
   1a. Ephemeral/Intermittent—Generally small creeks and headwaters that flow only during parts of each year, especially during wetter seasons of the year such as autumn and spring.
   1b. Permanent — Small headwater creeks, which maintain at least some permanent flows. In eastern Texas, these creeks often flow through forested areas; in the central and western parts of Texas, these creeks often have a springs or spring seeps associated with their flow.
2. Springs—Water outflows from aquifer sources.
3. Spring-run systems—Generally permanent flowing streams immediately downstream (usually within several kilometers of the spring source) from a headspring area.
4. Streams
   4a. Intermittent Plains streams—Larger order stream systems than headwater/creeks (above), however with large variations in flow, such that minimum or no flows occur during parts of most years (generally during summer).
   4b. Perennial streams—Permanent streams with at least some minimal flows during all parts of each year. This category describes most of the major tributaries of the major rivers of Texas (5, below).
5. Rivers—The largest category of lotic systems; these include, at the minimum, the middle to lower portions of each of the major rivers in Texas.
6. Sinkholes — Open depressions that allow surface communication with either the water table or an aquifer through fractures or surface slumping of (usually) limestone or karst formations.
7. Playa Lakes (prairie potholes, oxbow lakes, and resacas)—Semipermanent bodies of water filling depressions of topography. Included in this category are the Playa Lakes of the Llano Estacado, the prairie potholes (interior wetlands) of north and south Texas, and the oxbow or resaca lakes of eastern, coastal, and southern Texas.
8. Aquifers —Any of the seven major and 17 minor underground water reservoirs within the boundaries of the state.
9. Lakes—Primarily Caddo Lake in eastern Texas. Man-made reservoirs have been excluded from our analysis.
10. Swamps—Forest or shrub dominated wetland regions with extremely moist ground (usually standing water at the surface for at least half of each year) with periodic water level fluctuations; included are the associated bayous and waterways found with swamps. These are essentially restricted to the easternmost part of Texas.
11. Coastal aquatic systems—This catchall category includes the major and minor estuaries, beaches, and coastal waters of Texas.

Biotic Provinces (systems and/or components); individual province natural region associations follow terminology of LBJ School of Public Affairs (1978) and Diamond et al. (1987).

1. Austroriparian—The Piney Woods Association, including Longleaf Pine Forests and Mixed Pine-Hardwood Forests; part of the Oak Woods and Prairies Association, especially the Oak Woodlands; and part of the Gulf Coast Prairies and Marshes Association, especially the Upland Prairies and Woods subassociation.

TABLE 1.—Continued.

2. Texan—Includes part of the Oak Woods and Prairies Association, specifically the East and West Cross Timbers, and the Blackland Prairies Association, including the Grand Prairie and the main portion of the Blackland Prairie subassociations.
3. Kansan—The Rolling Plains Association, including the Mesquite Plains, the Escarpment and Canadian Breaks subassociations and the High Plains Association.
4. Balconian—The Edwards Plateau Association including the Live Oak-Mesquite Savannah, the Balcones Canyonlands, and the Lampassas Cut Plains subassociations, and the Llano Uplift Association including the Mesquite Savannah and the Oak and Oak-Hickory Woodlands subassociations.
5. Tamaulipan—The South Texas Brush Country Association including the Brush Country, the Bordas Escarpment, and the Subtropical Zone subassociations, and the Coastal Sand Plains Association.
6. Chihuahuan—The Trans-Pecos (except Guadalupe Mountains streams) Association including Mountain Ranges, Desert Grassland, Desert Scrub, Salt Basin, Sand Hills, and Stockton Plateau subassociations.
7. Navahonian—Includes only the Guadalupe Mountains streams in the Trans-Pecos Association.

those creeks or streams that permanently flow as opposed to those that maintain flow during only part of each year. Seven biotic provinces are recognized, the approximate boundaries of which are illustrated in Figure 1.

The greatest number of endangered and threatened organisms inhabit either large river or permanent stream habitats (Table 2). Spring and spring-run inhabiting organisms, in combination, are also among the most threatened animals. Prairie potholes and permanent creeks also have significant numbers of threatened species inhabiting these environments. Swamps, aquifers, lakes, and ephemeral creeks each contained fewer species that are considered endangered. We found no vertebrates occurring on the TOES list that were primarily inhabitants of either sinkholes or intermittent streams. We recognize that it is somewhat artificial to consider only vertebrates in these analyses, as many of the organisms inhabiting aquatic systems are invertebrates. Certainly the number of threatened organisms inhabiting aquifers and spring systems, as but one example, would be far greater if invertebrates were included in our analysis. For the most part, however, our knowledge of the invertebrate fauna of Texas aquatic communities is much more limited than that of the vertebrate fauna. Several conclusions are nonetheless evident. The larger rivers and streams, and spring systems of Texas contain many of the endangered and threatened organisms. Two biotic provinces contain relatively large numbers of endangered taxa: the Chihuahuan and the Austroriparian. In part, the relatively large number found in the Austroriparian is a reflection of the relatively diverse aquatic fauna found in eastern Texas. However, the Chihuahuan Desert fauna is relatively depauparate with respect to species and thus the large number of threatened taxa from this province is clearly indicative of the

TABLE 2. Classification of Texas aquatic communities by degree of endangerment. Values indicate the number of vertebrate species that are listed in the TOES list for vertebrates (TOES, 1988). Species found in more than one habitat type or biotic province are listed in the primary habitat(s) and all provinces that apply. Table 1a shows distribution among habitat types and biotic provinces for all aquatic species listed on the TOES vertebrate list and Table 1b shows the same data for fishes, amphibians, and reptiles only. A dash in a given column indicates that the habitat type is a prominent feature in the province, but no endangered or threatened aquatic vertebrates are found associated with that habitat type. A blank space in a given column signifies that a given habitat type does not exist (or is rare) in that biotic province.

1a. ALL SPECIES
Aquatic Habitat Type

Biotic province	1a	1b	2	3	4a	4b	5	6	7	8	9	10	Totals	%
Austroriparian	—	3			—	6	11		2	—	3	5	30	31.9
Texan	—	—			—	1	2			—			3	3.2
Kansan	—	—			—		1	—	—	—			1	1.1
Balconian	—	—	3	4	—	2	1	—		5			15	16.0
Tamaulipan	—	—			—		5		12	—			17	18.1
Chihuahuan	1	4	4	7	—	8	3	—	—	—			27	28.7
Navahonian	—	1											1	1.1
Coastal (24)														
Totals	1	8	7	11	0	17	23	0	14	5	3	5	94	100.0
Percent	1.1	8.5	7.4	11.7	0	18.1	24.5	0	14.9	5.3	3.2	6.4		

1b. EXCLUDING BIRDS AND MAMMALS
Aquatic Habitat Type

Biotic province	1a	1b	2	3	4a	4b	5	6	7	8	9	10	Totals	%
Austroriparian	—	3			—	5	9			—	1	2	20	27.4
Texan	—	—			—	1	—			—			1	1.4
Kansan	—	—			—		—	—	—	—			0	0.0
Balconian	—	—	3	4	—	2	—	—		5			14	19.2
Tamaulipan	—	—			—		4		9	—			13	17.8
Chihuahuan	1	4	4	7	—	7	2	—	—	—			25	34.2
Navahonian	—	—											0	0.0
Coastal (6)														
Totals	1	7	7	11	0	15	15	0	9	5	1	2	73	100.0
Percent	1.4	9.6	9.6	15.1	0	20.5	20.5	0	12.3	6.8	1.4	2.7		

threatened nature of their ecosystems (many small springs and runs flowing onto the desert floor or as tributaries to the Pecos River or the Rio Grande). The Balconian and the Tamaulipan also appear to have a significant number of endangered and threatened taxa inhabiting the aquatic systems in these provinces. The Texan, Kansan and Navahonian each contain the fewest threatened elements of all the biotic provinces of Texas. In each of these, however, the most endangered animals appear associated with the largest available water sources (that is, large rivers in the Texas and Kansan provinces and permanent creeks in the Navahonian province). There appear to be only minor differences in the

TABLE 3. Total known native fishes, number of TOES-listed fishes, and the percentage of fishes that are considered endangered, threatened or watchlist species in each of the biotic provinces of Texas.

Biotic province	Total native species	TOES list total	Percent of native fishes endangered
Austroriparian	105	13	12.4
Texas	80	0	0
Kansan	46	0	0
Balconian	75	9	12.0
Tamaulipan	59	3	5.1
Chihuahuan	39	22	56.4
Navahonian	LT10	0	0

distribution of endangered vertebrates among habitats and provinces when all aquatic vertebrates are included as opposed to inclusion of only fishes, amphibians, and reptiles. The greatest differences either among habitats or provinces were generally about four percent and most comparisons were much less. We interpret this as evidence that when habitats are jeopardized on a large scale (such as the placement of dams on the major river systems in Texas) or when limited habitats are disrupted (such as the depletion of isolated spring systems and their runs such as in central and west Texas), large portions of the aquatic community from diverse taxonomic backgrounds are similarly impacted.

In our analyses, more than half of the Chihuahuan native fishes were found to be threatened with extinction, more than four times the percentage of any other biotic province (Table 3). While alarming, this is not surprising given the general reduction in water as one moves from the more mesic Austroriparian across Texas to the much drier Chihuahuan and Navahonian provinces. Much of the Chihuahuan endangered fauna is associated with springs, their runs and relatively small permanent streams, all in limited and declining supply in this province. The magnitude of the overall impact on the Chihuahuan fishes is, however, considerable. The Balconian and the Austroriparian, each with approximately 12 percent of their native fishes endangered, appear to differ with respect to the types of habitats that are facing threats. The Austroriparian endangered fishes are to a large degree dependent upon large river systems, which have been greatly modified in this province. the endangered Balconian fishes appear to be somewhat similar to the Chihuahuan endangered fishes with respect to habitat types because a relatively large fraction of threatened species inhabit, and are dependent upon, aquifers and springs or their associated runs, habitats that have been, and are continuing to be greatly impacted in the Balconian province. No endangered fishes were found to be primarily associated with the Texan, Kansas or Navahonian provinces, in part because the species that make up the aquatic biota of these regions tend to be wide-ranging plains species that are rather tolerant to a wide range of environmental conditions including tremendous variation in flow conditions.

In conclusion, there appears to be a diverse array of aquatic habitat types in the state of Texas. No one threatened habitat type can be isolated that would apply equally to all regions of the state because the large area of Texas includes a large number of biotic zones, each with unique hydrographic features. There is, and has been for many decades, a trend of decreasing and progressively modified water sources throughout the state (TDWR, 1981) and we predict that as this trend continues, an increasing fraction of the aquatic communities in Texas will face endangerment. For some aquatic species, wise conservation would come too late; several taxa are already extinct. However wise management and conservation of most threatened aquatic habitats in the state is necessary if other elements of these aquatic communities are expected to persist.

Acknowledgments

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Literature Cited

Blair, W. F. 1950. The biotic provinces of Texas. Texas J. Sci., 2:93-117.

Brune, G. 1975. Major and historical springs of Texas. Rept. Texas Water Devl. Board, 189: 1-95.

———. 1981. Springs of Texas. Branch-Smith, Inc., Fort Worth, 566 pp.

Conner, J. V., and R. D. Suttkus. 1986. Zoogeography of freshwater fishes of the western Gulf slope of North America. Pp. 413-456, *In* The zoogeography of North American freshwater fishes. (C. H. Hocutt and E. O. Wiley, eds.), John Wiley & Sons, NY, 866 pp.

Diamond, D. D., D. H. Riskind, and S. L. Orzell. 1987. A framework for plant community classification and conservation in Texas. Texas J. Sci. 39:203-221.

Hubbs, C. 1954. Corrected distributional records for Texas fresh-water fishes. Texas J. Sci., 6:277-291.

———. 1957. Distributional patterns of Texas fresh-water fishes. Southwestern Nat., 2:89-104.

———. 1982. A checklist of Texas freshwater fishes. Tech Ser., Texas Parks and Wildlife Dept., 11:1-14.

LBJ School of Public Affairs. 1978. Preserving Texas' natural heritage. LBJ School Publ. Affairs, Pol. Res. Proj. Rept., 31:1-34.

Smith, M. L., and R. R. Miller. 1986. The evolution of the Rio Grande basin as inferred from its fish fauna. Pp. 457-485, *in* The zoogeography of North American freshwater fishes. (C. H. Hocutt and E. O. Wiley, eds.), John Wiley & Sons, New York, 866 pp.

Texas Department of Water Resources. 1981. Water use, projected water requirements, and related data and information for the standard metropolitan statistical areas in Texas. LR-141, 224 pp.

Texas Department of Water Resources. 1982. Texas water facts. Austin, 4th printing, 11 pp.

Texas Organization for Endangered Species. 1988. Endangered, threatened, and watchlist of vertebrates of Texas. TOES Publ., 6:1-16.

Appendix A. Distribution of endangered, threatened, and watchlist aquatic vertebrates by aquatic habitat type. Biotic province numbers and habitat type numbers are those found in Table 1. A notation "limited" for the habitat type indicates that the species is only rarely found. A notation "extinct" means the species likely is extinct.

Fishes	Biotic Province	(habitat type)
Polydon spathula	1	(5)
Scaphirhynchus platorynchus	1	(5)
Hiodon alosoides	1	(5)
Dionda diaboli	6	(3)
Gila pandora	6	(4b)
Notropis chihuahua	6	(5)
Notropis simus simus	6	(5)
Notropis buccula	1	(5)
Notropis proserpinus	6	(3)
Notropis chalybaeus	1	(4b); 4(3) (limited)
Notropis maculatus	1	(1b)
Notropis hubbsi	1	(4b)
Notropis orca	5	(5)
Campostoma ornatum	6	(1b)
Satan eurystomus	4	(8) (limited)
Trogloglanis pattersoni	4	(8) (limited)
Ictalurus lupus	6	(1b,4b)
Cyprinodon elegans	6	(3)
Cyprinodon pecosensis	6	(4b)
Cyprinodon eximius	6	(4b,1b)
Cyprinodon bovinus	6	(2,3)
Gambusia gaigei	6	(2)
Gambusia amistadensis	6	(2) (extinct)
Gambusia nobilis	6	(4b,2,3)
Gambusia senilis	6	(4b)
Gambusia heterochir	4	(2,3) (limited)
Gambusia georgei	4	(3) (limited)
Syngnathus affinis		(coastal)
Centropomis parallelus	5	(5)
Micropterus treculi	4	(4b)
Stizostedion canadense	1	(5)
Percina maculata	1	(5,4b)
Ammocrypta clara	1	(4b)
Etheostoma fonticola	4	(2,3) (limited)
Etheostoma grahami	6	(3,4b)
Etheostoma radiosum	1	(4b,5)
Awaous tajasica	5	(5)
Amphibians		
Ambystoma talpoideum	1	(1b)
Eurycea latitans	4	(8)
Eurycea nana	4	(2)
Eurycea tridentifera	4	(8)
Notopthalmus meridionelis	5	(7)
Siren intermedia texana	5	(7)
Typhlomolge robusta	4	(8)
Bufo houstonensis	1	(lb) (limited)

Bufo marinus	5	(7)
Hypopachus variolosus	5	(7)
Leptodactylus fragilis	5	(7)
Rhinophrynus dorsalis	5	(7)
Smilisca baudinii	5	(7)
Syrrhophus cystignathoides	5	(7)
Syrrhophus guttilatus	6	(1a)
Reptiles		
Caretta caretta		(coastal)
Chelonia mydas		(coastal)
Dermochelys coriacea		(coastal)
Eretmochelys imbricata		(coastal)
Kinosternon hirtipes murrayi	6	(1b,3)
Macroclemys temminckii	1	(5)
Malaclemys terrapin littoralis		(coastal)
Alligator mississippiensis	1	(5,9,10); 5 (5,7)
Crotalus horridus atricaudatus	1	(10)
Nerodia harteri harteri	2	(4b)
Nerodia harteri paucimaculata	4	(4b)
Birds		
Pelecanus occidentalis		(coastal)
Plegadis chihi		(coastal)
Mycteria americana	1	(7,9,10); 5 (7)
Dendrocygna bicolor	1,5	(7)
Cairina moshata	5	(7)
Elanoides forficatus	1	(10)
Haliaeetus leucocephalus	1	(5,9); 2,3,4,5,6,8 (5); 7 (1b)
Buteo albicaudatus		(coastal)
Falco peregrinus tundrius		(coastal)
Grus americana		(coastal)
Jacana spinosa		(coastal)
Numenius borealis		(coastal) (extinct?)
Sterna antillarum antillarum		(coastal)
Sterna antillarum athalassos	2	(5)
Sterna fuscata		(coastal)
Rynchops niger		(coastal)
Mammals		
Ondatra zibethicus ripensis	6	(4b)
Lutra canadensis	1	(4b,5,10)
Tursiops truncatus		(coastal)
Stenella plagiodon		(coastal)
Feresa attenuata		(coastal)
Kogia simus		(coastal)
Kogia breviceps		(coastal)
Physeter macrocephalus		(coastal)
Trichechus manatus		(coastal)

GEOCHEMICAL PROSPECTING FOR IRON-RICH SKARN DEPOSITS AND ALLUVIAL EQUIVALENTS: AN EXAMPLE FROM THE EASTERN CAPITAN MOUNTAINS, LINCOLN COUNTY, NEW MEXICO

Scott Ellinger and Joseph C. Cepeda
Department of Biology and Geosciences and Killgore Research Center,
West Texas State University, Canyon, Texas 79016

Abstract.—Panned concentrates and bulk stream sediment samples were used to define areas of skarn mineralization at the contact between the Capitan Mountains instrusion and the adjacent Permian sedimentary section. Samples were collected at 1.6-kilometer (one-mile) intervals and analyzed for Co, Cu, Fe, Mg, Mn, Mo, Pb, and Zn. Anomalies were detected for Fe, Mg, and Mn. Concentrations of these elements ranged from 100-1825 ppm for Mn and 13,600 to 217,200 ppm for Fe in the bulk sediment samples.

The highest element concentrations were in samples collected in the drainages of the Hale Canyon area and metal values remained uniform or increased slightly downstream. This atypical behavior is the apparent result of erosion of alluvial sediments downstream from the contact. The bulk of the iron in the vicinity of the Capitan Mountains is contained in these deposits. *Key words:* Capitan Mountains; geochemical sampling; stream sediments.

The east-west trending Capitan Mountains of east-central New Mexico (see Fig. 1) consist of a Tertiary granitic intrusion into Permian sedimentary rocks. The most abundant mineralization occurs at the margin of the intrusion in the form of magnetite-rich skarns. Geochemical exploration techniques were used to define areas of mineralization at the contact and in alluvial deposits downslope from the contact.

Location

The area of study is within the Lincoln National Forest and, in part, the Capitan Mountains wilderness area located in central Lincoln County, New Mexico (Fig. 1). Most of the area is within the Arabela and Capitan Mountains USGS 15 minute quadrangles. The western limit of the study area is the summit of the Capitan Range, elevation 3108 meters (10,200 feet). The study encompasses an area of about 180 square kilometers (70 square miles).

Accessibility

Primary access into the study area is gained on Forest Service road 57 on the south, Forest Service road 256 and 163 on the north, and county road 130 on the north. The extreme northeastern part of the study area is accessible from a road extending from Arabela to Pine Lodge. The National Forest Service classifies these roads as primitive. That portion of the study area within the Capitan Mountains Wilderness Area is penetrated by both marked and unmarked hiking trails leading to the higher portions of the Capitan Mountains.

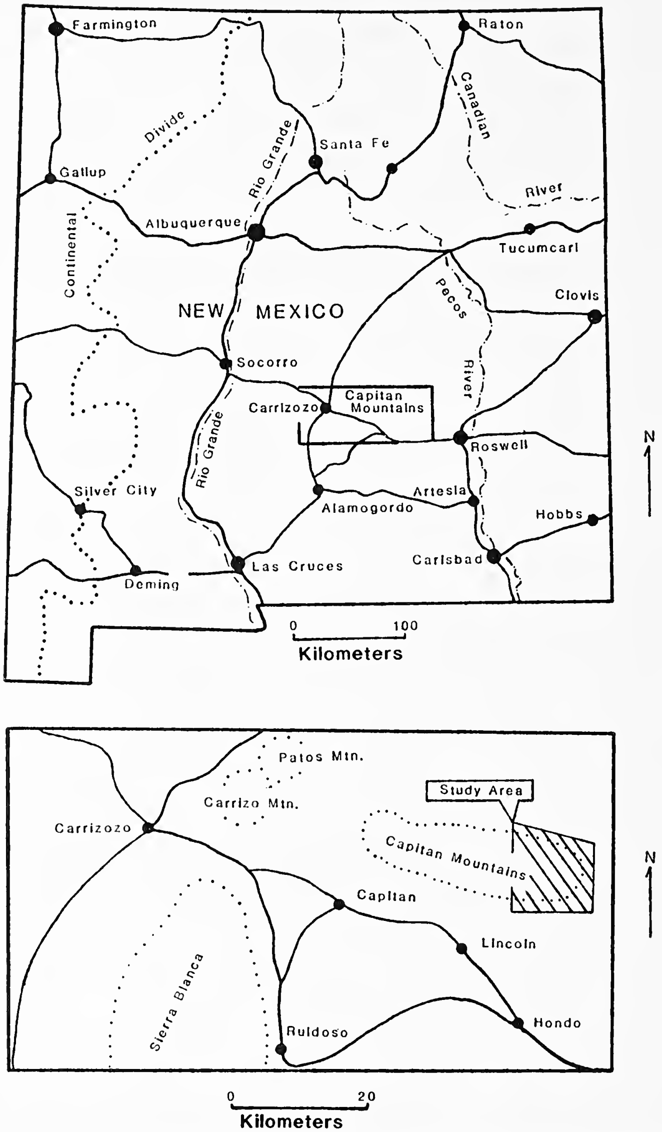

FIGURE 1. Index map showing location of the Capitan Mountains and study area.

Purpose

The purpose of this study was to further evaluate the mineral resource potential of the eastern end of the Capitan Mountains, and to compare the sensitivity of various sampling techniques in this climatic environment and mode of mineralization. Results of this study may be applied to mineral exploration elsewhere.

The eastern end of the Capitan Mountains was selected because a detailed multimedia geochemical survey could be employed as a suitable exploration technique. Isolated stream sediment samples analyzed during a recent National Uranium Resource Evaluation (NURE) investigation revealed some anomalous element concentrations warranting further study (Union Carbide, 1981).

Geography

Slopes of the Capitan Mountains range from 11 to 15 degrees (Kelley, 1971), and are heavily timbered with spruce, fir, aspen, ponderosa pine, oak, and juniper. The transition between vegetation types begins at a slightly lower elevation on the north slopes than on those to the south. Vegetation ranges from the pinyon-juniper association between 1800 and 2200 meters (6000 to 7200 feet) through a transition zone between 2200 and 2700 meters (7200 to 9000 feet) dominated by ponderosa pine, to the spruce-fir association above 2700 meters (9000 feet) (Martin, 1964).

Half of the annual precipitation falls in the summer months during brief but often heavy thunderstorms occassionally accompanied by hail. Average annual precipitation ranges from 63.5 centimeters (25 inches) to 76.2 centimeters (30 inches). Much of the precipitation in the winter falls as snow in the upper elevations where the average annual snowfall totals more than 1.2 meters (four feet) (Sprankle, 1983).

Mineral Deposits

The principal mineral deposits in the Capitan Mountains area are iron, manganese, and thorium. The deposits of iron occur mostly as skarn deposits within the Permian San Andres Formation. The largest iron deposit near the Capitan Mountains, the Capitan iron deposit, has been described by Kelley (1952) as lying in gently westward-dipping San Andres Limestone underlain by the western end of the Capitan Mountains intrusion. To the east, other iron prospects and the Arabela manganese prospect are known to lie near the contact of the San Andres Formation and the Capitan Mountains alaskite (Griswold, 1959). The manganese ore itself, however, has been reported by Tuftin (1984) to occur within a shear zone in the alaskite. Also, small amounts of gold (0.02 ounces per ton) and silver (less than one ounce per ton) were assayed from material in the area of the Arabela Manganese Mine (Tuftin, 1984). Thorium deposits are located near Capitan Pass and thorium minerals occur as joint or fracture fillings in the intrusive rock and are associated with alaskite breccia zones (Tuftin, 1984). According to a NURE investigation, some uranium deposits are located on the north slopes of the Capitan Mountains, near Capitan Peak.

Sample Collection and Preparation

Stream sediment samples were collected (see Fig. 2) from the principal streams at 1.6 kilometers (one mile) intervals beginning at the Lincoln National Forest boundary and continuing upstream until stream sediments became absent. Follow-up sampling techniques consisted of collecting samples at 183-meter (200 yards) intervals upstream from sample

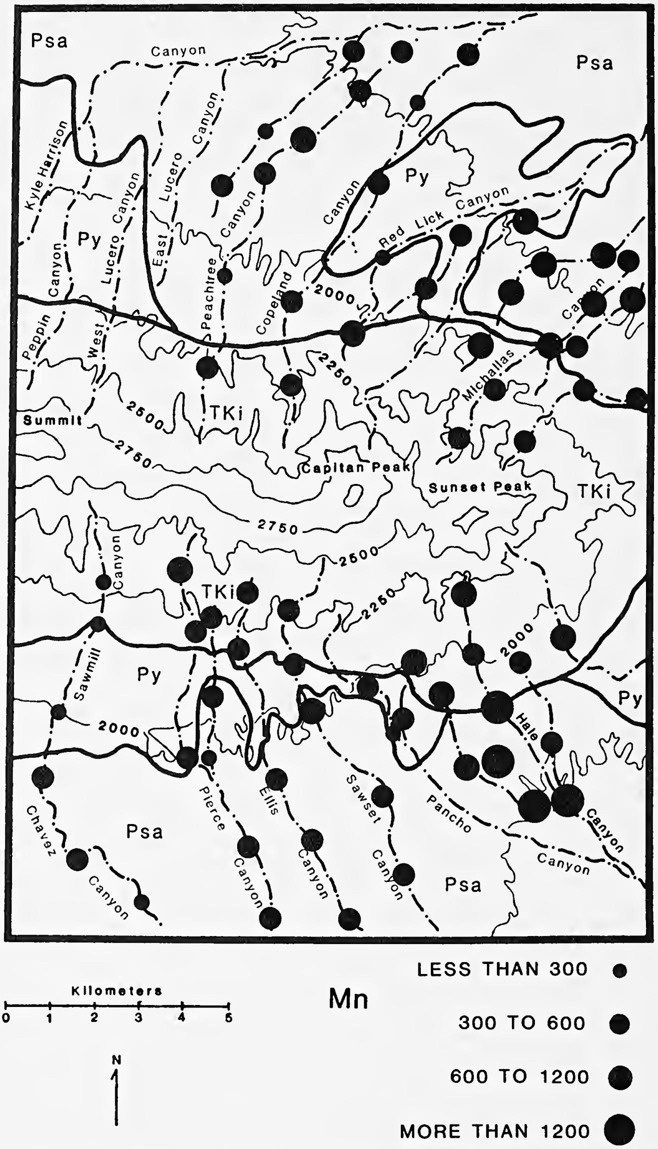

FIGURE 2. Manganese content (in parts per million) of bulk stream sediment samples (less than 60-mesh fraction).

sites showing anomalously high metal values and collecting samples traversing the streams from bank to bank.

Using a plastic scoop, bulk samples were collected as near the middle of the stream as possible, placed into a clean polyethylene bag, and the location marked on a map. Sample sizes ranged from 2.5 to 3.0 kilograms. After collection, samples were transported to the laboratory and air dried on nonabsorbent plastic plates. After drying, aluminum splitters were used to obtain a representative 70-gram aliquot from each bulk sample. The 70-gram aliquots were then seived to collect the less than 60-mesh fraction (particles less than 0.25

millimeters in diameter). The 30- to 60-mesh (particles 0.25 to 0.50 millimeters in diameter) fractions were retrieved for mineral identification purposes. The less than 60-mesh fractions were then split to obtain representative one-gram samples, which were stored in individual 20-milliliter test tubes prior to digestion.

The remainder of the bulk samples each were panned down to five to 10 grams and placed into clean polyethylene bags. the bags were later re-opened and the panned concentrates air dried while remaining in the bags. After drying, the panned concentrates were sieved to obtain a 30- to 60-mesh fraction and a minus 60-mesh fraction. Again, the 30- to 60-mesh fraction was saved for mineral identification purposes. Aluminum splitters were used to collect representative one-gram aliquots, which were placed into individual 20-milliliter test tubes before digestion.

A hot acid bath using a mixture of HCl and HNO_3 was used to put elements in solution. The procedure was taken from Cepeda (1986), and was used for both the bulk and panned concentrate samples.

Five milliliters of HCl and three milliliters of HNO_3 were added to the one-gram samples, and the test tubes then were placed into a warm test tube heater. After 30 minutes, five millimeters of HCl and five millimeters of distilled H_2O were added, and the solutions were boiled down to approximately nine millimeters, taking about eight hours. After cooling, the solutions were diluted to 25 millimeters, filtered through #2 Whatman filter paper, and stored in a test tube prior to analysis.

For organic rich samples, digestion was accomplished by adding three millimeters of HNO_3 to the one-gram samples. After resting on the warm test tube heater for more than an hour, 10 millimeters of HCl and five millimeters of distilled H_20 were added. The solution was then boiled down to approximately nine millimeters diluted to 25 millimeters, filtered, and stored.

A few drops of HF were used to break a frothy emulsion sometimes produced by organic rich samples. This precaution, however, did not prevent frothing in all organic rich samples. In such cases, gradual heating of the solutions was used to make the frothing more controllable.

Atomic Absorption Spectrophotometry

A Perkin-Elmer Model 4000 spectrophotometer and air-acetylene flame were used to analyze solutions for Co, Cu, Fe, Mg, Mn, Mo, Pb, and Zn. Calibration standards were prepared from cobalt nitrate (Co), cupric sulfate (Cu), ferrous ammonium sulfate (Fe), magnesium sulfate (Mg), manganous sulfate (Mn), molybdenum trioxide (Mo), lead chloride (Pb), and zinc chloride (Zn). USGS Geochemical Exploration (GXR) Standards were used as internal standards. Iron concentration in the six standards ranges from 34,200 parts per million (ppm) to 247,000 ppm (Gladney and Burns, 1984). In the range below 50,000 ppm, the analytical error ranges from 36 to 58 percent, but error decreased with increasing Fe concentration and is less than 3.3 percent above 100,000 ppm. The error at the lower concentration is probably a function of the calibration curve for the spectrophotometer. Manganese concentrations in the standards range from 140 to 960 ppm, and error ranged from 23 to 34 percent.

RESULTS

Iron and manganese concentrations of the less than 60-mesh fractions of stream sediment samples are illustrated in Figures 2-5. Similar data are available for Co, Cu, Mo, Pb, and Zn, but these latter elements did not show any substantial anomalies.

The greatest elemental concentrations were detected near the contact of the Permian sedimentary rocks and the Capitan Intrusion. From this contact element concentrations gradually decrease downstream, although

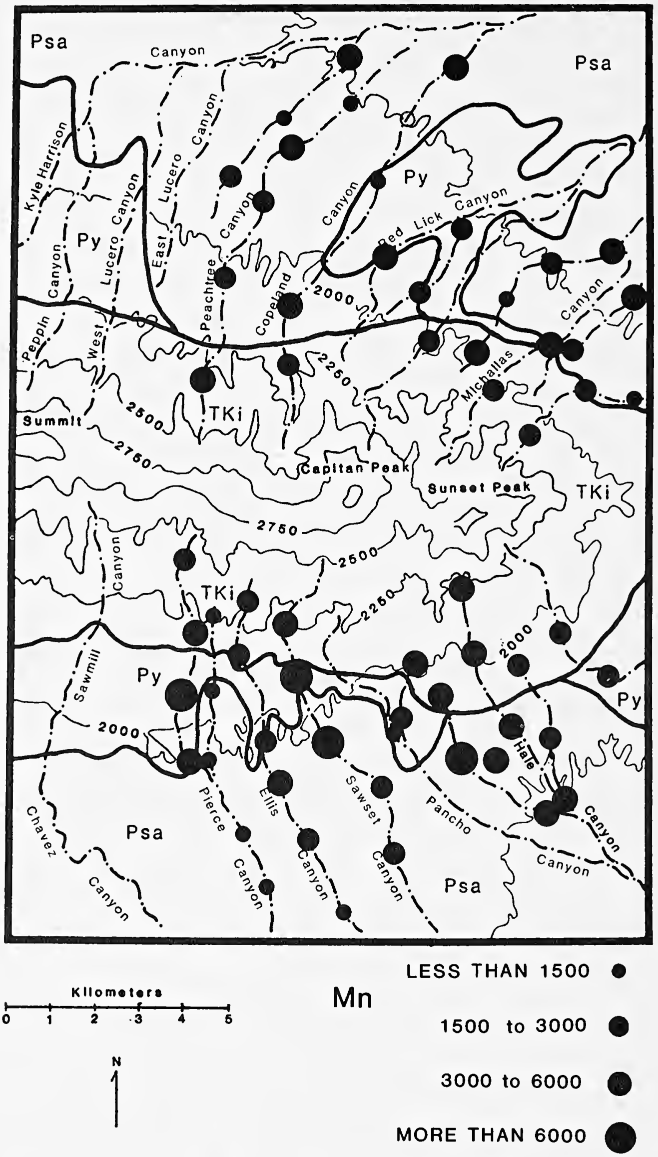

FIGURE 3. Manganese content (in parts per million) of stream sediment panned concentrates (less than 60-mesh fraction).

alluvium influx produces an occasional higher than normal element concentration three to five kilometers downstream from the contact.

Manganese

Manganese content of bulk stream sediment samples in the less than 60-mesh fraction ranged from 100 to 1825 ppm (see Fig. 2). Mn content of sediments within the Capitan intrusion ranges from 100 to 1100 ppm with concentrations generally increasing outward toward the contact. Concentrations downstream from the contact range from 250 to 1825 ppm. A few streams, such as in Pierce Canyon, had a maximum concentration adjacent to the contact and a general decrease downstream. However, most drainages showed a generally uniform concentration or even an increase downstream. Highest metal values were in the eastern part of the study area, particularly in the drainages near Hale Canyon, where concentrations of 1800 ppm or more were encountered in the bulk sediment samples.

Panned concentrates showed a range of Mn concentrations from 250 to 11,350 ppm (see Fig. 3). The greatest anomaly is just downstream from the contact in Pierce Canyon at the western margin of the study area. However, the drainages near Hale Canyon showed concentrations greater than 5000 ppm. We found no evidence of secondary precipitation of Fe and Mn, such as crusts or concretionary accumulations, in the stream sediments.

Iron

Iron concentrations in the bulk sediment samples for the less than 60-mesh fraction ranged from 13,600 to 217,200 ppm (see Fig 4). Values of Fe in stream sediments collected in areas underlain by the Capitan intrusion ranged from 15,000 to 87,000 ppm and the highest values were generally closed to the margin of the intrusion.

The highest concentrations were in the Hale Canyon area and the highest value recorded was just downstream from the contact. However, metal values generally remained uniform or even increased slightly downstream. No outstanding iron anomalies were evident on the north side of the Capitan Mountains.

Panned concentrates (see Fig. 5) showed iron values ranging from 26,375 to 946,600 ppm. Again, the outstanding anomalies were in the drainages of the Hale Canyon area. Concentrations were highest near the contact, and declined generally downstream, but only slightly.

Cobalt, Copper, Magnesium, Molybdenum, Lead, and Zinc

The concentration of magnesium in the bulk and panned concentrate samples revealed that it was much more abundant in the bulk sample (up to 220,325 ppm) than in the panned concentrate samples. Mineralogical analysis of the samples indicated the presence of abundant dolomite rhombohedrons in the bulk sample and no traces of Mg-bearing skarn minerals in either the bulk or panned samples. The ranges of concentration in the bulk samples for the base metals were: Cobalt (0-25 ppm), Copper (0-50 ppm), Molybdenum (75-2550 ppm), Lead (75-325 ppm) and Zinc (50-1625 ppm). The large range of concentrations for Mo, Pb, and Zn may warrant further study.

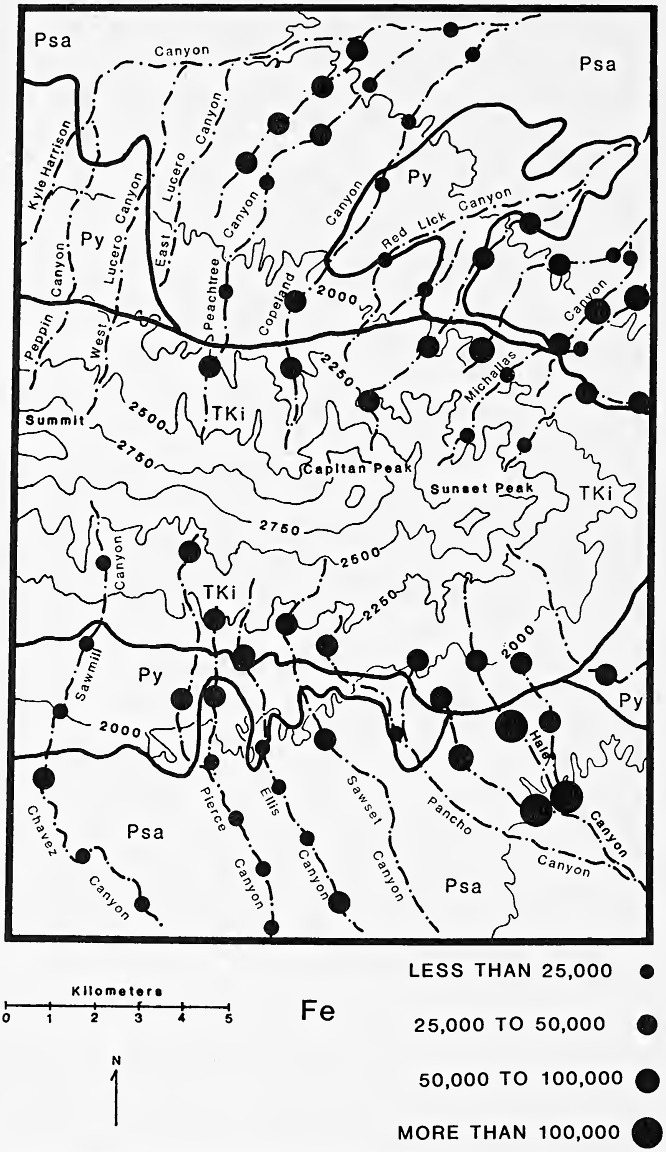

FIGURE 4. Iron content (in parts per million) of stream sediment samples (less than 60-mesh fraction).

In general, NURE anomalous locations and those identified in this study coincided. Anomalies in stream sediment detected by the NURE investigation included, barium (Ba), cerium (Ce), copper, lanthanum (La), lead, manganese, niobium (Nb), silver (Ag), thorium (Th), yttrium (Y), and zinc. In the Hale Canyon area, Ag, Ba, Ce, Cu, La Pb, and Zn anomalies were detected by the NURE study, and Fe and Mn anomalies

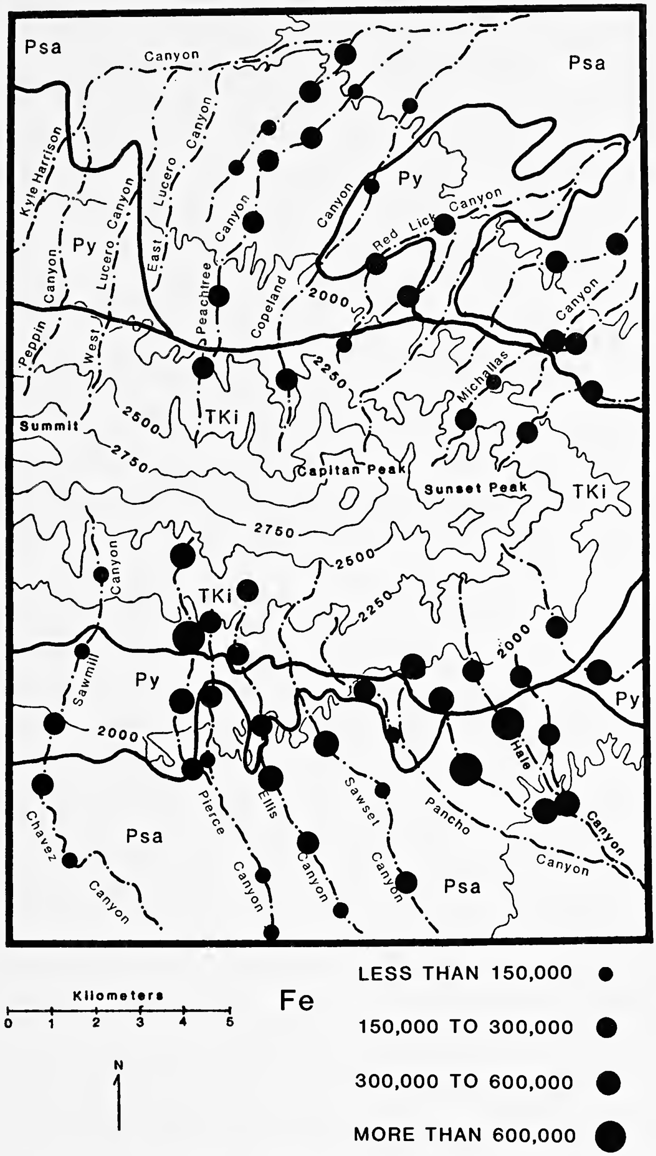

FIGURE 5. Iron content (in parts per million) of stream sediment panned concentrates (less than 60-mesh fraction).

were detected by this study. NURE detected Nb and Y anomalies near Sawmill Canyon are near Fe and Mn and anomalies of this study.

Mineralogy of the Stream Sediment

The 30- to 60-mesh (0.25 to 0.50 mm diameter) fraction from 18 samples collected just downstream from the igneous-sedimentary rock contact were examined using oil immersion techniques to determine their mineralogical composition. Stream sediment consisted mostly of feldspar and quartz. Heavy minerals included magnetite with lesser amounts of sphene, biotite, anatase, ilmenite and, rarely, staurolite, actinolite, and zircon.

Where panned concentrate Fe anomalies were detected, sand-size magnetite composed approximately 50 weight percent of the panned concentrate, with sphene and anatase being the next most common constituents. Where iron is not anomalous, magnetite composed approximately one to 10 weight percent of the panned concentrate, with sphene and biotite next in abundance.

Pink dolomite crystals, up to 0.50 mm, in diameter, occurring as aggregates attached to calcite, quartz, and feldspar grains, produce Mg anomalies. Abundant dolomite crystals give anomalous samples a pinkish color, easily distinguished from stream sediment collected elsewhere. In anomalous samples, no actinolite, and only a few biotite grains were found.

Sphene, possible producing the Mn anomaly in Pierce Canyon, may be derived from granite near the Tide deposit. Alluvial sphene crystals, up to a millimeter in diameter, are approximately the same size as those found in granite throughout the Capitan intrusion.

Chamberlin (1986, personal communication) has noted that Ce, La, Nb, Y, Na, and Ba, concentrations increase towards the eastern end of the Capitan intrusion, and that strong Ce and La anomalies near sunset Peak may represent alluvial bastnaesite, or sphene, but not monazite. Monazite may be excluded because thorium, a common constituent of monazite, was not detected by the NURE study. Bastnaesite was not identified in panned concentrate samples. However, with its honey yellow color and easily split laminae, it may be mistaken for fractured sphene crystals.

Discussion

Typically, abundance of elements in stream sediments decreased downstream from the source of the anomaly. Because the source of the iron, manganese, and magnesium anomalies are skarn deposits concentrated at the contact between the Capitan intrusion and the Permian sedimentary rocks, a decrease in metal content is expected downstream from this contact. Some drainages follow this expected trend, Pierce Canyon for example, but many do not.

The most obvious deviation is in the drainages near Hale Canyon, in the southeastern part of the study area. This is also where the highest iron concentrations in stream sediments are found.

Fieldwork in the Capitan Mountains confirms the existence of some skarn material, primarily magnetite-actinolite skarn near the intrusive contact at the head of Pierce Canyon (Tide prospect) and at the head of Red Lick Canyon. However, in the drainages in the vicinity of Hale Canyon, where the highest downstream anomalies are found, no skarn is exposed at the contact. Abundant boulders and cobbles of magnetite occur in the streambed, but there is no evidence of *in-situ* effects of Fe-Mn percipitation on cobbles and boulders. Preliminary sampling and analysis of the alluvial material downstream from the contact reveals that the iron content is as high as 143,700 parts per million. We are fairly certain that the bulk of the Fe is contained within the alluvial material and not in skarn deposits. Erosion of the alluvial deposits downstream from the intrusive contact is responsible for the high concentrations of metals in the streambed sediments, at a considerable distance from the igneous-sedimentary contact.

Acknowledgments

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Literature Cited

Cepeda, J. C. 1986. Copper in soil samples downslope from copper-tungsten mine tailings, Cleora district, Chaffee County, Colorado. Texas J. Sci., 38:59-64.

Gladney, E. S., Burns, C. E. 1984. 1982 compliation of elemental concentration data for the United States Geological Survey's Geochemical Exploration Reference Samples GXR-1 to GXR-6. Geostandards Newsletter, 8:119-154.

Griswold, G. B. 1959. Mineral deposits of Lincoln County, New Mexico. Bull. New Mexico Bur. Mines Mineral Res., B 67:1-117.

Kelley, V. C. 1952. Origin and Pyrometasomatic zoning of the Capitan Iron Deposits, Lincoln County, New Mexico. Econ. Geo. 47:64-83.

———. 1971. Geology of the Pecos country, southern New Mexico. Mem. New Mexico Bur. Mines Mineral Res., 24:1-78.

Martin, W. C. 1964. Some Aspects of the natural history of the Capitan and Jicarilla mountains, and Sierra Blanca region of New Mexico. New Mexico Geol. Soc. Guidebook, 15:171-176.

Sprankle, D. G. 1983. Soil Survey of Lincoln County Area, New Mexico. U.S. Dept. Agric., Soil Conserv. Serv., 217 pp.

Tuftin, S. E. 1984. Mineral investigation of the Capitan Mountains Wilderness Area, Lincoln County, New Mexico. U.S. Bur. Mines, Open-File Rept. MLA 20-84, 20 pp.

Union Carbide—Oak Ridge Gaseous Diffusion Plant. 1981. National Uranium Resource Evaluation Program, Hydro-geochemical and stream sediment reconnaissance basic data for Roswell Quadrangle, New Mexico. U.S. Dept. Energy, Grand Junction, Rept. no. GJBX-397 (81), 187 pp.

NOTES ON THE BIOLOGY OF THE BIG-EARED CLIMBING RAT, *OTOTYLOMYS PHYLLOTIS*, ON THE YUCATAN PENINSULA, MEXICO

JAMES ALDEN LACKEY

Department of Biology, State University of New York College at Oswego, Oswego, New York 13126

ABSTRACT.—Mark-and-release studies of the big-eared climbing rat, *Ototylomys phyllotis*, on the Yucatán Peninsula, México, and published data on a laboratory population of this species suggest an unusual ecological niche. Assuming rates of growth of offspring in a laboratory population were similar to those in the field, young apparently begin foraging as early as 11 days of age. This activity is correlated with highly precocial development, presumably in part a consequence of the longest gestation period known among myomorph rodents. The long gestation period allows the birth of relatively large young; the ratio of litter weight to female weight appears to be greater than that found among close relatives. The young reached sexual maturity in only 30 days in a laboratory population. This life history pattern may be an adaptation to short life expectancy, estimated in another field study on the Yucatán Peninsula to be as short as eight months. The home range apparently includes a large vertical component. Distances from trap sites to burrow entrances indicate the availability of a large number of refuge sites at ground level. *Key words*: biology; climbing rat; *Ototylomys*; Mexico.

Disney (1968) obtained data on the natural history of *Ototylomys* during his study of vectors of leishmaniasis in Belice (formerly British Honduras). Lawlor (1969, 1982) revised the genus, recognized one species and three subspecies, and summarized the literature on this species. Helm (1973, 1975) studied reproduction, growth, and development in a laboratory population derived from animals obtained at the study site of the present report, and described several unusual aspects of the ontogeny such as the long gestation period and rapid postnatal development. The remainder of the literature on this species consists of a few brief reports pertaining to specialized topics and anecdotal information.

This report presents the first data on the natural history and behavior of *Ototylomys* to be obtained by mark-and-release methods, thereby providing the first information for this species on such topics as home range, behavior upon release (that is, kinds and number of refuge sites), and estimated age when young first enter the trappable population. This information, along with that from previously reported laboratory studies, suggests the existence of an unusual life history, and several hypotheses are presented here to account for this strategy. The field data in this report were obtained during studies of the white-footed mouse, *Peromyscus leucopus* (Lackey, 1978). Reports of several other studies on the biology of rodents of the Yucatán Peninsula, some of them ecological associates of *Ototylomys phyllotis*, are in preparation.

METHODS

The study site was located in the state of Campeche in southern México, near the base of the Yucatán Peninsula, and was described in detail elsewhere (Lackey, 1973). There was field work at many other places in the region, including two other mark-and-release sites (sites "B" and "C") and reference is made to some data from those sites, but *Ototylomys* was common only at the site described here (site "A" in Lackey, 1973). Briefly, site A was located 7.5 km. W of Escárcega in a second-growth forest having a canopy 15 to 20 meters high with a few emergent trees. Undergrowth varied in density and was denser in areas having the least canopy overhead. The nearest field was at least 100 meters distant. Mark-and-release trapping was conducted for a total of 13 days (3-11, 22-25 May 1971); there was a small amount of trapping in August. A 10 × 10 grid was established with trap stations 15.2 meters (50 feet) apart, encompassing an area of 1.88 hectares (4.65 acres). One Sherman live trap (7.5 × 8.75 × 22.5 centimeters) baited with rolled oats was set within one meter of the stake marking the station. Each animal was toe-clipped, and the following data were recorded: sex, condition of testes (scrotal or nonscrotal), state of lactation, presence of palpable embryos, standard linear measurements, weight, presence of external parasites, behavior upon release, refuge sought (for example, burrow, log, tree), and distance and direction from trap to refuge site. Supplemental trapping at other sites is described and summarized in the Results section.

RESULTS

Population sample and estimated age—Thirteen female and seven male *Ototylomys* were trapped a total of 33 times at site A; 17 individuals were marked and released, and three others were initially trapped on the last day of field work. There was a variety of ages represented in the sample. Caution must be exercised when attempting to apply laboratory data on growth and development to field populations for estimating age, but a careful comparison of data from Helm (1975) and from the present study seems to allow limited application of those data. Body length and weight were selected for use in estimating age; growth of hind feet and ears rapidly reaches a plateau and are useless after an age of about four weeks, and tail length was not used because of necrosis of the tail in some individuals in the laboratory (Helm, 1975). A graph of body length versus weight was used for comparing data from the laboratory population studied by Helm (1975) and from the field population in the present study. Body length (measured separately from total length) was assumed to be less sensitive to laboratory effects on growth than was weight and, therefore, was selected as the independent variable used in assessing possible laboratory effects on weight; the accuracy of this procedure, however, remains unknown without appropriate field studies. There was a close correspondence between the laboratory and the field data sets, except weights for laboratory animals appeared slightly lower for a given body length; small sample size for the field population might account for this discrepancy.

Estimated age of individuals in the field population was calculated by making an age estimate based on body length, and another estimate based on weight, using growth curves in Helm (1975); those two estimates

Table 1. Estimated age of *Ototylomys phyllotis* trapped in May. See text for explanation of method for estimating age.

Field no.	Sex	Date of first capture	Estimated age (days) at first capture, based on body length and on weight at first capture: Body length	Weight	Average
6	F	May 5	10	11	11
16	M	May 24	12	13	13
1	M	May 3	12	16	14
8	M	May 6	14	14	14
14	M	May 23	19	19	19
13	F	May 22	22	17	20
17	F	May 24	19	20	20
7	F	May 6	21	(a)	21
11	M	May 22	29	21	25
15	F	May 24	31	35	33
2	M	May 3	30	39	35
3	F	May 3	90	79	85
5	F	May 5	90	92	91
4	F	May 5	85	100	93
10	M	May 11	90	102	96
12	F	May 22	(b)		
9	F	May 7	(b)		
18	F	May 25	(b)		
19	F	May 25	(c)		
20	F	May 25	(d)		

(a) Weight datum clearly in error and not included; age estimate based on body length only.
(b) Weight and body length indicate age in excess of 14 weeks; error in age estimate likely high.
(c) No measurements taken at time of capture; termed "adult" in field notes.
(d) No measurements taken at time of capture; termed "subadult" in field notes.

were then averaged (Table 1). Among animals estimated to be probably in excess of 14 weeks old, age estimates based on body length were sometimes greatly different from estimates based on weight; therefore, ages of those individuals are considered unknown. If the weight of a laboratory animal was in fact less than that of a field animal of the same age, ages of field animals would be overestimated, that is, field animals would be younger than the estimate given; the disparity in age estimates, however, is likely no more than a few days during the first several weeks because of the steepness of growth curves during that period.

Habitat—The habitats in which *Ototylomys* was found in Campeche closely resembled some of those described by Birney et al. (1974), Jones et al. (1974), and Lawlor (1969) in other parts of the Yucatán Peninsula. Mammalian ecological associates of *Ototylomys* in Campeche usually were the same as reported by those authors.

At site A, there were 1300 trap-nights in May during the mark-and-release studies and an additional 200 trap-nights in August in which 11 more *Ototylomys* were trapped, yielding a total of 31 individuals in this forest habitat. In addition to sites A, B, and C, trapping was conducted at 31 other sites near Escárcega and Champotón (approximately 80 km N Escárcega), representing five habitats. The habitats (excluding study site B, abandoned corn field in which no *Ototylomys* was trapped, and site C, corn field in use in which one *Ototylomys* was trapped); number of trapnights; number of *Ototylomys* trapped; and percent trapping success were, respectively: forest, 947, 17, 1.8; forest-field interface, 730, 1, 0.1; brushy field, 823, 0, 0; abandoned corn field (that is, not planted within the past year), 144, 3, 2.1; corn field in current use, 771, 3, 0.4; total, 3415, 55, 1.6. These results and those reported in the literature clearly demonstrate a strong correlation between capture sites of this species and vegetative cover, particularly forest.

Reproductive biology.—There were few indications of reproductive activity during the May study period. Males 10, 11, and 14 had scrotal testes on 11, 22, and 23 May, respectively; females 9 and 19 had palpable embryos on 24 and 25 May, respectively, and female 12 was lactating on 22 May.

The gestation period of *Ototylomys* averaged 52 days (50-52 days for nonlactating females) in a laboratory population (Helm, 1975). Assuming this gestation period reflects that in the wild, one can estimate the time of conception of individuals for which reasonable age estimates can be made by adding 52 days to the estimated age (in days) at initial capture and projecting this total backward in time from the date of that capture. Such calculations indicate that the estimated dates of conception for the first 15 individuals listed in Table 1 were 12, 14, 15, and 18 December, 6, 9, and 28 February, and 1, 2, 4, 6, 12, 14, 14, and 21 March. (Note that these estimates do not match the sequence in which individuals are listed in Table 1.) The dates in December obviously are more likely to include significant error than are later dates. Estimates of time of conception assume no delay between copulation and beginning of embryonic development, that is, no delay in fertilization or implantation.

Parasites.—One botfly (*Cuterebra*) larva was found in the scrotum of one male, and two larvae in the scrotum of another; one botfly larva was found in the inguinal region of one female, and two larvae in the same region of another female. There was a tick on the throat of one female, and a tick near the left ear of one male. In a study of cutaneous leishmaniasis in Belice approximately 250 km SE of Escárcega, Disney (1968) found *Ototylomys* was the principal mammalian host of leishmaniasis, with lesions always on the tail. These lesions rarely ulcerated and likely would not be noticed unless specifically examined. In the present study there were no observations of such lesions among the 55 animals trapped.

Behavior after release.—Among the 29 releases for which data are available, there were 13 instances when the climbing rat entered a hole within approximately one meter of a tree or log; in seven of those instances, the hole was located at the base of a tree; in six instances the hole was located adjacent to or beneath a log. In 12 releases the animal entered a hole more than one meter from a tree or log, and in four instances the animal did not enter a hole. Among the 29 releases there were three instances in which the animal climbed a tree, ultimately seeking a ground refuge in two instances; in five instances the animal ran along logs or branches lying on the ground while enroute to a hole. The trunk diameters of trees climbed by an animal were estimated in two instances, and were four centimeters and 25 centimeters; the heights climbed were two meters and 2.5 meters, and the diameters of branches along which the animals then moved were one centimeter and half a centimeter. Distances from the release site (trap) to a hole in which an animal took refuge (and the number of instances) were as follows: 0-1.0 meter (10); 1.1-2.0 meters (3); 2.1-3.0 meters (1); 3.1-4.0 meters (5); 4.1-5.0 meters (2); 6.1-10 meters (4).

Home range.—The few captures of *Ototylomys* during the mark-and-release study, and the possibility that the trap stations were too far apart to characterize the home range adequately, make it impossible to draw firm conclusions on home range size and shape (Fig. 1). Individuals caught more than once were never recaptured more than two stations distant (30 meters) from the point of initial capture (except 34 meters in one instance in which the two stations were separated on a diagonal). One individual (no. 4) was caught five times, four at one station and once at an adjacent station; another (no. 2) was captured four times, three at one station and once at an adjacent station.

Discussion

Habitat.—In Belice, Disney (1968) found *Ototylomys* only in "low bush" and "medium bush," categories of forest structure characterized by diameter of tree trunks; the species was absent from "immature bush" in which trunk diameter in a sample of 200 trees in no instance exceeded 10 centimeters. *Ototylomys* comprised 52 percent of the specimens of rodents trapped in "low bush," where trunk diameter greater than 10 centimeters was exhibited by six to 14 percent of the trees sampled, and 57 percent in "medium bush," where trunk diameter greater than 10 centimeters was exhibited by more than 14 percent of the trees. Tree diameters were not measured in the present study, but field notes and numerous photographs of site A and other sites indicate that nearly all *Ototylomys* were trapped in habitats resembling "medium bush." Capture sites of this species (Fig. 1) clearly exhibit clustering, but the basis of that distribution was not obviously related to habitat type.

Home range and territoritality.—Data obtained on home range were few but indicated a home range that seemed small for an animal the size

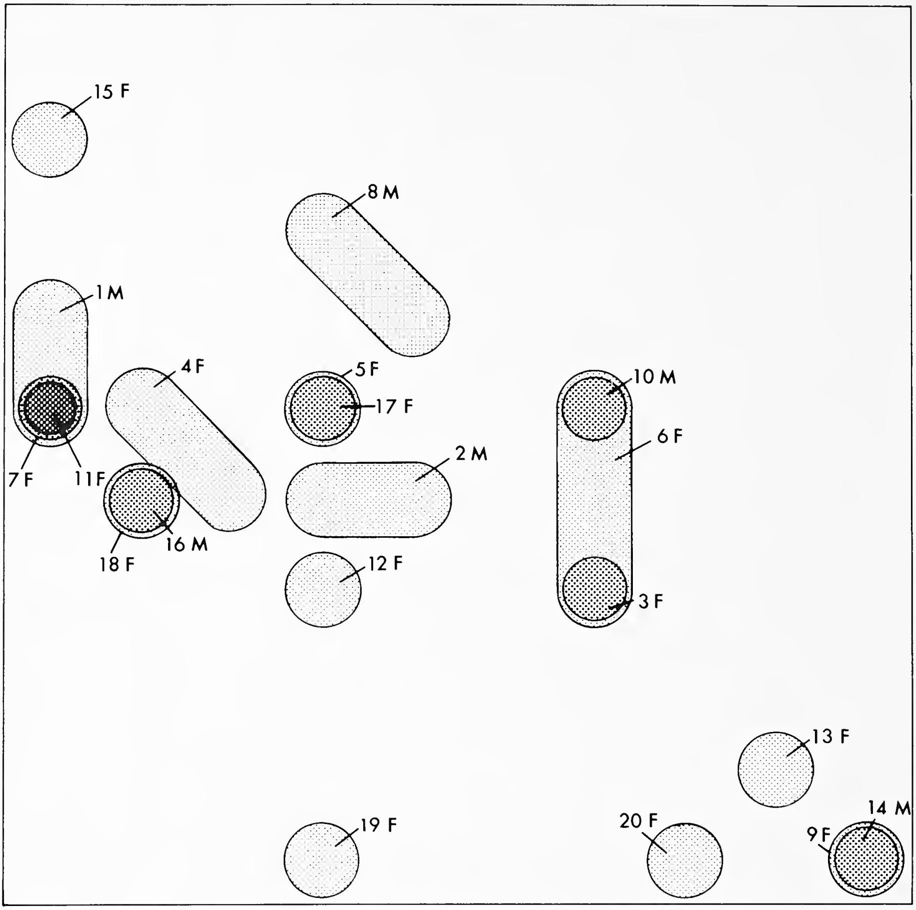

FIGURE 1. Distribution of *Ototylomys* in second-growth forest, Campeche, Mexico. Individual field number and sex (F, female; M, male) are indicated.

of *Ototylomys*, thus suggesting that much of the home range is located above ground level. That *Ototylomys* is at least partially arboreal has been suggested by various authors (for example, Burt and Stirton, 1961; Disney, 1968; Lawlor, 1969) is supported by observations in the present study on behavior following release from traps. Disney (1968) reported capturing far more individuals of *Ototylomys* in traps set in trees than on the ground, but there was seasonal variation in capture sites. In that study, traps were set in trees at heights of zero to four meters and four to eight meters; approximately five times as many individuals of *Ototylomys* were caught at the lower level. A three-dimensional home range for this species seems a safe assumption, but details of the frequency of use of various parts of the home range remain unknown—that is, seasonal, sexual, and age variation; stability of home range size and shape over time; and overlap of home ranges.

In the present study, 13 (52 percent) of the burrow entrances entered were no more than two meters from the trap site; trap stations were 15.2 meters apart, thus half the entrances were no more than one-seventh the distance to the next trap station. Captures of some individuals at several different trap stations suggests this species has access to more than one burrow entrance for refuge, but the question remains whether these holes would be used under less stressful conditions than those following release from a live trap. No information was obtained on the organization of the burrow systems, such as the number of entrances.

A conclusive demonstration of the existence or absence of territoriality requires more data than were obtained in the present study, but the few data suggest territoriality. In the mark-and-release study, there were six trap stations at which two or more *Ototylomys* were trapped. Based on age estimates presented in Table 1, all three individuals trapped at station A6 (Fig. 1) were less than four weeks old (age at initial capture). At the other five stations, in each instance one of the animals was less than three weeks old and the other one more than seven weeks old. Although age estimates are not considered precise, the age difference in each instance was apparent. These few observations point to territoriality, with territories being established between the ages of four and seven weeks. Clearly, much more information on the subject is needed.

Ecological niche.—Several aspects of the niche of this species are unusual, as illustrated when comparing ontogeny and reproductive biology among *Ototylomys* and several other muroid rodents sympatric with *Ototylomys* in various parts of its range: Peters' climbing rat, *Tylomys nudicaudus*, an arboreal species with a body weight several times that of *Ototylomys*; vesper rat, *Nyctomys sumichrasti*, an arboreal species about the same size as *Ototylomys*; and the Yucatán deer mouse, *Peromyscus yucatanicus*, sympatric with *Ototylomys* at the study site and about one-half the weight of *Ototylomys*. Data for *Ototylomys* is from Disney (1968) and Helm (1975), those for *Tylomys* from Helm (1973, 1975), those for *Nyctomys* from Birkenholz and Wirtz (1965), and those for *Peromyscus yucatanicus* from Lackey (1976). A summary of published data on these species and a comparison of their niches follows:

(1) The gestation period (nonlactating) of 50 to 52 days in *Ototylomys* may be the longest recorded among myomorph rodents, whereas that of *Tylomys* is 37 to 39 days, *Nyctomys* , 30 days, and *P. yucatanicus*, 27 to 28 days. Disney (1968) noted that as the breeding season approached, visibly pregnant *Ototylomys* were recorded at the same time as testis size increased in males, whereas one would expect testis size to increase prior to that time. Testis size was reported as an average, and there remains the possibility that a small number of males was responsible for most of the pregnancies early in the breeding season. These results, along with the observation that a female isolated in a cage for 174 days gave birth, were

interpreted by Disney (1968) as indicating the possibility of delayed fertilization or delayed implantation in this species, although not necessarily the usual mode of reproduction.

(2) When expressed as a percentage of adult dimensions attained at various ages, growth rates of *Ototylomys* in the laboratory are somewhat lower than those reported for *Nyctomys* and are considerably lower than those of *P. yucatanicus*. Rates of postnatal development of *Ototylomys*, however, are exceptionally high and exceed those of virtually all myomorphs of similar (or smaller) species (see Helm, 1975: table 3 for summary). For example, eye-opening in *Ototylomys* occurred at two to six days of age, compared to eight to 14 days in *Tylomys*, 15 to 18 days in *Nyctomys*, and 13 to 21 days in *P. yucatanicus*; opening of the auditory meatus (or response to a sharp noise) occurred at two to six days in *Ototylomys*, six to 13 days in *Tylomys*, and 11 to 17 days in *P. yucatanicus* (no data for *Nyctomys*). A "decoupling" between rates of growth and rates of development was noted by Lackey (1978) for *Peromyscus leucopus*, with the Yucatán subspecies exhibiting rates of growth similar to those of the Michigan subspecies but having significantly higher rates of development—for example in eye opening, ear opening, and age at sexual maturity. In the Escárcega area, *P. leucopus* inhabits various kinds of fields, whereas the sympatric *Ototylomys* is largely a forest inhabitant; this comparison indicates relatively rapid rates of development are not necessarily associated with a particular kind of habitat.

(3) The average number of young in a litter of *Ototylomys* was 2.3, each neonate weighted 10.2 grams, or 16 percent of adult weight (about 60 grams), and total litter weight was 23.8 grams, or 38 percent of average adult weight. In contrast, the number of young in a litter of *Nyctomys* was 2.0, each neonate weight 4.7 grams, or 7.8 percent of adult weight, and the total litter weight was 9.4 grams, or 15.6 percent of adult weight (adult weight 60 grams). In *P. yucatanicus*, litter size was 3.5, each neonate weighed 2.5 grams, or 11.7 percent of adult weight (30 grams), total litter weight was 8.7 grams, or 29 percent of adult weight. All litter sizes cited are based on laboratory animals. These data indicate a larger investment by *Otoylomys* on the basis of individual neonate weight compared to female weight, and weight of the litter compared to female weight.

(4) Disney (1968) compared the body size of wild-caught pregnant females of *Ototylomys*, and the body size of wild-caught males having a testis size indicating breeding condition, with body sizes of known-age males and females in a laboratory population, and concluded that the earliest age of sexual maturity in both sexes was about one month. Helm (1975) reported females mating as early as 29 days of age, but males not before 175 days. In Helm's laboratory population, female sexual maturity

as indicated by vaginal opening occurred between 21 and 70 days of age; descent of testes occurred between 15 and 38 days (averages not available). In *P. yucatanicus*, the average age at vaginal opening was 51 days, and for initial descent of testes 45 days (ranges not available). Data for *Tylomys* and *Nyctomys* are not available, or are too few for comparison. The earlier age at sexual maturity in *Ototylomys* than in the much smaller *P. yucatanicus*, is unexpected on the basis of body size.

(5) In an analysis of the distribution of body measurements according to season, Disney (1968) concluded that in Belice *Ototylomys* might not live more than eight months under field conditions. When captures were grouped into three-month intervals and body length measurements were distributed among five body length classes within each interval, the class including the largest individuals always included only a small percentage of the sample. In a small sample of known-age individuals raised in captivity by Disney (1968), animals reached the largest class of body length at approximately eight months of age. Similar analyses for *Tylomys* and *P. yucatanicus* are not available for comparison.

The preceding comparisons and the additional data below allow some characterization of the niche of *Ototylomys*. Only two documented aspects of reproduction and ontogeny are common to *Ototylomys, Tylomys,* and *Nyctomys*, species in which habits and habitats generally are similar—these are small litter size (number of young) and roughly comparable rates of postnatal growth. Among these similar (and possibly closely related) species, *Ototylomys* is distinguished by its much longer gestation period and earlier attainment of various stages of postnatal development. The long gestation period might be a mechanism allowing various stages of development to be attained early in postnatal life through the production of neonates completing *in utero* some of the development the other species undergo following birth. The selective advantages of such a presumed adaptation perhaps are an increased ability of offspring to sense (for example, see, hear) the environment early in life, and increased neuromuscular control during locomotion. Such abilities likely would enhance traveling outside the nest at an earlier age, thereby allowing young to supplement their food intake beyond milk, an opportunity to learn about their environment during travels with a parent, and perhaps improved ability to escape predation (particularly so if there is a high risk of predation of young at the nest site). Age estimates in Table 1 indicate several young were first captured when only 11-14 days old, yet in a laboratory population, young continued to cling to their mother's teats until approximately 30 days of age (Helm, 1975). There are, however, no data to indicate whether the young that were trapped were eating food in addition to milk or eating only solid food.

If one assumes the young are not fully weaned until 30 days of age, and are able to increase their caloric intake as a result of eating supplementary food prior to weaning, their rates of growth and development should thereby be increased, assuming the milk supply of the female is inadequate by itself to support such rates and that the foraging activities do not utilize all the energy obtained from the foraging. Laboratory data may be inappropriate for testing this hypothesis because lactating mothers have ready access to unlimited food; in the wild, food may be limiting, or the time required to obtain and digest sufficient food may not be available or may subject the mother to a significantly increased risk of predation. The food habits of *Ototylomys* are not well known, but likely include fruit and leaves (Lawlor, 1982), foods typically low in caloric content.

The question at this point is the nature of the selective advantage of a high rate of postnatal development in *Ototylomys*. The answer may involve life expectancy, possibly only eight months (Disney, 1968). Specific adaptations in response to short life expectancy might differ according to resource levels: in the example of *Peromyscus leucopus*, Lackey (1978) hypothesized that life expectancy of the Yucatán population was shorter than that of a Michigan population because of periodic severe environmental disturbance in the grain fields where the Yucatán population lives; a mark-and-release study indicated a higher population turnover rate there than was found in the Michigan population. The responses to this apparent high mortality appeared to be increased rates of development including an earlier age at sexual maturity, larger litters, little or no lactation-induced delay in the gestation period, a larger mass of newborn in relation to female weight, neonate weight scarcely varying with litter size, the breeding season extending throughout the year, and young from large litters growing and developing at nearly the same rates as those from smaller litters. The food supply in grain fields was assumed to be larger than that available to the Michigan population, and it further was assumed females could convert plentiful food rapidly into embryonic tissue and milk, thereby allowing rearing of large litters nearly as fast as smaller litters. If one assumes the food supply available to a pregnant or lactating *Ototylomys* in a forest habitat is significantly less than that available to *P. leucopus* in grain fields, it follows that the rates of postnatal growth and development of the *Ototylomys* offspring likely would be lower than those of *P. leucopus* offspring. One effect of this limitation in growth and development might be less time available to *Ototylomys* offspring for producing multiple litters, assuming the risk of predation is constant throughout life. Foraging at an early age seems a plausible adaptive response to a food supply inadequate to support the rapid postnatal development that compensates for a short life expectancy. A combination of nursing and foraging is found in the young of various other precocial mammals, such as ungulates.

Known predators of *Ototylomys* include owls (Goodwin, 1946) and a snake (Disney, 1968). That predation, or possibly some other cause of death such as disease or parasitism, may be significant is supported by Disney's (1968) estimate of a life expectancy of eight months in the wild. Perhaps males, at least, suffer high mortality owing to a social system like that found in the marsupial *Antechinus stuartii* in which males die at the conclusion of the breeding season (females, although living longer, also experience but one breeding season) (Lee et al., 1977).

Several hypotheses emerge from the foregoing: 1) there is strong selection on a female *Ototylomys* to raise her young quickly to sexual maturity (possibly 30 days) because of short life expectancy; 2) the early sexual (and other) developmental stages of offspring are achieved in part by means of a long gestation period, which also may provide greater protection for the young than they might experience in a nest; 3) the precocial young begin foraging to supplement the mother's milk supply at an age of as early as 11 days, thereby helping sustain high rates of development; 4) the selection pressures responsible for this suite of adaptations are predation or other causes of death that decrease life expectancy severely, and possibly limiting food resources.

Ototylomys phyllotis represents a species with a life history that includes several extreme adaptations likely of value in research on life history strategies. Field data at this point, however, allow little more than development of hypotheses. A long-term field study of a population (or, better, two populations, one in a dry-forest habitat as found on the Yucatán Peninsula, and another in a wet-forest habitat) that includes study of parent-offspring relationships, reproductive biology, longevity, and territoriality, would be a significant addition to knowledge of life history strategies of forest-dwelling tropical rodents. Information on *Nyctomys*, a relative of *Ototylomys* but differing in several life history characteristics, also would be useful in interpreting life history strategies of both species.

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LITERATURE CITED

Birkenholz, D. E., and W. O. Wirtz, II. 1965. Laboratory observations on the vesper rat. J. Mamm., 46:181-189.

Birney, E. C., J. B. Bowles, R. M. Timm, and S. L. Williams. 1974. Mammalian distributional records in Yucatan and Quintana Roo, with comments on reproduction, structure, and status of peninsular populations. Occas. Papers Bell Mus. Nat. Hist., Univ. Minnesota, 13:1-25.

Burt, W. H., and R. A. Stirton. 1961. The mammals of El Salvador. Misc. Publ. Mus. Zool., Univ. Michigan, 117:1-69.

Disney, R. H. L. 1968. Observations on zoonosis: leishmaniasis in British Honduras. J. Appl. Ecol., 5:1-59.

Helm, J. D., III. 1973. Reproductive biology of *Tylomys* and *Ototylomys*. Unpublished Ph.D. dissert., Michigan State Univ., East Lansing, 38 pp.

———. 1975. Reproductive biology of *Ototylomys* (Cricetidae). J. Mamm., 56:575-590.

Jones, J. K., Jr., H. H. Genoways, and T. E. Lawlor. 1974. Annotated checklist of mammals of the Yucatan Peninsula, Mexico II. Rodentia. Occas. Papers, Mus. Texas Tech University, 22:1-24.

Lackey, J. A. 1973. Reproduction, growth, and development in high-latitude and low-latitude populations of *Peromyscus leucopus* (Rodentia). Unpublished Ph.D. dissert., Univ. Michigan, Ann Arbor, 128 pp.

———. 1976. Reproduction, growth, and development in the Yucatan deer mouse, *Peromyscus yucatanicus*. J. Mamm., 57:638-655.

———. 1978. Reproduction, growth, and development in high-latitude and low-latitude populations of *Peromyscus leucopus* (Rodentia). J. Mamm., 59:69-83.

Lawlor, T. E. 1969. A systematic study of the rodent genus *Ototylomys*. J. Mamm., 50:28-42.

———. 1982. Ototylomys phyllotis. Mamm. Species, 181:1-3.

Lee, A. K., A. J. Bradley, and R. W. Braithwaite. 1977. Corticosteroid levels and male mortality in *Antechinus stuartii*. Pp 209-220 *in* The Biology of marsupials. (B. Stonehouse and D. Gilmore, eds.), University Park Press, Baltimore, 486 pp.

USING COLOR-INFRARED AERIAL PHOTOGRAPHY TO DISTINGUISH CHINABERRY (*MELIA AZEDARACH* L.) INFESTATIONS IN SOUTHERN AND SOUTH-CENTRAL TEXAS

J. H. Everitt, D. E. Escobar, and R. W. Neck
USDA, Agricultural Research Service, 2413 E. Highway 83, Weslaco, Texas 78596 and
Texas Parks and Wildlife Department, 4200 Smith School Road,
Austin, Texas 78744 (RWN)

Abstract.—Chinaberry (*Melia azedarach* L., Meliaceae) is a deciduous tree introduced to the United States as an ornamental and has escaped to become naturalized over a large area. It is abundant in many riparian woodlands in south-central and southern Texas where it is invading native plant communities. Color-infrared (CIR) aerial photography was evaluated for distinguishing chinaberry in south-central and southern Texas. Plant canopy reflectance measurements showed that chinaberry had significantly higher ($P = 0.05$) near-infrared (0.85 μm wavelength) reflectance than that of four associated plant species on three dates during the growing season. The high near-infrared reflectance of chinaberry caused it to have a distinct, bright red image on CIR aerial photos that could be distinguished easily from other plant species. The optimum time to identify chinaberry on CIR photos was in August and September. Computer-based image analyses of a CIR film positive transparency showed that chinaberry populations generally could be quantified from associated vegetation and other land-use features. These results showed that CIR aerial photography is a useful tool to detect and monitor the spread of chinaberry in wildland areas. *Key words*: remote sensing; near-infrared reflectance.

Chinaberry (*Melia azedarach* L.) is a deciduous tree up to 15 meters tall with dark green leaves and a rounded crown. A native of Asia, chinaberry was introduced to the United States as an ornamental and escaped to become naturalized over a wide area. It occurs along stream bottoms, ditches, and in thickets and waste places from Texas to Florida and north to Oklahoma, Arkansas, and North Carolina (Vines, 1960; Jones, 1975). Although generally not considered a noxious species, chinaberry produces a large number of viable seed (Vines, 1960), grows rapidly, and often forms dense stands that reduce light to other understory vegetation. Chinaberry is particularly abundant in many riparian woodlands of south-central and southern Texas where it is becoming a major element in otherwise native plant communities.

Remote sensing techniques offer a timely, cost-effective means to obtain reliable and sequential data for natural resource inventories (Tueller, 1979). Several researchers have shown that color-infrared (CIR) aerial photography can be used successfully to identify shrub and tree species (Sayn-Wittgenstein, 1961; Driscoll and Coleman, 1974; Heller and Ulliman, 1983; Everitt and Villarreal, 1987; Neck et al., 1987). Our objective was to evaluate CIR aerial photography with computer-aided image processing techniques for distinguishing chinaberry and quantifying its distribution in south-central and southern Texas.

MATERIALS AND METHODS

This study was conducted in three areas of Texas. Study sites were located near Austin (Travis County) in south-central Texas, near Sinton (San Patricio County) in southern Texas, and near Weslaco and Mercedes (both Hidalgo County), and Harlingen (Cameron County) in the Lower Rio Grande Valley. Aerial photographs, ground truth observations, and spectroradiometric reflectance measurements were conducted for this study. Ground truth observations were conducted to verify aerial photos, whereas reflectance measurements were made to help interpret aerial photos. Aerial photographs and reflectance measurements were obtained at different dates in the growing season to study the plants in various phenological stages.

Spectroradiometric plant canopy reflectance measurements were made in the field near Weslaco in September 1987, and June and August 1988. Reflectance measurements were made on chinaberry, hackberry (*Celtis laevigata* Willd.), and Mexican ash (*Fraxinus berlandieriana* A. DC.). Hackberry and Mexican ash are common trees that grow in association with chinaberry. Reflected radiation of seven randomly selected plant canopies of each species were measured with an Exotech Model 20 spectroradiometer at 0.05 μm increments over the 0.50 to 0.90 μm range (Leamer et al., 1973). An attempt was made to measure typically healthy plants of each species. (Trade names are included for the benefit of the reader and do not imply endorsement of, or a preference for, the product listed by the U.S. Department of Agriculture.) Measurements were made with a sensor that had a 15-degree field-of-view placed 3.0 meters above each plant canopy. Reflectance data for live oak (*Quercus virginiana* Mill.) and honey mesquite (*Prosopis glandulosa* Torr.) measured over the same spectral range and with the same instrumentation also are included here (Everitt et al., 1987). These latter data were collected in 1983 and 1984 on approximately the same dates and under similar climatic conditions as those for chinaberry and the other two species. Live oak and honey mesquite also grow in association with chinaberry.

Kodak Aerochrome CIR (0.50-0.90 μm) type 2443 film was used for all aerial photos. Photographs were taken with both Hasselblad (70 mm) and Fairchild (23 cm) cameras. Some photos were taken with two Hasselblad cameras equipped with different lenses (80 mm and 150 mm). Each Hasselblad camera had 4 by 0-2 and 3.5 by CB-1.5 filters and an aperture setting of f8 at 1/500 sec. The Fairchild camera was equipped with yellow 15 and cc 50B filters and had an aperture setting of f9.6 at 1/100 sec. Photos were taken at scales of 1:3,500, 1:6,000, 1:7,000, 1:12,000, 1:20,000, and 1:35,600. Photos were taken near Sinton on 6 and 13 August 1987, near Weslaco, Mercedes, and Harlingen on 26 August and 15 September 1987, and near Austin on 25 September 1987. Additional photos were taken near Sinton and Austin on 19 June 1988, near Sinton on 30 June, 7 July, and 9 August 1988, and near Weslaco and Mercedes on 26 May, 28 June, 20 July, and 11 August, 1988. All photos were taken between 1100 and 1530 hrs (CDT) under sunny conditions using a fixed-wing aircraft.

After viewing CIR transparencies on a light table, ground surveys were made at the various sites. Observational data were recorded relative to plant species, density, and cover, and ground photographs were taken to help interpret aerial photographs.

A CIR film transparency of chinaberry obtained near Sinton was digitized using a image processing system that consisted of a PC-AT clone computer having a Matrox MVP/AT board and Matrox processing software. The transparency was digitized off a light table using a Cohu (Model 1810) color video camera. The digitized image was subjected to a computer program for classification. The program identified areas where chinaberry occurred in the image and replaced these areas with orange pixels. The computer classified image presented here was photographed from a color monitor.

Reflectance data were studied at the 0.55, 0.65, and 0.85μm wavelengths, representing, respectively, the green light reflectance peak, the red light chlorophyll absorption band, and a wavelength on the near-infrared plateau. Data for the five plant species at each

TABLE 1. Mean canopy reflectance of chinaberry and four associated plant species on three dates for three wavelengths.

	Canopy reflectance values [1] wavelengths, μm		
Dates and plant species	0.55	0.65	0.85
June 1988			
Chinaberry	4.0 cd	1.9 b	43.2 a
Hackberry	5.8 a	2.6 a	36.2 b
Honey mesquite[2]	4.8 bc	2.5 a	28.7 cd
Live oak[2]	3.6 d	2.5 a	26.7 d
Mexican ash	5.1 ab	2.6 a	32.2 bc
August 1988			
Chinaberry	4.7 b	2.4 cd	51.3 a
Hackberry	5.6 a	3.1 a	32.7 b
Honey mesquite[2]	4.8 ab	2.8 ab	30.5 bc
Live oak[2]	3.0 c	2.0 d	26.5 c
Mexican ash	4.5 b	2.5 bc	28.9 bc
September 1987			
Chinaberry	5.4 a	3.3 a	46.2 a
Hackberry	4.0 b	2.5 b	29.6 cd
Honey mesquite[2]	4.9 a	3.4 a	27.2 d
Live oak[2]	3.1 c	1.9 b	35.6 b
Mexican ash	5.4 a	3.3 a	33.9 bc

[1] Values within columns at each date of sampling followed by the same letter do not differ significantly at the 0.05% probability level according to Duncan's multiple range test.

[2] Reflectance data for honey mesquite and live oak were obtained in June and August 1984, and September 1983, from Everitt et al. (1987).

wavelength were subjected to an analysis of variance. Duncan's multiple range test was used to test statistical significance among means at the 0.05 percent probability level (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Field spectroradiometric mean canopy reflectance values of chinaberry and four associated woody plant species at three wavelengths for three dates during the growing season are given in Table 1. Reflectance values of chinaberry at the 0.55 μm (green light reflectance peak) visible wavelength did not differ significantly ($P = 0.05$)) from those of several species on all three sampling dates. At the 0.65 μm (red light chlorophyll absorption band) visible wavelength, chinaberry had significantly lower ($P = 0.05$) reflectance than the other species in June, but in August and September its reflectance was similar to that of several species. The similar visible reflectance values among the species was attributed to their comparable foliage color; visible reflectance is primarily affected by plant pigment (Myers et al., 1983). The species varied in color from generally dark green (chinaberry and live oak) to variable paler green tones (hackberry, honey mesquite, and Mexican ash).

Chinaberry had significantly higher ($P = 0.05$) reflectance at the 0.85 μm near-infrared wavelength than the other species on all sampling dates (Table 1). Near-infrared reflectance in vegetation is highly correlated with plant density (Myers and Allen, 1968; Wiegand et al., 1974; Everitt et al., 1986). An overhead view of the five species showed that chinaberry had greater leaf density and less gaps in its canopy than the other species on all dates. Chinaberry also had a planophile (horizontal-leaf) canopy structure on all sampling dates that also contributed to its high near-infrared reflectance (Allen et al., 1975; Everitt et al., 1986). With the exception of live oak, the other species had intermediate (mixed-leaf orientation) canopy structures. Live oak generally had a planophile structure, but its canopy had more gaps than that of chinaberry. Internal leaf structure measurements were not made, but this also would contribute to the near-infrared reflectance measurements (Gausman, 1974).

Figures 1B and 1C show CIR positive prints of riparian areas near Sinton and Austin, Texas, respectively. The Sinton photograph was acquired in August 1987, whereas that near Austin was taken in September 1987. Chinaberry (arrows) has a distinct bright red image response in both photos that easily can be distinguished from other vegetation, soil, and water. Other tree species are characterized by various shades of magenta, dull red, and reddish brown, whereas dead trees have a gray tone. Herbaceous species are represented by various shades of magenta and pale brown, bare soil and rock have an olive to white tone, and water has a blue to white color. The bright red image of chinaberry was primarily attributed to its high near-infrared reflectance (Table 1).

Ground truth surveys on 11 scattered sites randomly selected from CIR photographs of riparian and other areas of mostly natural vegetation near Mercedes, Harlingen, Sinton, and Austin in August and September of 1987 and 1988 resulted in visually correct identificaiton of chinaberry on all sites. Chinaberry had a similar image response at all locations. Chinaberry could be distinguished at various photographic scales (1:3,500 to 1:35,600), but the optimum scales were 1:6,000 or 1:7,000. Dense stands of chinaberry could be distinguished on 1:20,000 and 1:35,600

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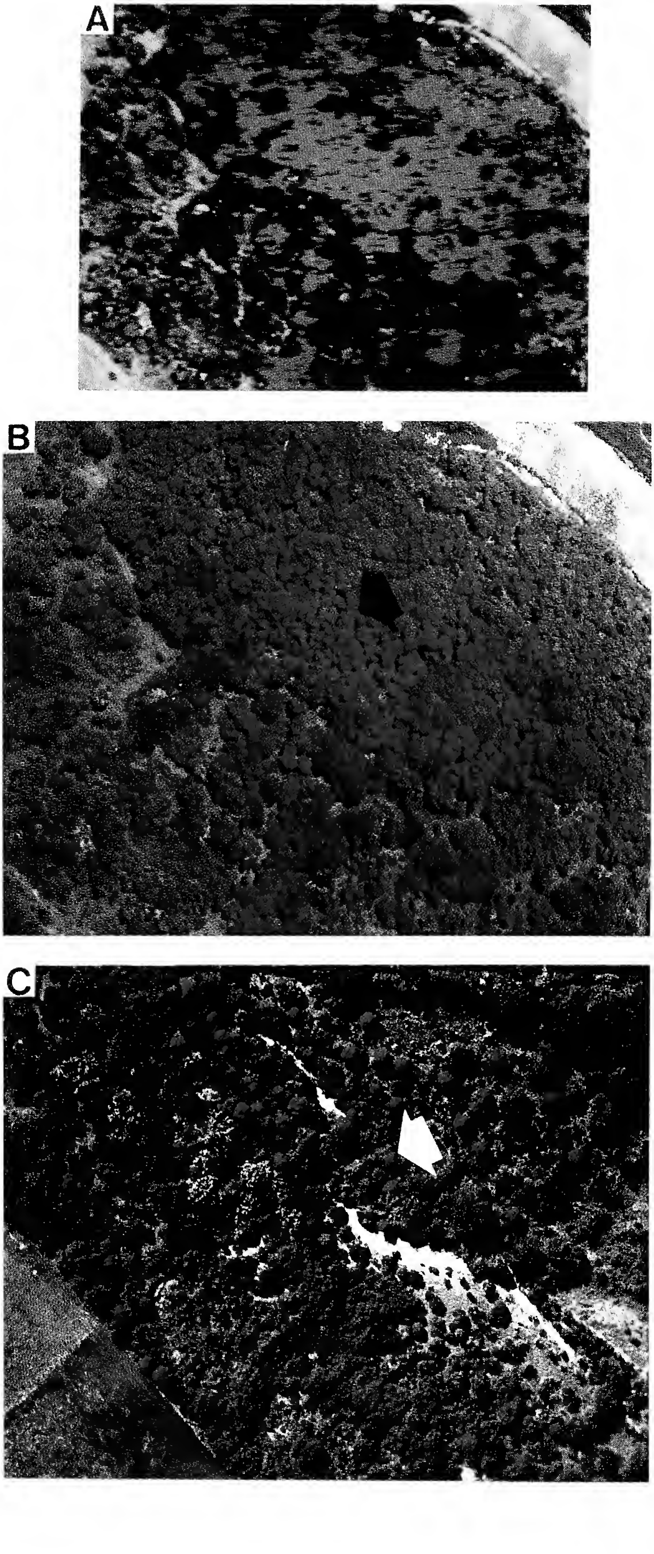
FIGURE 1. Color-infrared positive prints of riparian areas near Sinton (B) and Austin, Texas (C). Arrows on the prints point to the bright red image of chinaberry. Both prints had an original photographic scale of 1:6,000. The Sinton photograph was acquired in August 1987, whereas the Austin photograph was taken in September 1987. Print A is a computer-classified digitized image of the CIR photo obtained near Sinton (B). Areas classified as chinaberry in print A have an orange code.


A
B
C

scale photos. Photos of chinaberry in late May, June, and July near Weslaco, Mercedes, and Sinton showed that its image response was not as distinct as in those photos acquired in August and September, but it could be distinguished in most photos. Although chinaberry had significantly higher ($P = 0.05$) near-infrared reflectance than that of associated species in June, its mean reflectance value and the spread between its reflectance value and that of some of the associated species generally was not as great as in August and September (Table 1). Apparently, the optimum time to identify chinaberry on CIR aerial photos is in August and September when its canopy is in peak foliage development.

Figure 1A shows the computer classification of the digitized CIR transparency of chinaberry near Sinton (Fig. 1B). Areas classified as chinaberry in Figure 1A have a orange code. The computer classified 23 percent of Figure 1B as chinaberry. A comparison of the computer-classified transparency of chinaberry to the CIR color print showed that the computer had generally identified most areas where chinaberry occurred. Slight misclassification was noted in the center of the CIR print where some of the other tree species were identified as chinaberry by the computer. Despite some misclassification with this technique, it has considerable potential for quantifying chinaberry populations and determining their area estimates on wildland areas.

Conclusions

Results from this study showed that CIR aerial photographs can be useful tools for distinguishing chinaberry in riparian and other wildland areas of central and southern Texas. Aerial surveys of chinaberry should be made in August or September when its canopy is in peak foliage development and when it has maximum near-infrared reflectance. Computer-based image analyses of a CIR film positive transparency showed that chinaberry populations generally could be differentiated quantitatively from associated vegetation and other land-use features. The ability to use remote sensing techniques to distinguish chinaberry in wildland areas should be useful to natural resource managers who are interested in monitoring its presence and spread in these areas.

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Literature Cited

Allen, L. H., Jr., H. W. Gausman, and W. A. Allen. 1975, Solar ultraviolet radiation in terrestrial plant communities. J. Environ. Qual., 4:285-294.

Driscoll, R. S., and M. D. Coleman. 1974. Color for shrubs. Photogram. Eng., 40:451-459.

Everitt, J. H., and R. Villarreal. 1987. Detecting huisache (*Acacia farnesiana*) and Mexican palo-verde (*Parkinsonia aculeata*) by aerial photography. Weed Sci., 35:427-432.

Everitt, J. H., A. J. Richardson, and P. R. Nixon. 1986. Canopy reflectance characteristics of succulent and nonsucculent rangeland plant species. Photogram. Eng. Remote Sensing, 52:1891-1897.

Everitt, J. H., R. D. Pettit, and M. A. Alaniz. 1987. Remote sensing of broom snakeweed (*Gutierrezia sarothrae*) and spiny aster (*Aster spinosus*). Weed Sci., 35:295-302.

Gausman, H. W. 1974. Leaf reflectance of near-infrared. Photogram. Eng., 40:183-191.

Heller, R. C., and J. J. Ulliman. 1983. Forest resource assessment. Pp. 2229-2324, *in* Manual of remote sensing (R. N. Colwell, ed.), Amer. Soc. Photogrammetry, Falls Church, Virginia, vol 2.

Jones, F. B. 1975. Flora of the Texas Coastal Bend. Rob and Bessie Welder Wildlife Foundation, Sinton, Texas, 262 pp.

Leamer, R. W., V. I. Myers, and L. F. Silva. 1973. A spectroradiometer for field use. Rev. Sci. Instrum., 44:611-614.

Myers, V. I., and W. A. Allen. 1968. Electrooptical remote sensing methods as nondestructive testing and measuring techniques in agriculture. Appl. Optics, 7:1818-1838.

Myers, V. I., M. E. Bauer, H. W. Gausman, W. G. Hart, J. L. Heilman, R. B. McDonald, A. B. Park, R. A. Ryerson, T. J. Schmugge, and F. C. Westin. 1983. Remote sensing applications in agriculture. Pp. 2111-2228, *in* Manual of remote sensing (R. N. Colwell, ed.) Amer. Soc. Photogrammetry, Falls Church, Virginia, vol. 2.

Neck, R. W., S. J. Ingle, and M. R. Davis. 1987. Color-infrared aerial photography as a tool in identification and conservation of subtropical thorn woodlands in the Lower Rio Grande Valley. Proc. 11th Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences, Amer. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, pp. 102-108.

Sayn-Wittgenstein, L. 1961. Phenological aids to species identification on air photographs. Tech. Note, Canadian Dept. For. 104: 1-26.

Steel, R. G. D. and J. H. Torrie. 1980. Principles and procedures of statistics. McGraw-Hill Book Co., New York, 481 pp.

Tueller, P. T. 1979. Rangeland remote sensing interpretation problems. Proc. Remote Sensing of Natural Resources, Moscow, Idaho, pp. 450-465.

Vines, R. A. 1960. Trees, shrubs, and woody vines of the Southwest. Univ. Texas Press, Austin, 1104 pp.

Wiegand, C. L., H. W. Gausman, J. A. Cuellar, A. H. Gerbermann, and A. J. Richardson. 1974. Vegetation density deduced from ERTS-I MSS response. Pp. 93-116, in Proc. 3rd Earth Res. Tech. Satellite-1 Symp. U.S. Govt. Printing Office, Washington, D.C. (Sec. A, NASA SP-35) 1:1-976.

COULOMETRIC TITRATION OF 2-MERCAPTOPROPIONIC ACID AND 4-MERCAPTOBUTANOIC ACID WITH ELECTROGENERATED HYPOBROMITE

CINDY COOK, NICK ELBAUM, AND R. J. PALMA, SR.
Department of Chemistry, Midwestern State University, Wichita Falls, Texas 76308

ABSTRACT.—A rapid and sensitive method is described for the direct determination of sulfur compounds by coulometric titration using biamperometric end point detection. From 12 to 115 μg of 2-mercaptopropionic acid and 4-mercaptobutanoic acid were satisfactorily analysed. *Key words*: coulometric titration; sulfur compounds; biamperometric end point.

A rapid and sensitive method for determining small amounts of 2-mercaptopropionic acid and 4-mercaptobutanoic acid at high pH was desired. Coulometric titration with electrogenerated hypobromite seemed to be an attractive approach for the two acids being investigated. Coulometric titrations with electrogenerated hypobromite have been reported for other compounds (Arcand and Swift, 1956; Krivis et al., 1963; Purdy et al., 1963; Bosshart and Feldman, 1966; Gibbs and Palma, 1974).

Hypobromite is produced when bromine disproportinates in a weakly basic solution, $Br_2 + 2OH^- \rightleftharpoons BrO^- + Br^- + H_2O$. In acid solutions, hypobromite is not produced at all, and at high pH, the BrO^- disproportinates to bromate, $3\ BrO^- \rightleftharpoons 2\ Br^- + BrO_3^-$. Because bromine is volatile, it is more convenient to produce the hypobromite electrolytically from bromide ion, $Br^- + 2\ OH^- \rightleftharpoons BrO^- + H_2O + 2e^-$ $E^\circ = -0.76v$.

EXPERIMENTAL METHODS

Apparatus

A Leeds and Northrup coulometric analyser was the constant current source. The accuracy of the current was checked by measuring the voltage across precision resistors with a potentiometer. The generating anode was a circular platinum grid 3.5 centimeters in diameter and four centimeters in height. The counter electrode was platinum foil, 1.3 square centimeters, isolated in a shield tube with a fine, (4-5 μm pore diameter), sintered frit. The indicator electrodes were 14 centimeters platinum wire helices. The indicating and generating electrodes were placed on an equal potential contour (Sawyer and Robers, 1974). A 150-milliliter beaker with a plastic cap and asbestos insulation served as the titration vessel. The voltage applied across the indicator electrodes was supplied by a Sargent Model XV polarograph. The same instrument was used for automatic recording of the biamperometric indicator current at a sensitivity of 0.004 μA/mm. A 600 r.p.m. constant speed magnetic stirrer was used to reduce indicator current fluctuations. The start of the coulometer and indicator current recorder were synchronized.

Reagents

Analyte solution: Dissolve 102.9 grams of sodium bromide and 510 milligrams of sodium tetraborate decahydrate and dilute with deionized water to one liter. Adjust pH to 8.3 with

TABLE 1. Analytical results for 4-mercaptobutanoic acid, (4mb), a 2-mercaptopropionic acid (2mp).

	μg added a	μg found a	Mean error (%)	Standard deviation (%)
2-mp	12.81	12.87	0.47	0.11
	54.15	54.01	-0.28	0.04
	106.44	106.65	0.20	0.09
4-mb	15.80	15.44	-1.03	0.41
	68.30	68.61	0.45	0.18
	114.33	115.04	0.62	0.06

a = Each value is the average of at least four sets. Each set consists of eight to nine serial analysis of one sample.

perchloric acid. Catholyte solution: Dissolve 510 milligrams of sodium tetraborate decahydrate with deionized water to one liter and adjust pH to 8.3 with perchloric acid. The thiol solutions were prepared with deionized and deaerated water at 0.1M in 2-mercaptopropionic acid or 4-mercaptobutanoic acid. They were then standardized titrimetrically using both a standard iodine solution and a standard sodium hydroxide solution as titrants. These concentrated thiol solutions were diluted serially to the desired concentrations with deionized and deaerated water and then stored in amber glass bottles under a nitrogen atmosphere.

Recommended Procedure

Pretreat the generating and indicator electrodes by soaking in concentrated nitric acid, followed by a 0.1-molar ferrous sulfate rinse and a deionized water rinse, (Hargis and Boltz, 1964), and then short ciruit for 10 seconds. After the plastic sealer cap and electrodes are mounted on the cell, add 100 milliliters of the analyte solution and bubble nitrogen through the solution for 10 minutes. Continue nitrogen sweep during titration. Apply a potential of 200 mv with the polarograph and adjust the stirring rate until a small and stable indicator current is established. Use a generating current of 0.643 mA for samples containing less than 50 μg of thiol and 6.43 mA for samples containing more than 50 μg. Pretitrate the analyte solution. Add the sample from a microburet inserted through the sample port of coulometric titration cell. Start the coulometer and the recorder simultaneously and record the indicator current until a sharp curve is obtained, indicating the end point. Near the end point, the anode becomes depolarized and the diffusion current, which is now proportional to the concentration of thiol, sharply decreases. The sharp rise in current after the end point is due to the excess hypobromite generated. The recorder paper is calibrated in μeq/mm. Allow 15 to 20 seconds for the next sample to react with the excess hypobromite before continuing the generation of additional hypobromite. The total titration time is less than four minutes.

RESULTS AND DISCUSSIONS

Typical analytical results obtained are listed in Table 1. Each value is the average of at least four sets. Each set consisted of eight to nine sequential titrations of one sample.

Effect of pH.—The quantitative electrogeneration of hypobromite from basic bromide solutions at pH's higher than 7.8 has been demonstrated previously (Bosshart and Feldman, 1966). The formation of bromate in a bromide solution at pH less than 9.0 has also been demonstrated (Gibbs

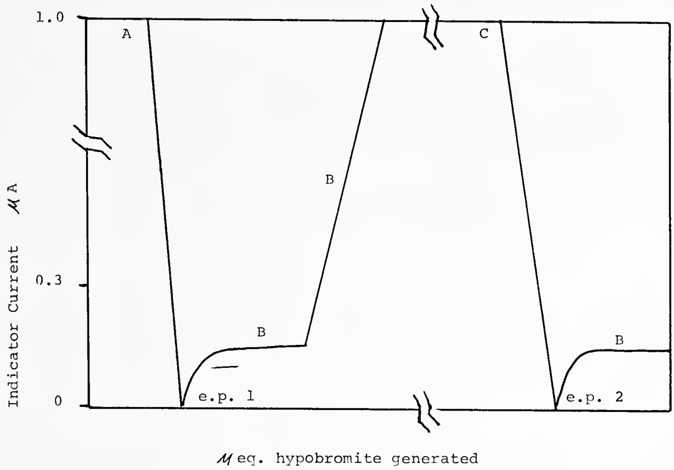

FIGURE 1. Coulometric titration of 68.30 µg of 4-mercaptoacetic acid indicating current 0.004 µA/mm. A—first sample added; B—excess hypobromite; C—second sample added.

and Palma, 1974). It has been shown that the positive error found in volumetric hypobromite titrations was due to the presence of bromate and temperature (Forkas et al., 1949). The effect of pH on the determination of 2-mercaptopropionic acid and 4-mercaptobutanoic acid was checked at various pH values from 8.0 to 9.4. A severe rounding of the end point, which required extrapolation, was noted in all trials of pH values greater than 8.8. This might be due to slower kinetics and some bromate formation. A pH of 8.3 was found to give the best results for both acids.

Effect of excess hypobromite—Preliminary studies indicated that the amount of hypobromite initially generated before adding the mercapto-acid sample was proportional to the positive error found. Generation of hypobromite past the end point at an indicator current that corresponded to less than five percent of the total required for the next sample rendered this cause of error negligible. The best results were obtained when the acid is titrated in a set of four to 13 samples in series. The first and second aliquots titrated always showed high positive errors. After 13 samples had been titrated, the electrodes became contaminated and had to be pretreated again. The use of large platinum helix indicator electrodes, high stirring speeds, and a sensitivity of 0.004 µA/mm with the polarograph resulted in end point detection graphs that required no extrapolation of the equivalence point. The pen of the recorder is nearly off scale during most of the titration. The end point is indicated by a sharp V shape with traverses the entire width of the chart (Fig 1). The samples are titrated sequentially and the amount of titrant generated for each sample is measured from one end point to the next, so there is no need to account for the excess hypobromite generated, pretitrate or use a blank. therefore, seven to eight different samples can be titrated easily in 30 minutes.

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LITERATURE CITED

Arcand, G. M., and E. H. Swift. 1956. Coulometric titration of ammonia with hypobromite. Anal. Chem., 28:440-446.

Bosshart, R. E., and F. Feldman. 1966. Direct coulometric titration of hydrogen peroxide with electrogenerated hypobromite. Anal. Chem., 38:1400-1403.

Forkas, L., M. Levin, and R. J. Block. 1949. The reaction between hypochlorite and bromides. J. Amer. Chem. Soc., 7:1988-1991.

Gibbs, R. A., and R. J. Palma, Sr. 1974. Coulometric titration of free cyanide with electrogenerated hypobromite. Anal. Letters., 7:167-172.

Hargis, L., and D. F. Boltz. 1964. Titration of anthranilic acid with electrogenerated bromine. Talanta, 11:47-62.

Krivis, A. F., G. R. Supp, and E. S. Gazda. 1963. Direct coulometric titrations with hypobromite ion. Anal. Chem., 35:2216.

Purdy, W. C., G. D. Christian, and E. C. Knoblock. 1963. Coulometric titration of ammonia with hypobromite using a direct amperometric end point detection. Anal. Chem., 35:2217-2219.

Sawyer, D. S., and J. L. Roberts, Jr. 1974. Exper. Electrochemistry for chemists, John Wiley and Sons, New York, 424 pp.

Present addresses: Cook, Department of Chemistry, University of Indiana, Bloomington, Indiana; Elbaum, Department of Chemistry, Texas A&M University, College Station.

MAMMALIAN FOSSILS FROM BENEATH THE PATTERSON RANCH PEARLETTE VOLCANIC ASH IN THE SEYMOUR FORMATION, KNOX COUNTY, TEXAS

Donna R. Griffin

Department of Biology, Midwestern State University, Wichita Falls, Texas 76308

Abstract.—The Patterson Ranch local fauna was recovered from the Seymour Formation of Knox County, Texas, beneath a bed of Pearlette Type O volcanic ash that is stratigraphically lower than the Pearlette Type O volcanic ash beneath which the Vera faunule is found. Eleven taxa of mammals have been identified: ?*Sorex, Cryptotis parva, Spermophilus* cf. *franklinii, Geomys* sp., *Perognathus* sp., *Onychomys pedroensis, Reithrodontomys moorei, Peromyscus* sp., *Microtus llanensis, Ondatra annectens*, and *Felis* sp. The mammalian fauna of the Patterson Ranch is perhaps slightly older than that of the Vera faunule. *Key words*: Pearlette volcanic ash; Seymour Formation; Pleistocene mammals.

In the middle of the Pleistocene Epoch, volcanic activity discharged the Type O Pearlette volcanic ash. The ash settled as dust over the landscape of the Great Plains from Nebraska, through Kansas and Oklahoma, to northern Texas. Rains washed the ash into ponds and lakes where it floated until waterlogged, than sank to form a thick bottom mud. The beds of compacted ash, virtually insoluble to ground water and rain, protected the lake bottom sediments beneath them, preserving fossilized bones and shells that had come to rest before the ash had fallen. The ash beds often form flat tops of hills and vertical cliffs as more easily eroded materials adjacent to them are removed.

C. W. Hibbard (1944) noted the significance of the Pearlette ash in Meade County, Kansas, and gave the name Cudahy local fauna to the assemblage of small mammals found beneath the ash there. Confusion followed in attempting to correlate fossil faunas from beneath other ash beds in the Great Plains region. Not until the 1970s was it shown that there were several Pearlette ash events, some as early as two million years ago, of which the Type O ash was only one (Izette et al., 1971; Naesser et al., 1971; Boellstorff, 1972). The Type O ash is significant because it is widespread and often covers fossiliferous clays. It has been dated at 600,000 years before present. The Type O ash is a time-marker wherever found. All fossils occurring in the sediments immediately beneath the Pearlette Type O ash beds supposedly are contemporary.

Hibbard and Dalquest (1966) discovered beds of Pearlette Type O ash in the valley of the South Fork of the Big Wichita River in Knox County, Texas. Vertebrates found in the brown clay immediately beneath the ash beds were included in the Vera local faunule, named after the nearby town of Vera. Large mammals found in the sands and gravels beneath these brown clay deposits were included in the Gilliland local fauna. Dalquest and Carpenter (1989) discovered an aggregation of small

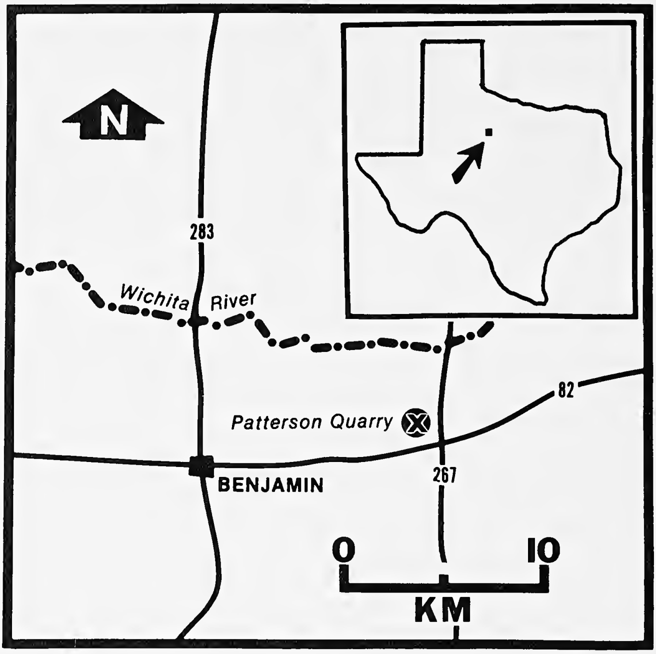

FIGURE 1.—Map showing the area of the Seymour Formation, Knox County, Texas; location of the Patterson Ranch quarry is indicated by X. Inset shows the map locality in relation to Texas.

mammalian fossils in the part of the sands and gravels of the Seymour Formation that had furnished large mammals of the Gilliland local fauna, and termed the site the Burnett Quarry. This quarry is only a kilometer from a major collecting locality and ash bed where the Vera faunule was obtained, but it is lower in the section and, therefore, older. The mammalian microfauna from the Burnett Quarry resembles, but is different from, that of the Vera faunule.

In the course of field work in the Seymour Formation, Dalquest and Carpenter came upon a bed of Pearlette Type O volcanic ash at a relatively low elevation. The bottom of the ash in the Seymour Formation typically lies approximately five meters above the Permian bedrock. At the new site (Fig. 1), which is no more than four kilometers from both Burnett Quarry and the type locality of the Seymour Formation, where the Vera faunule was collected, the ash is only two meters above Permian sediments (Fig. 2). The materials between the fossiliferous gray clay and the Permian red beds are sand and gravel. No compaction has occurred and there is no evidence that the ash has been "let down" by erosion. The ash bed seems to lie at the level at which it was deposited more than half a million years ago.

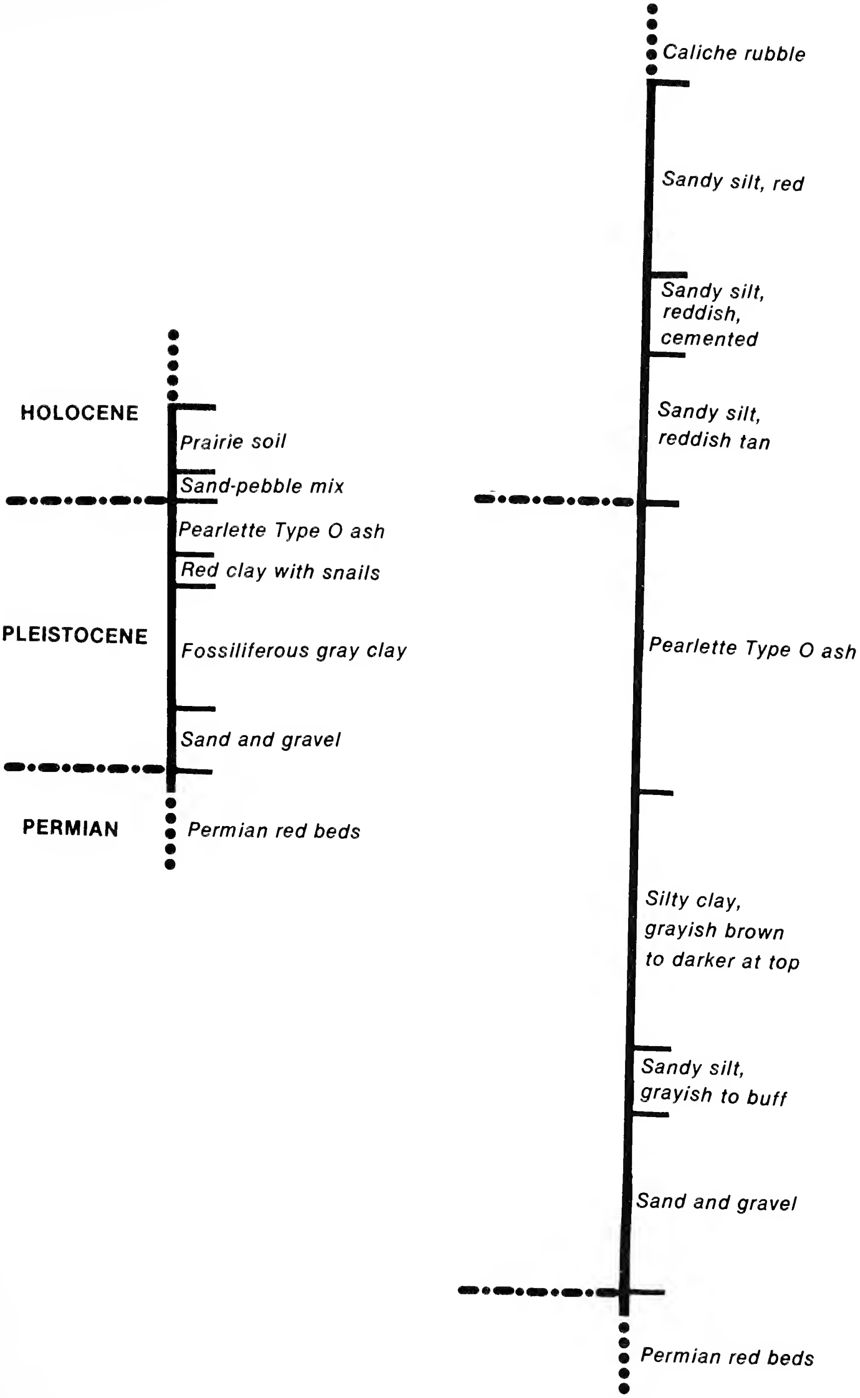

FIGURE 2.—Stratigraphic sections of the Patterson Ranch site and the Vera faunule site.

Because the ash is stratigraphically beneath the level of the higher "normal" ash beds, its position must be explained. Faulting may be rejected; the Permian beds are extensive and almost free of any but minor faults, and there is no discernible evidence of faulting at the site of the ash bed.

More probable explanations are: 1) the Patterson ash bed is synchronous with normal ash beds, but settled in a pond or lake that lay at a lower elevation than the normal beds, or 2) the Patterson ash bed is slightly older than the normal beds and the three-meter difference in thickness represents actual time.

The Seymour Formation, where the two sites are located, was named by Cummins (1893) and consists mainly of stream and lake sediments. The area was mapped by Gordon (1913), and Stricklin (1961) described the geology. The vertebrate paleontology and geology of the Seymour deposits along the South Fork of the Big Wichita River were summarized by Hibbard and Dalquest (1966).

Methods and Materials

Approximately two tons of gray fossiliferous clay were dug from the wall of the ravine and screen washed. The concentrate, consisting of shells, pebbles, and fossils, was sifted through quarter-inch screen to remove larger pebbles, and sorted under a 10X jeweler's lens. Mammalian specimens recovered were compared to modern and fossil specimens in the Midwestern State University collections. Measurements, given in millimeters, were made with an ocular micrometer accurate to 0.01 mm.

Species Accounts

Cryptotis parva.—A specimen (MWSU 12440) consists of a right mandibular fragment bearing m1-m3, the alveolus of p4, and a portion of an incisor. The ramus contains two mental foramen, one under the anterior and one under the posterior roots of m1. The alveolar length of p4-m3 is 3.69 mm. The greatest length of m1-m3 is 3.25 mm. The fossil jaw compared closely to that of modern *Cryptotis parva* from Wichita County, Texas. The alveolar length of p4-m3 of the modern form is 3.69 mm, and the greatest length of m1-m3 is 3.19 mm. The least shrew still inhabits grasslands in the general area where the Patterson Ranch is located (Hall, 1981).

?*Sorex.*—A fragmentary left ramus bearing m1-m2 and the alveolus of m3 was recovered (MWSU 12442). the alveolar length of m1-m3 is 3.25 mm. The greatest length of m1-m2 is 2.69 mm. This specimen cannot be identified to genus due to the lack of definitive characters such as mandibular condyles and p4. The horizontal ramus is of almost uniform depth throughout the fragment. Today, *Sorex* occurs no closer to the Patterson Ranch site than north-central New Mexico (Hall, 1981).

?Sciuridae, unidentified tooth.—A single greatly worn tooth (MWSU 12468) was recovered from the Patterson Ranch that measures 1.63 mm

TABLE 1.—Measurements (mm) of molars and incisors of *Geomys* sp.

Molars				Incisors (width)
Upper		Lower		
Length	Width	Length	Width	
1.00	1.94	1.13	2.06	1.88
1.06	1.94	1.06	1.75	2.31
1.06	2.00	0.94	1.81	2.56
0.94	1.81	0.94	1.56	2.25
0.94	1.88	1.69	1.94	2.00
1.13	2.06			1.75
1.00	1.44			2.44
1.13	2.13			2.31
1.06	1.94			2.00
0.94	1.69			
1.69	1.75			

in length, 1.50 in width, and the crown height is 1.19. There are two rounded roots of equal size and length. The tooth was compared to those of several types of modern squirrels. The p4's of most sciurids examined have rounded anterior roots but broad, flattened posterior roots. However, some sciurid p4's do possess two rounded roots of equal size, and the tooth is probably a p4; it is not sufficient for generic determination.

Spermophilus cf. *franklinii.*—Two upper and two lower first or second molars and an upper fourth premolar were found that are similar in size to those of *Spermophilus franklinii.* The upper molars (MWSU 12443) both measure 2.31 mm in length and 2.88 in width. The lower molars (MWSU 12444) measure 2.19 and 2.31 mm in length, and 2.75 and 2.88 mm in width, respectively. Both the length and the width of the p4 are 2.00 mm. Today, the southernmost distribution of *S. franklinii* is in southern Kansas (Hall, 1981).

Geomys sp.—One p4 (MWSU 12446), five lower molars (MWSU 12447), 11 upper molars (MWSU 12448), nine incisors (MWSU 12450), and several tooth fragments were recovered. The length of the p4 is 1.94 mm, the width of the anterior loph is 1.56 and the posterior loph width is 1.75. The measurements of the molars and incisors are given in Table 1.

The fossil gopher teeth were compared with those of males and females of modern *Geomys bursarius* and also to those of *G. tobinensis. Geomyus tobinensis* is the gopher commonly found in Cudahy type faunas. The Patterson Ranch p4 and molars are slightly larger than those of *G. tobinensis* (Dalquest and Carpenter, 1989), but size is not a good basis for species determination because size of the teeth in pocket gophers is variable and there is strong sexual dimorphism. The Patterson Ranch p4 does not have a continuous anterior enamel border. It has parallel-

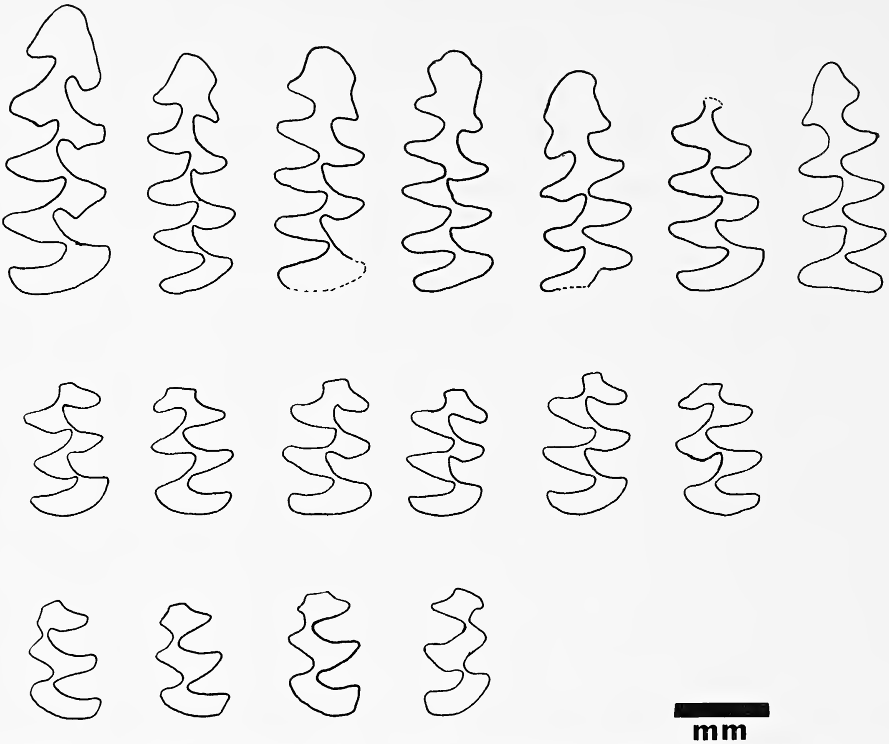

Figure 3.—Occlusal enamel pattern variations in *Microtus llanensis* lower molars. First row, lower first molars (m1); second row, lower second molars (m2); and third row, lower third molars (m3).

sided re-entrant angles with the typical "U" shaped valleys of *Geomys*, and the general shape corresponds to that of *Geomys*. Finally, the molars of the Patterson Ranch fossil specimen are elliptical in shape. The Patterson Ranch p4 nearly matches a male *G. bursarius* in length, but the width is considerably less than in the modern gopher.

Perognathus sp.—A single p4 (MWSU 12445) measuring 1.38 by 1.38 mm was found at the Patterson Ranch. It corresponds in size to the teeth of living *Perognathus hispidus*, which inhabit the area today (Hall, 1981).

Peromyscus sp.—A greatly worn m1 (MWSU 12449) of a large *Peromyscus* was recovered; the length is 2.00 mm and the width is 1.25. *Peromyscus cragini*, the common deer mouse of Cudahy-type faunas, is a much smaller mouse than the Patterson Ranch *Peromyscus*. Unfortunately, the m1 is too worn to show important details, and identification to species thus cannot be made with certainty.

Reithrodontomys moorei.—A left jaw fragment containing the lightly worn m1 (MWSU 12452) was recovered from the Patterson Ranch. The length of the tooth is 1.38 mm and the width is 0.84. The fossil compares

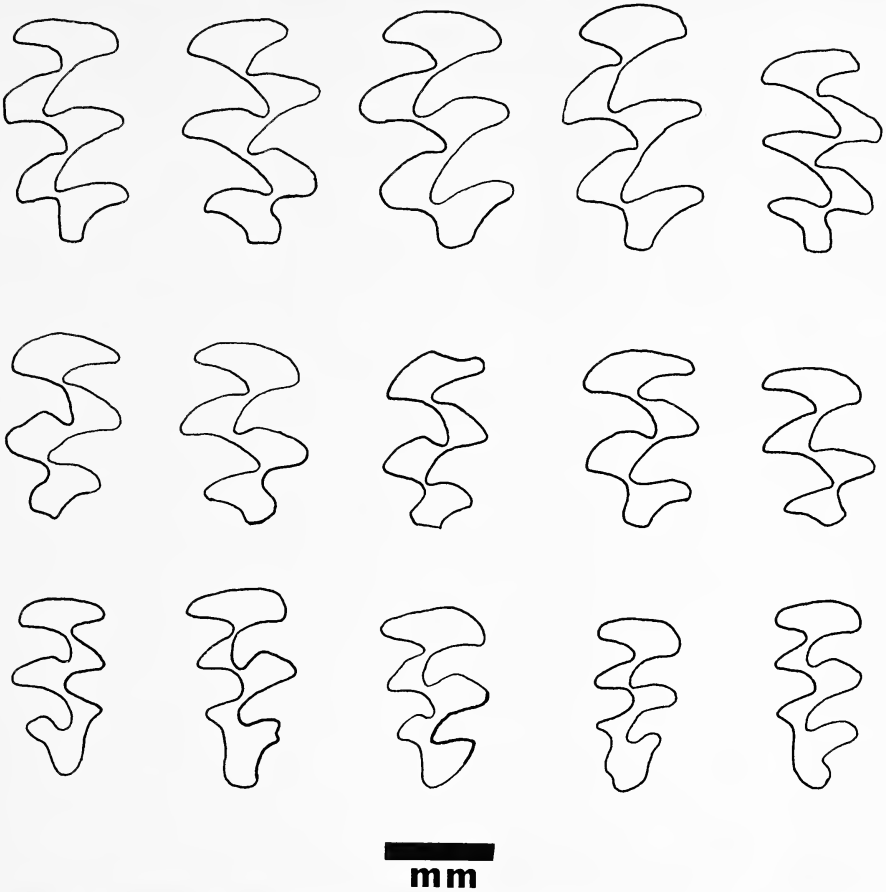

FIGURE 4.—Occlusal enamel pattern variations of *Microtus llanensis* upper molars. First row, upper first molars (m1); second row, upper second molars (m2); and third row, upper third molars (m3).

in characteristics and size (Paulson, 1961) with *Reithrodontomys moorei*, the most common harvest mouse found in Cudahy-type faunas.

Onychomys pedroensis.—This species is represented by an isolated left m1 (MWSU 12454) measuring 1.94 by 1.19 mm, and by two isolated left m2's (MWSU 12453) measuring 1.94 by 1.44 and 1.81 by 1.50 mm. The fossil teeth were compared to those of modern *Onychomys leucogaster* and found to be larger in size. The length and width of the m1 falls within the range given by Carleton and Eshelman (1979) for *O. pedroensis*, but both the width and the length of the Patterson Ranch fossil m2's exceed all measurements listed by those authors.

Microtus llanensis.—*Microtus llanensis* was the most common mammalian fossil found at the Patterson Ranch. Seven isolated m1's (MWSU 12455), and several m2's (MWSU 12456), m3's (MWSU 12460), m1's

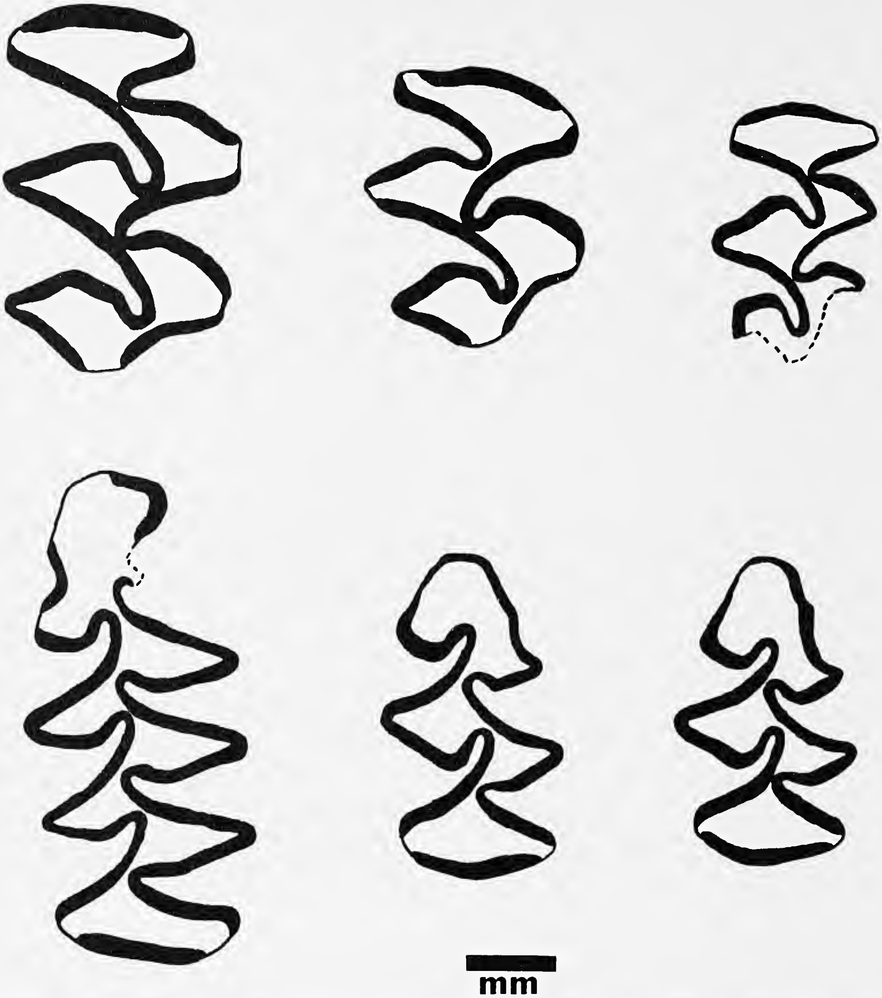

FIGURE 5.—Occlusal enamel patterns of *Ondatra annectens*. First row: upper first molar (m1), upper second molar (m2), and upper third molar (m3). Second row: lower first molar (m1), lower second molar (m2), and lower second molar (m2).

(MWSU 12458), m2's (MWSU 12459), m3's (MWSU 12460), and numerous incomplete teeth (MWSU 12461) were recovered.

The largest m1 of the seven measures 3.25 by 1.38 mm. The m1's (Fig. 3, first row) consist of a posterior loop, three alternating closed triangles, and a confluent fourth and fifth triangles that open widely into the anterior loop. The m2's (Fig. 3, second row) have a posterior loop followed by four alternating triangles. The first and second triangles are tightly closed and the fourth and fifth are confluent. There are three salient angles on both the labial and lingual sides. The m3's (Fig. 3, third row) consist of a posterior loop and three triangles. The first and second

TABLE 2. Measurements (mm) of teeth of *Ondatra annectens*.

Tooth	Length	Width
Rm1 (MWSU 12464)	4.38	3.00
Rm2 (MWSU 12465)	3.25	2.69
Rm3 (MWSU 12466)	Broken	
Lm1 (MWSU 12462)	5.75	2.56
Lm2 (MWSU 12463)	3.75	2.25
Lm3 (MWSU 12463)	3.56	2.13

triangles are confluent. The m1's (Fig. 4, first row) have an anterior loop and four tightly closed alternating triangles. The m2's (Fig. 4, second row) have an anterior loop and three alternating tightly closed triangles. There are two salient angles on the lingual side and three on the labial side. The m3's (Fig. 4, third row) are characterized by a hooked posterior loop followed by three alternating triangles and an anterior loop.

Ondatra annectens.—Six isolated teeth of a small muskrat were recovered from the Patterson Ranch (Fig. 5). Measurements are listed in Table 2. The teeth have two well-developed roots. The m1 falls within the length-width range of the scatter plot given by Nelson and Semken (1970). The m3, m1, and m2 measurements are slightly larger than those given by Eshelman and Hager (1984).

Felis sp.—A second proximal phalanx (MWSU 12467) of a cat was recovered from the Patterson Ranch. The greatest length is 27.1 mm, distal breadth is 7.9, mid-shaft breadth is 6.1, and proximal breadth is 10.1. The fossil was larger than *Felix rufus* but smaller than a female *F. concolor*.

DISCUSSION AND CONCLUSIONS

The Vera faunule and the Patterson Ranch fauna are similar, but differences can be noted (Table 3). Four taxa (*Cryptotis parva, Perognathus* sp., *Microtus llanensis*, and *Ondatra annectens*) are common to both sites. Two genera found in the Vera faunule are absent from the Patterson Ranch local fauna (*Blarina* and *Scalopus*). Two genera (*Reithrodontomys* and *Peromyscus*) occur in the Patterson Ranch local fauna but not the Vera faunule.

The ?*Sorex* from the Patterson Ranch could be *Sorex cinereus* or a closely related species such as *S. haydeni*. The ground squirrels obtained from both sites are similar and may be the same species. Hibbard and Dalquest (1966) noted that their *Spermophilus* was approximately the same size as *Spermophilus franklinii*. *Geomys* from the two sites are quite different. The Patterson Ranch gopher is larger and has the typical characteristics of a *Geomys* p4. *Geomys tobinensis* is a smaller species in which the p4 resembles that of a *Thomomys*. *Onychomys* from the two sites are different; the Vera *Onychomys* is small, the Patterson Ranch *O.*

TABLE 3.—Comparisons of the small mammalian fossils of the Vera faunule and the Patterson Ranch local fauna.

Faunal list	Vera faunule	Patterson Ranch local fauna
?*Sorex*		X
Sorex cinereus	X	
Cryptotis parva	X	X
Blarina cf. *brevicauda*	X	
Scalopus sp.	X	
Spermophilus sp.	X	
Spermophilus cf. *franklinii*		X
Geomys sp.		X
Geomys tobinensis	X	
Perognathus sp.	X	X
Onychomys sp.	X	
Onychomys pedroensis		X
Reithrodontomys moorei		X
Peromyscus sp.		X
Microtus llanensis	X	X
Microtus paroperarius	X	
Ondatra sp., large	X	
Ondatra annectens	X	X

pedroensis considerably larger. *Ondatra annectens* occurs at both sites, but the Vera faunule also has a larger species.

Most of the species unique to each site are represented by few specimens and may reflect sampling error. The Patterson Ranch local fauna is of an age similar to that of the Vera faunule but may be slightly older, the ash representing an earlier phase of the same ash fall.

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LITERATURE CITED

Boellstorff, J. D. 1972. Fission tract ages of shards from some mid-continent Pleistocene volcanic ash deposits. Geol. Soc. Amer., Abstr. with Programs, 4:274.

Carleton, M. D., and R. E. Eshelman. 1979. A synopsis of fossil grasshopper mice, genus *Onychomys*, and their relationships to Recent species. Univ. Michigan Papers, Paleontol., 21:1-63.

Cummins, W. F. 1893. Notes on the geology of northwest Texas. Geol. Surv. Texas, Fourth Annual Report (1892):179-238.

Dalquest, W. W., and R. M. Carpenter. 1989. Early Pleistocene (Irvingtonian) mammals from the Seymour Formation, Knox and Baylor counties, Texas exclusive of Camelidae. Occas. Papers Mus., Texas Tech Univ., 124:1-28.

Eshelman, R., and M. Hager. 1984. Two Irvingtonian (medial Pleistocene) vertebrate faunas from north-central Kansas. Spec. Publ. Carnegie Mus. Nat. Hist., 8:384-404.

Gordon, C. H. 1913. Geology and underground waters of the Wichita region, north-central Texas. U.S. Geol. Surv., Water Supply Pap., 317:1-88.

Hall, E. R. 1981. The mammals of North America. John Wiley and Sons, New York, 2nd ed., 1:xv + 1-600 + *90* and 2:vi + 601-1181 + *90*.

Hibbard, C. W. 1944. Stratigraphy and vertebrate paleontology of Pleistocene deposits of southwestern Kansas. Bull. Geol. Soc. Amer., 55:707-754.

Hibbard, C. W., and W. W. Dalquest. 1966. Fossils from the Seymour Formation of Knox and Baylor counties, Texas, and their bearings on the late Kansan climate of that region. Contrib. Mus. Paleo., Univ. Michigan, 21:1-66.

Izette, G. A., R. W. Wilcox, J. D. Obradovich, and R. L. Reynolds. 1971. Evidence for two Pearlette-like ash beds in Nebraska and adjoining areas. Geol. Soc. Amer., Abstr. with Programs., 3:657.

Naesser, C. W., G. A. Izette, and R. E. Wilcox. 1971. Zircon fission-tract ages of Pearlette-like volcanic ash beds in the Great Plains. Geol. Soc. Amer., Abstr. with Programs, 3:657.

Nelson, R. S., and H. A. Semken. 1970. Paleoecological and stratigraphic significance of the muskrat in Pleistocene deposits. Bull. Geol. Soc. Amer., 81:3733-3738.

Paulson, G. R. 1961. The mammals of the Cudahy fauna. Papers Michigan Acad. Sci., Arts, Letters, 46:127-153.

Stricklin, F. L., Jr. 1961 Degradational stream deposits of the Brazos River, central Texas. Bull. Geol. Soc. Amer., 72:19-35.

AN ILLUSTRATIVE EXAMPLE OF SHRINKAGE ESTIMATOR MODELS

DOVALEE DORSETT AND PATRICK L. ODELL
Baylor University, Waco, Texas 76798

ABSTRACT.—The efficiency of the James-Stein shrinkage estimator is compared with several optimally combined estimators and three ad hoc estimators. The estimators are vector valued estimators of a non-random vector parameter. The criterion of scalar mean squared error and matrix mean squared error are discussed: *Key words*: mean-squared error; multivariate estimator; James-Stein shrinkage estimators; combined estimators.

This paper was motivated by the discussion of the James-Stein estimator in the latest edition of T. W. Anderson's classic text in multivariate statistical analysis, (Anderson 1984). Three items in this discussion stimulated our curosity: the first was the statement, "However, Stein (James and Stein, 1961) showed the startling fact that this conventional estimator (the arithmetic vector mean, $\bar{X}$) is not admissible with respect to the loss function that is the sum of mean squared errors of the components when $\Sigma = I$ (the covariance matrix Σ is the identity matrix I) and $p \geq 3$ (the size of the vector)."

We failed to find this "startling" for we are well aware of the fact that if one changes the criteria of excellence (the payoff), then the optimal strategy may change. In fact, we would be startled if it failed to change!

The second item, was the results reported in a table extracted from Efron and Morris (1977) and displayed to clarify the gains observed when using the James-Stein estimator in place of the vector sample mean when $p = 10$ and $\Sigma = \sigma^2 I$.

We will have more to discuss about this example later but will note that it appears from the table that one must be able to guess substantially better than one estimates. The James-Stein estimator depends on an original guess.

The third item is that the shrinkage estimator (the James-Stein estimator) is an extension of a general theory of linearly combining two vector estimators judiciously to form a third vector estimator that is better in the sense of minimizing the sum of mean squared errors.

Motivated by the example in Table 3.2 in Anderson, we consider several alternative definitions for the combined estimator and compute their respective sum of mean squared errors. The enlarged example and discussion hopefully gives a clearer and deeper insight into the important general topic of optimally combining information. The shrinkage estimation theory can play an important and fundamental role in a further development of this topic.

TABLE 1. Various estimator modesl; $\hat{\theta} = A_1\hat{\theta}_1 + A_2\hat{\theta}_2$.

Type	Restrictions
General	A_1 and A_2 are not restricted
Diagonal	$A_1 = D_1$ and $A_2 = D_2$ are diagonal
Convex	$A_2 = I - A_1$ and A_1 is not restricted
Scalar	$A_1 = a_1I$ and $A_2 = a_2I$; a_1 and a_2 are any scalar
Scalar Convex	$A_2 = I - A_1$ and $A_1 = a_1I$

DEFINITIONS AND NOTATION

Let $\hat{\theta}_1$, $\hat{\theta}_2$, $\hat{\theta}$ be three p × 1 vector estimators for the p × 1 parameter vector $\hat{\theta}$. If A_1 and A_2 are p × p matrices, then

$$\hat{\theta} = A_1\hat{\theta}_1 + A_2\hat{\theta}_2 \tag{1}$$

is the general linear combined estimator model for θ. If one wishes to maximize a criterion of excellence or minimize a risk (or cost), then the task is to select the matrices A_1 and A_2 so that the criterion is optimal. Stein chose the sum of mean squared error as his criterion, hence we do the same. That is, the payoff

$$m = E\,[(\hat{\theta} - \theta)^T (\hat{\theta} - \theta)] \tag{2}$$

is the scalar defined by sum of mean squared errors, and our task is to select A_1 and A_2 so that m is minimal. The symbol E (·) denotes the expectation of (·). In Table 1, several types of estimator models are defined symbolically. Also, various further conditions can be imposed on $\hat{\theta}_1$ and $\hat{\theta}_2$. These are:

(i) $\hat{\theta}_1$ and $\hat{\theta}_2$ are random variables;
(ii) $\hat{\theta}_1$ and $\hat{\theta}_2$ are unbiased estimators for $\hat{\theta}$;
(iii) $\hat{\theta}_1$ is a random variable and $\hat{\theta}_2 = \theta_2$ is not random (fixed);
(iv) $\hat{\theta}_1$ is an unbiased estimator and $\hat{\theta}_2 = \theta_2$ is not random.

The development of a theory for combining estimators for the matrix valued criterion, matrix mean squared error,

$$m = E\,[(\hat{\theta} - \theta)(\hat{\theta} - \theta)^T], \tag{3}$$

is developed elsewhere; (Lewis and Odell, 1971; Baksalary and Kala, 1983; Odell et al., 1988). Because m = trace (M) and we are primarily interested in shrinkage estimators, we consider only m as defined by (2) our criteron of cost.

Additional notation is defined and collected in Table 2 for ease of reference. Note that:

TABLE 2. Notation and symbols.

Symbol	Parameter
$M = E\,[\hat{\theta} - \theta)\,(\hat{\theta} - \theta)^{T}]$	Matrix mean squared error of θ
$m = E\,[\hat{\theta} - \theta)^{T}\,(\hat{\theta} - \theta)]$	Sum of scalar mean squared error (m.s.e.)
$m_{11} - E\,[\hat{\theta}_1 - \theta)^{T}\,(\hat{\theta}_1 - \theta)]$	Sum of scalar m.s.e. for $\hat{\theta}_1$
$m_{22} = E\,[\hat{\theta}_2 - \theta)^{T}\,(\hat{\theta}_2 - \theta)]$	Sum of scalar m.s.e. for $\hat{\theta}_2$
$m_{12} = E\,[\hat{\theta}_1 - \theta)^{T}\,(\hat{\theta}_2 - \theta)] = m_{21}$	Sum of cross squared errors for $\hat{\theta}_1$ and $\hat{\theta}_2$
$b_1 = E\,(\hat{\theta}_1 - \theta)$	Bias of $\hat{\theta}_1$
$B_2 = E\,(\hat{\theta}_2 - \theta)$	Bias of $\hat{\theta}_2$

(i) If $\hat{\theta}_2 = \theta_2$, a constant vector, then $B_2 = \theta_2 - \theta$, $m_{22} = B_2^{T}B_2$, $m_{12} = B_1^{T}B_2$;

(ii) if $\hat{\theta}_1$ and $\hat{\theta}_2$ are independent, than $m_{12} = B_1^{T}B_2$;

(iii) if $\hat{\theta}_1$ and $\hat{\theta}_2$ are unbiased estimator for $\hat{\theta}$ and independent, then $m_{12} = 0$, $B_1 = B_2 = \Phi$ and if $\hat{\theta}$ is convex, then $\hat{\theta}$ is an unbiased estimator for θ.

A FUNDAMENTAL RESULT

We will consider only the scalar model here, that is (1) becomes

$$\hat{\theta} = a_1\hat{\theta}_1 + a_2\hat{\theta}_2 \tag{4}$$

and we wish to select the scalars a_1 and a_a so that m is minimal. If one substitutes the right side of (4) into (2), then m in matrix notation is as follows:

$$m = [a_1, a_2]\begin{bmatrix} m_{11} + \theta^{T}\theta + B_1^{T}\theta + \theta^{T}B_1 & m_{12} + \theta\theta^{T} + B_1^{T}\theta + \theta^{T}B_2 \\ m_{21} + \theta\theta^{T} + B_2^{T}\theta + \theta^{T}B_1 & m_{22} + \theta\theta^{T} + B_2^{T}\theta + \theta^{T}B_2 \end{bmatrix}\begin{bmatrix} a_1 \\ a_2 \end{bmatrix} -$$

$$[a_1, a_2]\begin{bmatrix} \theta^{T}\theta + B_1^{T}\theta \\ \theta^{T}\theta + B_2^{T}\theta \end{bmatrix} - [\theta^{T}\theta + \theta^{T}B_1, \theta^{T}\theta + \theta^{T}B_2]\begin{bmatrix} a_1 \\ a_2 \end{bmatrix} + \theta^{T}\theta.$$

The value of a_1 and a_2, which gives the minimal value of $m = m_0$, is the solution to the following equations

$$\begin{bmatrix} m_{11} + \theta^{T}\theta + B_1^{T}\theta + \theta^{T}B_1 & m_{12} + \theta^{T}\theta + B_1^{T}\theta_2 + \theta_1^{T}B_2 \\ m_{21} + \theta^{T}\theta + B_2^{T}\theta + \theta^{T}B_1 & m_{22} + \theta^{T}\theta + B_2^{T}\theta + \theta^{T}B_2 \end{bmatrix}\begin{bmatrix} a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} \theta^{T}\theta + B_1^{T}\theta \\ \theta^{T}\theta + B_2^{T}\theta \end{bmatrix}.$$

We denote the 2×2 matrix by the symbol F in the equation. It is easy to compute the inverse of F and solve for a_1 and a_2, analytically. A Cramer's rule form of the solution can be instructive. The resulting minimal scalar sum of mean squared errors is

$$m_0 = \theta^T\theta - (\theta^T\theta + B_1^T, \theta^T\theta + B_2^T\theta)\,[F]^{-1}\begin{bmatrix} \theta^T\theta + B_1^T\theta \\ \theta^T\theta + B_2^T\theta \end{bmatrix},$$

where F again denotes the matrix on the far left side of the previous matrix equation.

Table 3 gives results and formulae that follow when various restrictions are imposed on the model.

SOME SPECIAL RESULTS FOR THE SCALAR CONVEX ESTIMATOR MODEL

Consider the convex combined estimator when $\hat{\theta}_1$ is unbiased and $\hat{\theta}_2 = \theta_2$, a nonrandom value given by an expert. Then (see Table 3) $a_1 = m_{22}/(m_{11} + m_{22})$ and $a_2 = 1 - a_1$ are the optimal weights that result in a sum of m.s.e.'s of

$$m_0 = m_{11}m_{22}/\ (m_{11} + m_{22}).$$

This in turn implies

$$m_0 \leq \min\,[m_{11}, m_{22}].$$

Note that one need not be an expert to improve $\hat{\theta}_1$ as an estimator, but guess in such a way that

$$m_{22} < m_{11},$$

for then $m_0 < m_{11}$ for all a_1 when

$$2\,[m_{22}/\ (m_{11} + m_{22})] - 1 \leq a_1 \leq 1.$$

If $m_{22} < m_{11}$, the lower limit of the inequality is less than 0, or $m_0 \leq m_{11}$, for all a_1 in the interval

$$0 \leq a_1 \leq 1.$$

Figures 1A and 1B can help clarify this argument.

TABLE 3. The properties of the minimal scalar mean squared error estimator models; $\hat{\theta} = a_1\hat{\theta}_{41} + a_2,\hat{\theta}_2$.

	Case	a_1	m_0
1.	$a_2 = (1-a_1)$ $m_{12} = 0$	$m_{22}/(m_{11}+m_{22})$	$m_{11}m_{22}/(m_{11}+m_{22})$
2.	$a_2 = (1-a_1)$ $m_{12} \neq 0$	$m_{22}/(m_{11}+m_{22}-2m_{12})$	$m_{11}m_{22}-2m_{12})/(m_{11}+m_{22}-2m_{12})$
3.	$E[\hat{\theta}_1] = \theta$ $E[\hat{\theta}_2] = \theta$ $m_{12} = 0$	$m_{22}/(m_{11}+m_{22}+m_{11}m_{22}/\theta^T\theta)$	$m_{11}m_{22}(m_{11}+m_{22}+m_{11}m_{22}/\theta^T\theta)$
4.	$E[\hat{\theta}_1] = \theta$ $E[\hat{\theta}_2] = \theta$ $m_{12} \neq 0$	$(m_{22}-m_{12})/(m_{11}+m_{22}-2m_{12}+m_{11}m_{22}/\theta^T\theta$	$(m_{11}m_{22}-m_{12}^2)/(m_{11}+m_{22}-2m_{12}+m_{11m}m_{22}/\theta^T\theta)$
5.	$E[\hat{\theta}_1] = \theta$ $\hat{\theta}_2 = \phi$	$\theta^T\theta/(m_{11}+\theta^T\theta)$ (see case 1; $m_{12} = 0$ and $m_{22} = \theta^T\theta$	$m_{11}\theta^T\theta/[m_{11}+\theta^T\theta]$ $m_{11}-m_{11}^2/[m_{11}+\theta^T\theta]$
6.	$E[\hat{\theta}_1] = \theta$, which implies $m_{12} = 0$ $m_{22} = B_2B_2$		

$$a_2 = \begin{vmatrix} m_{11} + \theta^T\theta & \theta^T\theta \\ \theta^T\theta + \theta^T B_2 & \theta^T\theta + \theta^T B_2 \end{vmatrix} \Big/ \begin{vmatrix} m_{11} + \theta^T\theta & \theta^T\theta + \theta^T B_2 \\ \theta^T\theta + \theta^T B_2 & 2\,(\theta^T\theta + \theta^T B_2) \end{vmatrix}$$

$$a_1 = \begin{vmatrix} \theta^T\theta & \theta^T\theta + \theta^T B_2 \\ \theta^T\theta + \theta^T B_2 & B_2^T\theta^T\theta + \theta^T\theta + 2\theta^T B_2 \end{vmatrix} \Big/ \begin{vmatrix} m_{11} + \theta^T\theta & \theta^T\theta + \theta^T B_2 \\ \theta^T\theta + \theta^T B_2 & B_2^T B_2 + \theta^T\theta + 2\theta^T B_2 \end{vmatrix}$$

However, it may be difficult to guess better than the estimator given by the data. For the special case of $\hat{\theta}_1 = \bar{x}$, and $\hat{\theta}_2 = \theta_2$, then $m_{22} = (\theta_2 - \theta)^2 = B_2^2$ and $| B_2 | \leq \sigma/n^{1/2}$. Clearly, as n increases, one must indeed guess well.

AN ILLUSTRATIVE EXAMPLE

We refer again to a most recent edition of T. W. Anderson's, *An Introduction to Multivariate Statistical Analysis* (1984), which contains a brief expository on the James-Stein estimator and motivates the following example. Let $\hat{\theta}_1 \sim N_p(\theta, I)$, be a normal variate, the expectation of which is the fixed parameter $p \times 1$ vector θ and the variance of which is a $p \times p$ identity matrix.

Table 4 lists the estimator models considered and their properties. This example gives the minimal scalar mean squared error, Case 4, which is the only model based on selecting an optimal matrix weight from the set of all matrix weights.

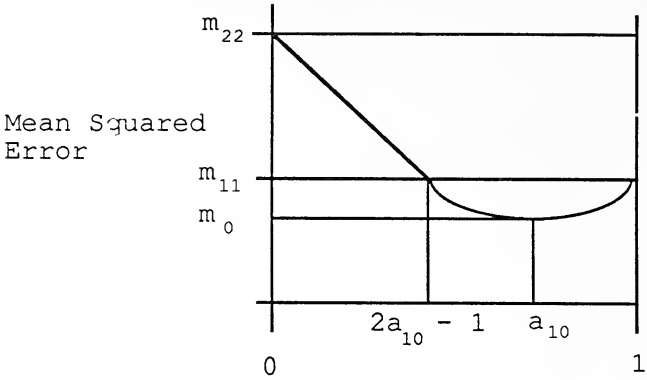

FIGURE 1A. Mean squared error, m_0 for scalar mean squared estimator when $0 \leq a_1 \leq 1$. Case a: when $m_{11} < m_{22}$, $a_{10} = m_{22} / (m_{11} + m_{22})$.

But first, note that only the estimator model based on diagonal matrix weights denoted in our Table 4 as Case 3, depends on the individual values of the elements of the vector $\theta = [\theta_1]$. The remaining models depend only on the squared length of the vector θ, that is $\theta^T\theta$. In order to compare Case 3 with our other case, we selected the following special cases

The length of of the vector	The parameter vector $[K = (\theta^T\theta)^{1/2}]$
p	$\underline{\theta}$
3	$K(1,2,1)^T/(6)^{1/2}$
6	$K(1,2,1,1,2,1)^T/(12)^{1/2}$
9	$K(1,2,1,1,2,1,1,2,1)^T/(18)^{1/2}$
12	$K(1,2,1,1,2,1,1,2,1,1,2,1)^T/(24)^{1/2}$,

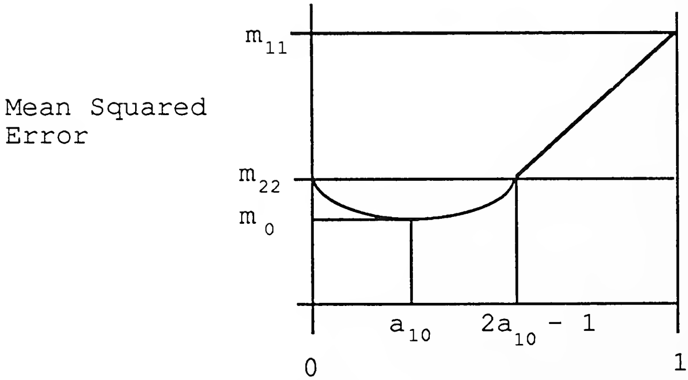

FIGURE 1B. Mean squared error, m_1 for scalar mean squared estimator when $0 \leq a_1 \leq 1$. Case b: when $m_{22} < m_{11}$.

TABLE 4A. The properties of various shrinkage estimators, $\hat{\theta}_1 \sim N_p(\theta, I)$, $\hat{\theta}_2 = \phi$.

Estimator model	Weight, A_1	m_0 — the scalar mean squared error
1. $\hat{\theta} = \theta_1$	$A_1 = I$	$m_0 = p$
2. $\hat{\theta} = a_1\hat{\theta}_1$	$a_1\ \hat{\theta}\ \theta^T\theta / (p + \theta^T\theta)$	$m_0 = a_1 p = (\theta^T\theta / \theta^T\theta + p)p$
3. $\hat{\theta} = D_1\hat{\theta}_1$	$d_{ii} = \theta^T_i / (1 + \theta_1^2)$	$m_0 = p - \sum_{L=1}^{p} 1/ (1 + \theta_i^2)$
4. $\hat{\theta} = A_1\hat{\theta}_1$	$\theta\theta^T [I + \theta\theta^T]^{-1}$	$m_0 = \theta^T\theta / (1 + \theta^T\theta)$
5. $\hat{\theta} = \frac{1}{4}\ \hat{\theta}_1$	$A_1 = \frac{1}{4}\ I$	$m_0 = \frac{1}{16}\ p + \frac{9}{16}\ \theta^T\theta$
6. $\hat{\theta} = \frac{1}{2}\ \hat{\theta}_1$	$A_1 = \frac{1}{2}\ I$	$m_0 = \frac{1}{4}\ p + \frac{1}{4}\ \theta^T\theta$
7. $\hat{\theta} = \frac{3}{4}\ \hat{\theta}_1$	$A_1 = \frac{3}{4}\ I$	$m_0 = \frac{9}{16}\ p + \frac{1}{16}\ \theta^T\theta$
8. $\hat{\theta} = \hat{\theta}_s$	$A_1 = \left(1 - \frac{p-2}{\hat{\theta}^T_1\hat{\theta}_1}\right)\ I$	
	$m_0 = p - (p-2)^2 \frac{1}{2}\ e^{-1/2\ \theta^T\theta} \sum_{b=0}^{\infty} \left(\frac{\theta^T\theta}{2}\right)^B \frac{1}{\beta!\ (\frac{1}{2}\ p + \beta - 1)}$	

where K is selected so that the length of the vector θ is a preassigned value. We consider the cases when $K^2 = \theta^T\theta$, and $\theta^T\theta = 1,3,6,9,12$ and $p = 3,6,9,12,15,30$. It follows that for these specific vectors that $m_0 = p - p \{1/[1 + (2\theta^T\theta p + 2\theta^T\theta)^2]/[2p^2 + 3)\theta^T\theta)p]\}$. Note again that $m_0 < p$, and is a function of p and the squared length $\theta^T\theta$ of the vectors θ.

In general however for Case 3,

$$
\begin{aligned}
m_0 &= \sum_{i=1}^{p} \theta_i^2 / \ (1 + \theta_i^2) \\
&= \sum_{i=1}^{p} [1 - 1/ \ (1 + \theta_1^2)\,] \\
&= p - \sum_{i=1}^{p} [1/ \ (1 + \theta_i^2)\,].
\end{aligned}
$$

Also

(a) if $\theta = (\theta^T\theta)^{1/2}\ [1,0,\ldots, 0]$

then

$m_0 = \theta^T\theta / \ (1 + \theta^T\theta)$,

the mean squared error for the general matrix model, Case 4.

(b) if $\theta_j = \alpha$ for each i, then $\alpha = [\theta^T\theta / p]^{1/2}$

and

$$m_0 = p\theta^T\theta / \ (p + \theta^T\theta),$$

TABLE 4B. Various values of $E_l\ [1 / \hat{\theta}_l^T\hat{\theta}_l]$ and m_s; the scalar mean squared error for the James-Stein estimator $\hat{\theta}_s$ when $\hat{\theta}_l \sim N_p(\theta, I)$, and $\theta^T\theta = kp_j$; when $m_l = p = 3, 6, 9, 12$ and 15.

	p = 3		p = 6		p = 9		p = 12		p = 15	
K	$E[1/\hat{\theta}_l^T\hat{\theta}_l]$	$M(\hat{\theta}_s)$	$E[1/\hat{\theta}_l^T\hat{\theta}_l]$	$M(\hat{\theta}_s)$	$E[1/\hat{\theta}_l^T\hat{\theta}_l]$	$M(\hat{\theta}_s)$	$E[1/\hat{\theta}_l^T\hat{\theta}_l]$	$M(\hat{\theta}_s)$	$E[1/\hat{\theta}_l^T\hat{\theta}_l]$	$M(\hat{\theta}_s)$
.1	.906	2.094	.227	2.37	.130	2.63	.091	2.90	.070	3.17
.2	.822	2.178	.207	2.69	.118	3.22	.083	3.70	.064	4.18
.3	.748	2.25	.189	2.69	.109	3.66	.076	4.40	.059	5.03
.4	.681	2.32	.174	3.22	.100	4.10	.070	5.00	.054	5.87
.5	.622	2.38	.161	3.42	.093	4.44	.065	5.50	.050	6.46
.6	.570	2.43	.149	3.62	.086	4.79	.061	5.90	.047	7.06
.7	.523	2.46	.138	3.79	.080	5.08	.057	6.30	.044	7.56
.8	.481	2.52	.129	3.94	.076	5.28	.054	6.60	.042	7.97
.9	.443	2.56	.121	4.06	.071	5.52	.050	7.00	.039	8.41
1.0	.409	2.59	.114	4.18	.067	5.72	.048	7.20	.037	8.75
2.0	.210	2.79	.069	4.90	.042	6.94	.030	9.00	.023	11.18
3.0	.131	2.87	.047	5.25	.030	7.53	.018	10.10	.007	13.77
4.0	.094	2.91	.038	5.28	.019	8.07	.005	11.50	.001	14.88
5.0	.073	2.93	.029	5.54	.008	8.01	.001	11.90	.000	14.99
6.0	.059	2.94	.021	5.66	.002	8.90	.000	11.99	.000	14.99
7.0	.050	2.95	.012	5.81	.000	8.99	.000	11.99	.000	15.00
8.0	.043	2.96	.006	5.90	.000	8.99	.000	12.00	.000	15.00
9.0	.037	2.96	.002	5.97	.000	8.99	.000	12.00	.000	15.00
10.0	.033	2.97	.001	5.99	.000	8.99	.000	12.00	.000	15.00
15.0	.010	2.99	.000	5.99	.000	8.99	.000	12.00	.000	14.99
30.0	.000	3.000	.000	6.00	.000	9.00	.000	12.00	.000	15.00

which is the mean squared error for the diagonal matrix when all diagonal elements are equal, Case 2.

(c) By the inclusion property, we know then that

$$\theta^T\theta / (1 + \theta^T\theta) \le - \sum_{i=1}^{p} [\theta_i^2 / (1 + \theta_i^2)] \le p\theta^{tT}\theta / (p + \theta^T\theta)$$

or

$$m_0 (M_p) \le m_0 (D_p) \le m_0 (C_p)$$

where

M_p denotes the set of all p × p matrix weights

D_p denotes the set of all p × p diagonal matrix weights

C_p denotes the set of all p × p diagonal matrix weights with diagonal elements equal.

The scalar mean squared error for each of the cases listed in Table 4 are summarized in Table 5.

TABLE 5. Various values of m, the scalar mean squared error for estimator models in Table 4.

	p = 3					p = 6				
$\theta^T\theta$ **Case**	**1**	**3**	**6**	**9**	**12**	**1**	**3**	**6**	**9**	**12**
1	3.00	3.00	3.00	3.00	3.00	6.00	6.00	6.00	6.00	6.00
2	0.75	1.50	2.00	2.25	2.40	0.86	2.00	3.00	3.60	4.00
3	0.69	1.33	1.80	2.06	2.22	0.81	1.80	2.67	3.21	3.60
4	0.50	0.75	0.86	0.90	0.92	0.50	0.75	0.86	0.90	0.92
5	0.75	1.88	3.56	5.25	6.94	0.94	2.06	3.75	5.44	7.12
6	1.00	1.50	2.25	3.00	3.75	1.75	2.25	3.00	3.75	4.50
7	1.75	1.88	2.06	2.25	2.44	3.44	3.56	3.75	3.94	4.12
8	2.27	2.59	2.79	2.87	2.91	2.59	3.43	4.18	4.61	4.89

	p = 9					p = 12				
$\theta^T\theta$ **Case**	**1**	**3**	**6**	**9**	**12**	**1**	**3**	**6**	**9**	**12**
1	9.00	9.00	9.00	9.00	9.00	12.00	12.00	12.00	12.00	12.00
2	0.90	2.25	3.60	4.50	5.14	0.92	2.40	4.00	5.14	6.00
33	0.86	2.06	3.21	4.00	4.58	0.89	2.22	3.60	4.58	5.33
4	0.50	0.75	0.86	0.90	0.92	0.50	0.75	0.86	0.90	0.92
5	1.12	2.25	3.94	5.63	7.31	1.31	2.44	4.13	5.81	7.50
6	2.50	3.00	3.75	4.50	5.25	3.25	3.75	4.50	5.25	6.00
7	5.13	5.25	5.44	5.63	5.81	6.81	6.94	7.13	7.31	7.50
8	2.71	3.82	4.95	5.70	6.23	2.78	4.05	5.46	6.46	7.22

	p = 15					p = 30				
$\theta^T\theta$ **Case**	**1**	**3**	**6**	**9**	**12**	**1**	**3**	**6**	**9**	**12**
1	15.00	15.00	15.00	15.00	15.00	30.00	30.00	30.00	30.00	30.00
2	0.94	2.50	4.29	5.63	6.67	0.97	2.73	5.00	6.92	8.57
3	0.91	2.34	3.89	5.03	5.93	0.95	2.62	4.68	6.34	7.78
4	0.50	0.75	0.86	0.90	0.92	0.50	0.75	0.86	0.90	0.92
5	1.50	2.63	4.31	6.00	7.69	2.44	3.56	5.25	6.94	8.65
6	4.00	4.50	5.25	6.00	6.75	7.75	8.25	9.00	9.75	10.50
7	8.50	8.63	8.81	9.00	9.19	16.94	17.06	17.25	17.44	17.63
8	2.82	4.20	5.81	7.03	7.99	2.91	4.56	6.71	8.54	10.11

In order to compute the scalar squared error for the James-Stein estimators the values in Table 4A are required and we included those results.

DISCUSSION

Note that the shrinkage estimator (Case 8) and the optimal scalar model (Case 2) are close approximations of each other. In fact, the shrinkage estimator is the optimal estimator model with the unknown optimal value of a_1 is replaced by an estimator

TABLE 6. T. W. Anderson's Table 3.2 (modified) average mean squared error of James-Stein estimiator for $p \equiv 10$ and $\Sigma = \sigma^2 I$ (note $\theta_2 = \phi$ in our comparison).

Case 1		Case 8	Case 5
m_1	m_{22}	m_0	m_0
	$(\theta_2 - \theta)^T (\theta_2 - \theta) = \theta^T\theta$	shrinkage est.	$\hat{\theta} = 1/2\, \hat{\theta}_1 + 1/2\, \hat{\theta}_2$
p = 10	0.0 = 0.00p	2.00 = .200p	2.50 = .250p
10	0.5 = 0.05p	4.78 = .478p	2.65 = .265p
10	1.0 = 0.10p	6.21 = .621p	2.75 = .275p
10	2.0 = 0.20p	7.51 = .751p	3.00 = .300p
10	3.0 = 0.30p	8.24 = .824p	3.25 = .325p
10	4.0 = 0.40p	8.62 = .862p	3.50 = .350p
10	5.0 = 0.50p	8.86 = .886p	3.75 = .375p
10	6.0 = 0.60p	9.03 = .903p	4.00 = .400p

$$1 - (p - 2) / \hat{\theta}_1^T\hat{\theta}_1. \tag{6}$$

Compare Case 2 and Case 8 and note that

$$\theta^T\theta / (p + \theta^T\theta) = 1 - \frac{p}{p + \theta^T\theta},$$

a quantity not unlike (6).

Note also that normality assumptions are required for the James-Stein estimator, whereas on observing the values contained in Table 5 it is not all all convincing that the James-Stein estimator merits enthusiastic acceptance as a useful procedure. What it did indicate was that there exists a precise modeling methodology for combining an estimator $\hat{\theta}_1$ with an expert opinion $\hat{\theta}_2 = \theta_2$. It may be in that sense that the shrinkage estimator will endure and have wide application.

Now let us return to Table 3.2 in Anderson's text. Table 3.2 is duplicated in a modified form and displayed as our Table 6 so that one can compare the results with those reported in our Table 5.

Note that in every case considered in Table 6, the analyst "guesses" better than he "estimates." Also when $\theta_2 = \phi$, the guess is correct, that $m_0 = 2$ whereas $m_{11} = 10$.

Finally, consider the case in which the weights are extremely ad hoc, that is, the three estimators defined in Cases 5, 6, and 7. We will compare those with the James-Stein estimator in Case 8. Assume that one guesses θ by θ_2 about as well as one estimates θ by $\hat{\theta}_1$, that is, let $m_2 = \theta^T\theta = p$, then

Case 1: $m_0 = m_{11} = p$

Case 5: $m_0 = 10p/16 = 5p/8$

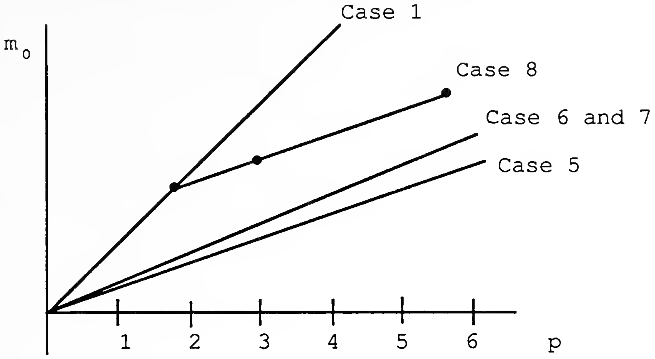

FIGURE 2. m_0 for cases 1, 5, 6, 7, and 8 for the special case when $\theta^T\theta = p$.

Case 6: $m_0 = p/2$

Case 7: $m_0 = 10p/16 = 5p/8$

and

Case 8: $m_0 = p - (p - 2)\frac{1}{2}e^{-p/2}\sum_{\beta=0}^{\infty}\left(\frac{p}{2}\right)^{\beta}\frac{1}{\beta!\,(p+\beta-1)}$.

Plots of these functions versus p are given in Figure 2.

Note that for all $p \leq 12$, that the value m_0 for

$$\hat{\theta} = 1/2\,\hat{\theta}_1$$

is smaller than m_0 for the James-Stein estimator and for all cases considered in our Table 5. Does this mean that if $\bar{X} = \hat{\theta}_1$ is an unbiased estimator for θ and $p \leq 12$, that we gain over its several competitors by using the ad hoc estimator

$\hat{\theta} = \theta_2 + \frac{1}{2}(\bar{X} - \theta_2) = 1/2\,\bar{X} + \frac{1}{2}\theta_2$, that is, for any guess θ_2 adjust by adding one half the negative of the deviation of θ_2 from $\bar{X}$? This is indeed "startling" and empirical ad "hocory." Or is the payoff criterion not a proper one for most applications?

LITERATURE CITED

Anderson, T. W. 1984. Introduction to multivariate statisical analyses. John Wiley and Sons, New York, 2nd ed., pp. 86-96.

Baksalary, J. K., and R. Kala. 1983. Estimation via linear combining two given statistics, Ann. Stat., 14:691-696.

Efron, B., and C. Morris. 1977. Stein's paradox in statistics. Sci. Amer., 236:119-127.

Lewis, T. O., and P. L. Odell. 1971. Estimators in linear models. Prentice Hall, pp. 69-71.

Odell, P. L., D. Dorsett, D. Young, and J. Igwe. 1988. Matrix foundations for combining vector estimators. Unpublished manuscript presented as a paper, SIAM Annual Meeting, Madison, Wisconsin, April 1988.

POTENTIAL IMPACT OF RATTLESNAKE ROUNDUPS ON NATURAL POPULATIONS

JONATHAN A. CAMPBELL, DANIEL R. FORMANOWICZ, JR.,
AND EDMUND D. BRODIE, JR.
Department of Biology, The University of Texas at Arlington, Arlington, Texas 76019

ABSTRACT.—Rattlesnake roundups in Texas are annual events that result in removal of large numbers of snakes from natural habitats. In addition, the preferred collecting method (spraying gasoline into dens) may affect other species living in rattlesnake communities and degrade the quality of the habitat. We examined the potential impact of these mass collections and the collection technique on natural populations through 1) qualitative surveys of three roundups, 2) a statistical analysis of the long-term dynamics of snake collections, and 3) a series of laboratory experiments designed to examine the effect of short-term exposure to gasoline fumes on the behavior of several vertebrate and one invertebrate species found in the natural communities affected.

Our surveys indicated that use of gasoline in collecting was widespread and that several species of snakes, other than *Crotalus atrox*, often were included in collections. The results of the analyses of number of snakes collected at the Sweetwater Roundup since its inception are difficult to intrepret because of a lack of information on undisturbed rattlesnake populations. Our analysis indicated that, although there has been a general increase in total number of snakes collected through the years, number of snakes collected per hunter has not increased. We also estimate the impact of removal of reproductive females from populations. Results of laboratory experiments indicated that exposure to gasoline fumes had important short-term effects on the species tested, resulting in animals losing their ability to right themselves. *Crotalus atrox*, the western diamondback rattlesnake and the target species of roundups, appeared to be most resistant to gasoline fume exposure. Short-term exposure also affected the ability of collared lizards and toads to forage efficiently up to seven days after exposure. *Key words: Crotalus atrox*; rattlesnake roundups; gasoline; Texas.

Rattlesnake roundups are traditionally held in the spring and early summer in various parts of the United States. Cities in Alabama, Florida, Georgia, Oklahoma, Pennsylvania, and Texas serve as sites for these events. The first organized roundup in the United States was reportedly held at Okeene, Oklahoma (Kilmon and Shelton, 1981). In Texas, the first roundups appear to have been held in 1958 and 1959 at Sweetwater and since that time the event has spread to other cities in the state (Brownwood, Big Spring, Ballinger, Freer, Lometa, and others). Rattlesnake roundups serve primarily as fund-raising events for local community organizations. Funds, in part, are raised through sale of snake skins to hide buyers (for use in articles of clothing and accessories) and snake meat. Roundups result in the removal of large numbers of rattlesnakes from natural habitats in Texas each year.

Crotalus atrox, the western diamondback rattlesnake, comprises the majority of snakes collected at roundups in Texas. Other species of crotalines as well as harmless species of colubrids often are included in collecting efforts. Proponents of rattlesnake roundups argue that mass collection of snakes that has occurred over the years has not affected snake population densities. As evidence that the snake populations have not been seriously disturbed, they point to the large numbers of snakes that continue to be brought into roundups across the state of Texas (Kilmon and Shelton, 1981). There is, however, little quantitative information available about the population ecology of *C. atrox* or the communities in which they occur. This is true not only in Texas, but throughout the distribution of this rattlesnake. *Crotalus atrox* is found in a wide variety of habitats (Gloyd, 1940) and is reportedly most common in rural dry areas (Tennant, 1984). Klauber (1972) described prime *C. atrox* habitat as "brushy, rocky country." Western diamondbacks overwinter in underground dens or hibernacula and it is while they are in these hibernacula, in the early spring, that most snakes are collected by hunters participating in roundups. The snakes normally emerge from dens in spring and engage in courtship and mating. Female *C. atrox* are ovoviviparous (bear live young) and apparently reproduce annually in the southern part of their range (Tinkle, 1962; Fitch, 1970; Klauber, 1972; Tennant, 1984). Fitch (1970) estimated that perhaps two-thirds of the adult females are reproductive in any given year. Litter size of *C. atrox* varies from nine to 16 young (Klauber, 1972; Tinkle, 1962). The snakes reach reproductive maturity at approximately 500 grams (Tinkle, 1962). The western diamondback is reported to feed primarily on small rodents; in one examination of the stomach contents of more than 200 *C. atrox*, 38 percent of the prey consisted of small mammals (Beavers, 1976). There is no quantitative information available in the literature on densities or dynamics of *C. atrox* populations. In addition, no data exist on the other species of snakes that are removed from the habitat during rattlesnake roundups. It is difficult, therefore, to assess the impact on *C. atrox* populations of the mass removal of individuals that results from rattlesnake roundups. The potential over-exploitation of populations of one or several species of snakes also may have unknown, direct effects on the ecology of other species of vertebrates (for example, small mammals, lizards) and invertebrates (insects, arachnids) in these habitats. The long-term survival and reproduction of all of the species in the affected habitats are obviously interdependent.

A second potentially important problem associated with rattlesnake roundups may be the effects of methods commonly employed by hunters to collect rattlesnakes on the quality of the habitat and more specifically on other species living in rattlesnake communities. The problem involves the introduction of a potentially hazardous chemical (usually gasoline—see Table 1) into underground hibernacula where rattlesnakes overwinter. Gasoline is sprayed into dens using garden-type sprayers and lengths of copper tubing. Snake hunters reportedly take great care to spray gasoline into the backs of dens to force the snakes towards the entrance rather than drive them farther back in to the dens (Kilmon and Shelton, 1981).

TABLE 1. Potentially hazardous components of leaded gasoline. Summarized from Materials Safety Data Sheet, Conoco, 1986.

Component	Potential hazard
Aromatic and paraffinic hydrocarbons	Kidney toxicity; liver, skin, and kidney tumorigen in laboratory animals.
Benezene	Slightly higher incidence of leukemia in humans.
Tetraethyl lead	Toxicity in the nervous system, blood, blood forming tissues, gastrointestinal tract, liver, pancreas, and kidneys.
Ethylene dibromide	Potential mutagen and tumorigen.
Ethylene dichloride	Potential mutagen and tumorigen.

Effects of exposure to this potentially hazardous chemical on *C. atrox* and other co-occurring species are not known although Kilmon and Shelton (1981) pointed out that "If too much gasoline is sprayed into the den and on the snakes, they do not emerge but die inside the den." The consequences of gasoline use in collecting may be critical to the stability and persistence of rattlesnake populations as well as other resident vertebrate and invertebrate populations.

In this study we 1) report the results of visits that were made to three roundups in Texas in the spring of 1986 at which we interviewed registered snake hunters for information concerning their methods of collecting and determined if snake species other than *C. atrox* were collected, 2) compiled and statistically examined available data on the total number or weight (or both) of rattlesnakes collected during roundups on a yearly basis, and 3) examined the effects of short-term exposure to gasoline fumes in the laboratory on the behavior of *C. atrox*, several other species of vertebrates, and one species of invertebrate which occur in the affected habitats.

METHODS

Survey of Rattlesnake Roundups

Rattlesnake roundups in Brownwood, Freer, and Sweetwater were visited in the spring of 1986. At each of these, we interviewed as many of the registered snake hunters as possible (15 each at Brownwood and Freer and 25 at Sweetwater). The questions that we posed to the hunters concerned the types of collecting techniques employed to capture *Crotalus atrox*. In particular, we attempted to determine the extent of gasoline, or other chemicals, used to drive snakes from their dens. The experiments concerning the effects of short-term exposure to gasoline fumes described below were based on these interviews. We also qualitatively sampled the range of species of snakes (other than the target species, *C. atrox*) that were collected and removed from the habitat during roundups.

Roundup Data

In addition to information from the interviews described above, we obtained data on the number of rattlesnakes or pounds of snakes (or both) collected at the Sweetwater roundup each year since its inception. There are 28 years of data (1959-1986) available on rattlesnakes captured for the Sweetwater roundup (Kilmon and Shelton, 1981; Sweetwater Jaycees, 1986). To our knowledge, data such as these were not available in complete form for any other roundup. Data on the number of registered snake hunters participating in the Sweetwater roundups for a nine-year period (1978-1986) also were available. For the years 1974 to 1979 and 1982 to 1986, the data only include pounds of rattlesnakes collected. We estimated the number of snakes collected in those years by calculating the mean weight for rattlesnakes taken during the years in which both number and pounds are reported (1.15 pounds or 520 grams; 1959-1972 and 1980-1981) and dividing that into the number of pounds of snakes collected during the years for which the number of snakes was not available. We also used these data to estimate total number of females, number of reproductive females collected, and the lost reproductive potential (number of offspring produced) for reproductive females removed from the populations.

Species Tested

The following vertebrate species were collected for use in the behavioral response to gasoline fume exposure experiments described below (vernacular names for the reptiles and amphibians from Smith and Brodie, 1982): western diamondback rattlesnake (*Crotalus atrox*); rat snake (*Elaphe obsoleta*); common kingsnake (*Lampropeltus getulus*); prairie kingsnake (*Lampropeltus calligaster*); racer (*Coluber constrictor*); collared lizard (*Crotaphytus collaris*); Woodhouse's toad (*Bufo woodhousei*). All individuals of amphibian and reptile species examined in this study were preserved in formalin at the conclusion of the experiments and have been deposited in the University of Texas at Arlington Collection of Vertebrates (UTA). In addition, one species of invertebrate, the house cricket (*Acheta domesticus*), was exposed to gasoline fumes in these experiments. The examination of the effects of fumes on an invertebrate species was important because long-term survival and reproductive success of several of the vertebrate species is dependent to some extent on the health of invertebrate prey populations in affected habitats.

Short-term Exposure Experiments

Experiments examining the effects of exposure to leaded gasoline fumes were conducted using the species mentioned above, in glass aquaria (26 by 52 by 31 centimeters). Hardware cloth platforms (eight centimeters high) were placed in the bottom of each aquarium, preventing animals from coming into physical contact with liquid gasoline but allowing exposure to the fumes. This design is conservative because animals in dens or burrows into which gasoline is sprayed may come into physical contact with the liquid. Each aquarium lid did not form an air tight seal, but concentrated fumes within the chambers. Individuals were randomly assigned to either a control or one of two experimental groups (except for *L. getulus* and *L. calligaster*, because of limited sample size). Control animals were handled in the same way as experimental animals but were not exposed to gasoline fumes. A summary of sample sizes for control and experimental groups by species is presented in Table 2. Prior to each test, 100 milliliters of leaded gasoline were introduced into the bottom of each aquaria. After 10 minutes, experimental animals were placed on the platforms in the test aquaria, the lid was secured, and the aquaria placed under a fume hood. Because the volitility of leaded gasoline is 100 percent, 10 minutes was adequate time for fumes to concentrate in the test chambers. Experimental *B. woodhousei* and *A. domesticus* were placed in small, window-screen chambers placed atop the platforms because they were small enough to slip through the hardware cloth. At the end of the exposure period (Table 2), animals were removed from test aquaria containing fumes and their righting response (ability to right themselves when placed on their dorsum, a standard test in toxicity studies—for example, see Formanowicz and Brodie, 1985) was examined.

TABLE 2. Sample sizes and exposure times of control and experimental groups for each species tested.

Species	Condition	N	Time exposed (minutes)
Crotalus atrox	control	8	0
	experiment 1	5	30
	experiment 2	5	60
Elaphe obsoleta	control	2	0
	experiment 1	2	30
	experiment 2	4	60
Coluber constrictor	experiment 1	1	30
Lampropeltus getulus	experiment 2	1	60
Lampropeltus calligaster	experiment 2	1	60
Crotaphytus collaris	control	5	0
	experiment 1	5	10
	experiment 2	5	30
Bufo woodhousei	control	6	0
	experiment 1	6	10
	experiment 2	6	30
Acheta domesticus	control	10	0
	experiment 1	10	10
	experiment 2	10	30

Righting responses of experimental animals were examined every 15 minutes for the first hour and every hour for the next 12 hours to determine the length of time to recovery from fume exposure. Animals that could not right after 12 hours were scored as did not recover and immediately preserved.

We also examined the effects of exposure to gasoline fumes on the foraging behavior of collared lizards, *Crotaphytus collaris*, and toads, *Bufo woodhousei.* Control and experimental animals, previously used in the exposure experiments described above, were held for seven days after exposure. During the holding period, animals were not fed but water was constantly available. *C. collaris* was held and tested in glass aquaria (26 by 52 by 31 centimeters) and *B. woodhousei* in containers that were 18 by 9 by 8 centimeters. Foraging behavior of *C. collaris* and *B. woodhousei* was examined by placing four crickets (*A. domesticus*, mean weight = 0.38 grams, not previously exposed to gasoline fumes) or four mealworm larvae (*Tenebrio molitor*, mean weight = 0.11 grams), respectively, into each chamber containing a lizard or toad. We recorded latency to first capture of a prey animal and total number of prey consumed by each control and experimental lizard or toad. Trials for *C. collaris* lasted 15 minutes and trials for *B. woodhousei* 60 minutes. Individuals that did not feed were given a latency to first capture of 15 and 60 minutes, respectively.

Statistical Analyses

Comparisons of data on latency to first capture and total number of prey captured between control and experimental groups of *C. collaris* and *B. woodhousei* were done using analysis of variance techniques (Sokal and Rohlf, 1981). Regression and correlation analyses and least squares fits were performed on number of snakes, estimated number of females, estimated number of reproductive females captured, estimated lost reproductive potential, and number of snake hunters from the 28 years of information gathered for the Sweetwater roundups by Kilmon and Shelton (1981) and the Sweetwater Jaycees (1986). In all statistical analyses described above, alpha was set at 0.05.

RESULTS

Survey of Roundups

Interviews of snake hunters (a total of 55) at the three roundups that were visited indicated that gasoline was the only chemical used in the collection of *Crotalus atrox*. Hunters interviewed were apparently unaware of any other chemical used for this purpose. The type of gasoline utilized was generally whatever was cheapest and most readily available. The consensus was that leaded gasoline was used most often. Collecting techniques involved putting gasoline into a metal garden sprayer and connecting a series of copper tubes to the sprayer. The copper tubes than were extended down into holes where rattlesnakes were suspected to occur. Apparently, care was taken to spray gas as far back into burrows or dens as possible to drive snakes out of rather than farther back into the burrow. The hunters indicated that species other than *C. atrox* also were driven from burrows, but the frequency and identity of these species were not readily discernable from their comments. We observed other species of snakes, in addition to *C. atrox*, brought in at the roundups, collected using the same techniques. They were western rattlesnakes (*Crotalus viridis*, massasauga rattlesnakes (*Sistrurus catenatus*), racers (*Coluber constrictor*), coachwhips (*Masticophis flagellum*), glossy snakes (*Arizona elegans*), and western bullsnakes (*Pituophis melanoleucus*).

At both Sweetwater and Brownwood, interviews with hunters revealed that the majority of snakes had been captured using gasoline and garden sprayers. At Freer, comments by hunters indicated that many snakes were brought in from long distances and most had been collected using gasoline. Some snakes captured locally were, however, collected by searching roads at night. Several individuals who had participated in roundups for a number of years expressed the opinion that many younger snake hunters are too liberal in their use of gasoline in collecting rattlesnakes. One individual commented that hunters sometimes "ruined the ecology of the holes" through excessive use of gasoline and that, if too much gasoline was used during collecting in a given area, it was not worthwhile to return to that area to hunt for snakes for several years.

Analysis of Roundup Data

We examined 28 years of data available on number of rattlesnakes collected for the Sweetwater rattlesnake roundup. Data on number of snakes collected each year (using estimated numbers for 1974-1979 and 1982-1986 as indicated in Methods) are presented in Fig. 1A. Mean number of rattlesnakes collected per year was 5563 (±3672 SD) with a range from 1900 to 15,680 snakes. Statistical analyses of these data indicated a significant positive correlation between number of rattlesnakes collected and year ($r = 0.532$; $P < 0.05$). Regression analysis indicated that the relationship between number of snakes and years was

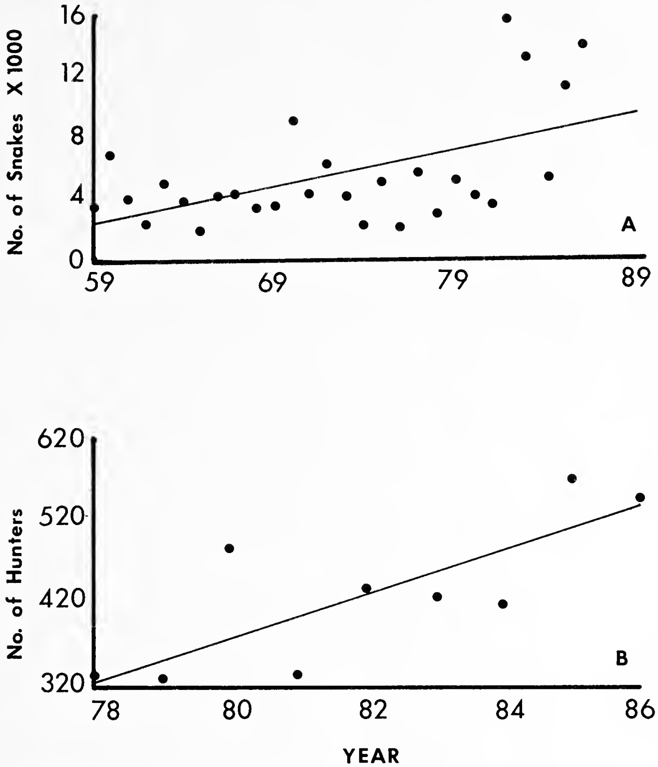

FIGURE 1. (A) Number of *Crotalus atrox* collected at the Sweetwater rattlesnake roundup each year for 28 years (1959-1986). For the years 1974-1979 and 1982-1986, numbers are estimates based on pounds of rattlesnake collected and the mean weight of snakes collected in years where both number and weight are reported. The line was fit by least squares regression. (B) Number of registered snake hunters involved in the Sweetwater roundup for the years 1978-1986. The line was fit by least squares regression.

significantly linear with a positive slope (Fig. 1A). The total number of rattlesnakes collected significantly increased over the 28 years of the roundups.

The number of snakes collected at roundups each year should depend, in part, on the number of snake hunters participating each year. Data on number of registered hunters per year were available for 1978 to 1986 (Kilmon and Shelton, 1981; Sweetwater Jaycees 1986; Fig. 1B). Regression and correlation analysis indicated a significant positive correlation between number of hunters and years ($r = 0.789$; $P < 0.01$) and a significant linear relationship with a positive slope (Fig. 1B). Generally, the number of registered snake hunters increased over the nine years for which data were available. The mean number of rattlesnakes collected per hunter also can be estimated for each of the nine years (Fig. 2A). Regression and correlation analysis of number of snakes collected

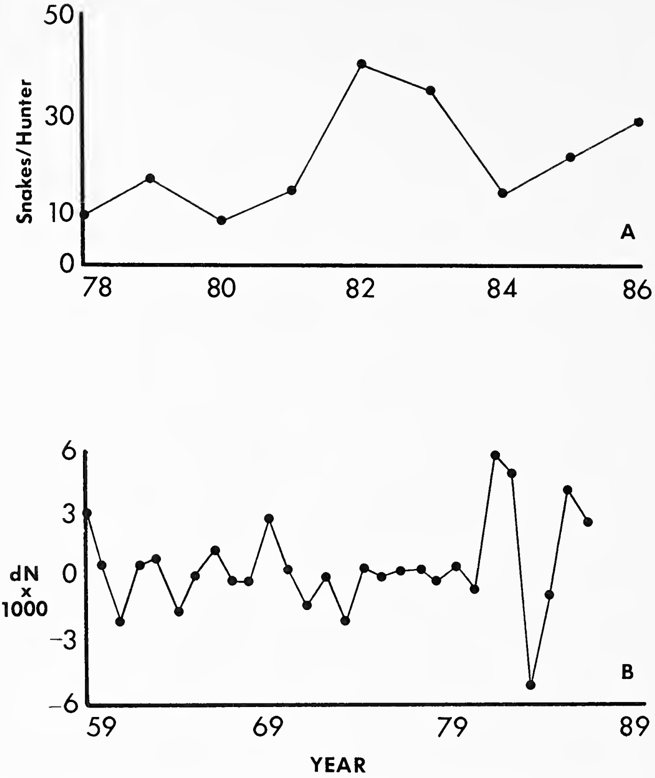

FIGURE 2. (A) The number of *Crotalus atrox* collected per registered snake hunter for the years 1978-1986. The line was fit by eye. (B) Change in the number of snakes collected (*dN*) as a function of time. The line was fit by eye.

per hunter by year indicated no significant relationship. This implies that the number of snakes collected per hunter per year did not change significantly over this nine-year period even though total number of snakes collected and number of hunters (Figs. 1A, 2A) significantly increased. To more closely examine the dynamics of the rattlesnake collection data, we examined the rate of change in number of rattlesnakes collected (the first derivative) over the full 28 years of available data (Fig. 2B). These data were subjected to regression analysis to determine if the net rate of change across the years was positive, negative, or approximated zero. The slope of the regression fit to these data was not significantly different from zero ($P > 0.50$), indicating that net rate of change in number of snakes collected over the 28 years approximated zero.

In summary, analyses of data for the number of *Crotalus atrox* collected over the 28 years of the Sweetwater roundup indicated that although total number of snakes collected increased significantly over the

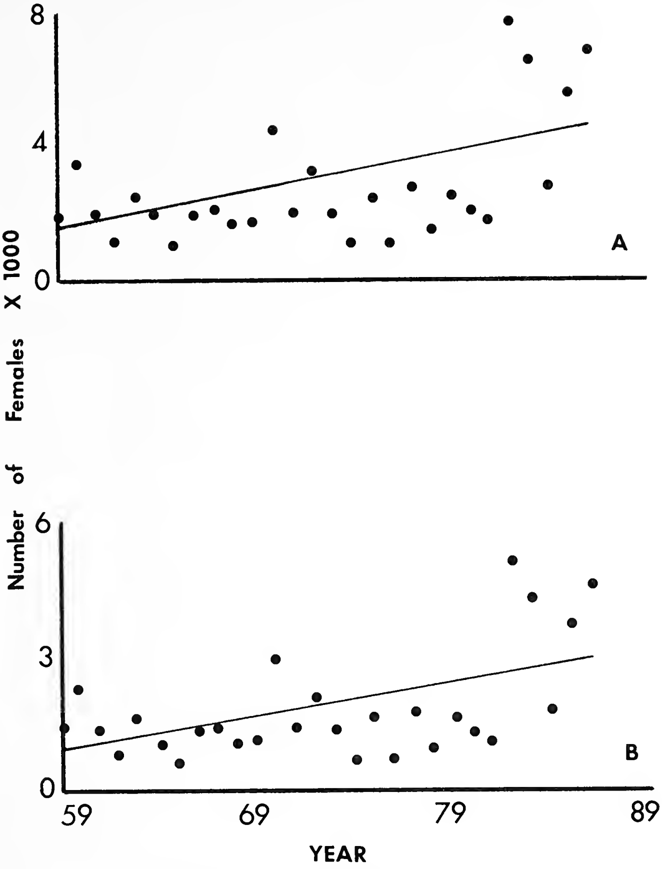

FIGURE 3. (A) Estimated number of female *Crotalus atrox* collected for each year of the Sweetwater roundup (1959-1986). See text for explanation of the estimation. (B) The estimated number of reproductive females collected for each of the 28 years. See the text for explanation of the estimation.

years (Fig. 1A), this increase may be accounted for by increased number of snake hunters (at least for the years 1978-1986). Evidence for this came from the lack of a significant increase in number of snakes collected per hunter (Fig. 2A) and the fact that net rate of change in number of snakes collected was approximately zero. This last result does not imply that there were no changes in number of snakes collected from year to year, it simply indicates that net rate of change across the years was negligible.

Estimates of number of females collected and lost reproductive potential.—If it is assumed that the sex ratio of *Crotalus atrox* collected at rattlesnake roundups is 50 percent male and 50 percent female (based on Klauber, 1972, and sex ratio theory of Fisher, 1930), the number of females collected over the 28 years can be estimated (Fig. 3A). If

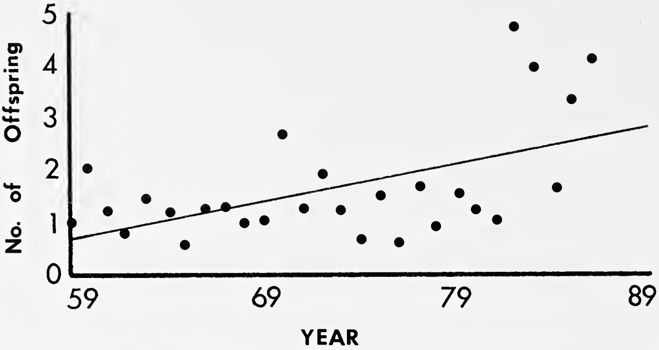

FIGURE 4. A plot of the estimated lost reproductive potential (number of offspring lost × 1000) as a result of removal of reproductive females during the period of 1959-1986.

approximately 66.7 percent of females were in reproductive condition in any given year (based on Tinkle, 1962, and Fitch, 1970), the number of reproductive females removed from the population each year (Fig. 3B) also can be estimated. These estimates assume that all snakes collected were adults. Our observations indicated that relatively few juvenile rattlesnakes are brought in at roundups. Given a litter size of nine for a small, reproductive female *C. atrox*, the minimum litter size from Tinkle, (1962), Fitch, (1970), and Klauber, (1972), the loss of reproductive potential for females removed from the population each year can be estimated. Minimum litter size was used because the mean weight of collected snakes (520 grams) is not much larger than estimated weight at sexual maturity (500 grams—Tinkle, 1962). Offspring are born in the autumn (Tinkle, 1962) and snakes are collected for roundups in early spring, before reproducing for that year. Litter size (nine) was multiplied by the humber of reproductive females to obtain an estimate of number of offspring lost each year (Fig. 4). Regression and correlation analyses of number of offspring lost across the 28 years indicated a significant positive correlation ($r = 0.53$; $P < 0.05$) between offspring lost and year and a significant linear relationship with a positive slope (Fig. 4).

Short-Term Exposure Experiments

Rattlesnakes.—Crotalus atrox was exposed to gasoline fumes for either 30 or 60 minutes. All *C. atrox* exposed to fumes were unable to right themselves after being removed from test chambers (Table 3). All control rattlesnakes were able to right themselves and exhibited tongue-flicking and rattling when disturbed. None of the snakes exposed to fumes tongue-flicked or rattled when disturbed immediately after being removed from test chambers. Time to recovery of the righting response (Table 3) for snakes exposed to fumes for 30 minutes ranged from 60 to 120 minutes. Time to recovery for snakes exposed for 60 minutes ranged

TABLE. 3. Results of the exposure experiments with *Crotalus atrox*.

Condition	N	Time exposed (minutes)	Righting response	Recovery time (hours)
Control	8	0	all	—
Experiment 1	5	30	none	1-2
Experiment 2	5	60	none	6.5-7*

*One animal did not recover within 12 hours.

from six to seven hours. One rattlesnake did not recover from 60 minutes of exposure.

Colubrid snakes.—Four species of colubrid snakes were exposed to gasoline fumes for either 30 or 60 minutes (Table 4). All colubrids exposed to fumes were unable to right themselves immediately after removal from test chambers, whereas all controls did exhibit the righting response (Table 4). Times to recovery for colubrids exposed to fumes for 30 minutes was approximately two hours and ranged from six to eight hours for those exposed for 60 minutes. Three snakes exposed to fumes for 60 minutes did not recover (one each of *Elaphe obsoleta, Lampropeltus getulus*, and *L. calligaster*).

Collared lizards.—Crotaphytus collaris was exposed to gasoline fumes for either 10 or 30 minutes. No lizards exposed to fumes were able to right themselves immediately after being removed from test chambers regardless of length of time exposed to fumes, but all control lizards exhibited the righting response (Table 5). Collared lizards exposed to fumes for 10 minutes recovered the ability to right themselves within 45 minutes. Lizards exposed for 30 minutes took approximately seven hours to recover the righting response except one lizard, which did not recover. Control and experimental lizards were tested seven days later in foraging experiments, results of which are described below.

TABLE 4. Results of the exposure experiments with colubrid snakes.

Species	Condition	N	Time exposed (minutes)	Righting response	Recovery time (hours)
Coluber constrictor	Experiment 1	1	30	none	2
Lampropeltus getulus	Experiment 2	1	60	none	*
Lampropeltus calligaster	Experiment 2	1	60	none	*
Elaphe obsoleta	Control	2	0	all	—
	Experiment 1	2	30	none	2*
	Experiment 2	4	60	none	6-8*

*One animal did not recover within 12 hours.

TABLE 5. Results of the exposure experiments with *Crotaphytus collaris.*

Condition	N	Time exposed (minutes)	Righting response	Recovery time (hours)
Control	5	0	all	—
Experiment 1	5	10	none	45 minutes
Experiment 2	5	30	none	7*

*One *C. collaris* did not recover within 12 hours.

Woodhouse's toad.—Experimental individuals of *Bufo woodhousei* were exposed to gasoline fumes for either 10 or 30 minutes (Table 6). Toads exposed to fumes for 10 minutes were unable to right themselves but recovered the righting response in 40 to 60 minutes of being removed from test chambers. None of the toads exposed for 30 minutes exhibited the righting response and none recovered from exposure. All control animals exhibited the righting response. Experimental and control toads were tested seven days later in foraging experiments, results of which are described below.

House crickets.—Experimental crickets, *Acheta domesticus*, were exposed to gasoline fumes for either 10 or 30 minutes (Table 7). Crickets exposed for 10 minutes were unable to right themselves after removal from test chambers. Seven of 10 recovered the righting response in from 45 to 60 minutes; three individuals did not recover. None of the crickets exposed for 30 minutes exhibited the righting response or recovered. All control *A. domesticus* exhibited the righting response.

Foraging Experiments

We examined the behavioral ramifications of exposure to gasoline fumes by comparing the foraging behavior (latency to first capture and total number of prey animals captured) of control and experimental individuals from the exposure experiments for *C. collaris* and *B. woodhousei.*

Collared lizards.—Analysis of variance indicated that total number of prey animals captured and latency to first capture (Table 8) were significantly ($P < 0.05$) affected by previous exposure to gasoline fumes in *C. collaris.* Both control lizards and those exposed to fumes for 10 minutes captured significantly ($P < 0.05$) more prey than lizards that

TABLE 6. Results of the exposure experiments with *Bufo woodhousei.*

Condition	N	Time exposed (minutes)	Righting response	Recovery time (hours)
Control	6	0	all	—
Experiment 1	6	10	none	40-60
Experiment 2	6	30	none	*

*Did not recover within 12 hours.

Table 7. Results of the exposure experiments with *Acheta domesticus*.

Condition	N	Time exposed (minutes)	Righting response	Recovery time (hours)
Control	10	0	all	—
Experiment 1	10	10	none	50-60
Experiment 2	10	30	none	*

*Did not recover within 12 hours.

were exposed for 30 minutes (Table 8). There was no significant difference in number of prey captured between control lizards and those exposed for 10 minutes. Control lizards and those exposed for 10 minutes had significantly shorter latency to first prey capture those exposed for 30 minutes (Table 8). There was no significant difference between controls and 10 minute exposure lizards.

Woodhouse's toads.—Number of prey animals eaten (Table 8) and latency to first capture (Table 8) were both significantly ($P < 0.05$) affected by previous exposure to gasoline fumes. Control *B. woodhousei* captured significantly more prey ($P < 0.05$) and had shorter latency to first prey capture ($P < 0.01$) than toads exposed to fumes for 10 minutes.

Discussion

Effect on Rattlesnake Populations

The results of analyses of number of rattlesnakes collected at the Sweetwater roundup since its inception appear, initially, to support the contention of snake hunters and roundup organizers (Kilmon and Shelton, 1981) concerning the increase in number of snakes brought into the roundups over the years. Our analyses, however, suggest that the increased number of *C. atrox* collected may be primarily a function of the increase in the number of registered hunters, at least over the years for which hunter data are available (1978-1986). When we examined the per hunter rate of snake collection (Fig. 2A), there were no significant changes in snakes collected per hunter per year. It is difficult to determine what this means in the context of *C. atrox* populations.

Table 8. The mean number of prey eaten and the latency to first prey capture for *Crotaphytus collaris* and *Bufo woodhousei* as a function of exposure to gasoline fumes.

Species	Exposure (minutes)	Number eaten (±SD)	Latency (minutes) (±SD)
Crotaphytus collaris	0	2.4 ± 0.52	1.0 ± 1.31
	10	2.8 ± 0.79	1.6 ± 1.42
	30	0.7 ± 0.47	5.8 ± 1.19
Bufo woodhousei	0	2.7 ± 0.28	2.7 ± 0.84
	10	1.3 ± 0.39	5.3 ± 1.13

Rattlesnake populations, as some have suggested (Kilmon and Shelton, 1981), indeed may not be seriously perturbed by the annual collections, but this cannot be determined from examination of the increase, or lack of decrease, in number of snakes collected over the years. It is equally likely that increased numbers of hunters are sampling or collecting a larger proportion of *C. atrox* populations. In other words, population densities are not necessarily staying the same. Increased number of snakes collected simply may be a function of increased sampling (collecting) effort.

Examination of the rate of change in number of rattlesnakes collected may provide more insight into the dynamics of annual rattlesnake collections. The net rate of change in number of snakes collected approximates zero (Fig. 2B). This implies that year-to-year variation (increases and decreases evident in Fig. 1A) roughly balances out. A qualitative examination of the data in Figs. 1A and 2A yields the impression that number of snakes collected fluctuates with peak years followed by poor years. These fluctuations may be the result of variation in number of hunters from year to year, but not enough data are available to evaluate this suggestion. If these annual collections are considered to be samples of rattlesnake populations (obviously nonrandom samples), the suggestion could be made that *C. atrox* population density is fluctuating in the habitats being collected. The implications of these fluctuations, and ultimately any conclusions drawn concerning the stability of rattlesnake populations, cannot be adequately tested or discussed because of lack of quantitative information on population dynamics of *C. atrox*, particularly those in undisturbed habitats.

To directly address the question of whether annual removal of large numbers of rattlesnakes has had and is having a deleterious effect on *C. atrox* populations, comparisons between year to year variation in populations not affected by the roundups and those that are affected need to be made. In addition, an examination of whether or not the size (weight) of rattlesnakes collected during roundups over the years has changed would be valuable in assessing the impact on natural populations. Such an analysis was not possible from data available to us because of the lack of information on number of snakes collected for the years 1974-1979 and particularly 1982-1986. Only the weight of snakes collected was available and the numbers we present are estimates for these years.

Estimates and analyses of number of reproductive females collected and lost reproductive potential are speculative but interesting. Increases in number of reproductive females removed from the population and, therefore, lost reproductive potential (number of offspring lost) have potentially significant long-term affects on the stability and persistence of *C. atrox* populations. Our estimates of lost reproductive potential are conservative because 1) we have calculated the number of offspring lost for only one year for each set of reproductive females collected; 2) the mean weight of snakes collected during the roundups was 520 grams, and, therefore, the average rattlesnake collected had been sexually mature for a relatively short period of its reproductive lifetime (assuming the onset of sexual maturity at 500 grams—Tinkle, 1962); and 3) *C. atrox* longevity, from the few data available, appears to be more than 10 years (Klauber, 1972). Lost reproductive potential projected over the reproductive lifetime of an average female rattlesnake would obviously be much higher.

Exposure to Gasoline Fumes

Exposure to gasoline fumes had dramatic and obvious effects on the animals tested. All individuals exposed to fumes, regardless of species or length of time exposed, were unable to exhibit the righting response immediately after removal from test chambers. The species of snakes (*C. atrox* and several colubrids) and the collared lizards (*C. collaris)* appeared to be the most resistant to the effects of gasoline fumes. This conclusion is drawn from the observation that only one snake (an *Elaphe obsoleta*) and one lizard did not recover from 30 minutes of exposure. Among the snakes, *C. atrox* (the target species in the collection) appears to be most resistant to the effects of fumes; only one of 10 rattlesnakes tested did not recover from exposure, and it had been exposed for 60 minutes. Four of nine colubrid snakes tested did not recover from exposure (one at 30 minutes, three at 60 minutes of exposure). Collared lizards were not tested at 60-minute exposure. None of the toads (*B. woodhousei*) or crickets (*A. domesticus*) recovered from 30 minutes of exposure. The exposure experiments that we conducted are conservative because 1) the small sample sizes of each species examined, 2) we did not allow animals to come into physical contact with gasoline, and 3) we removed animals from exposure to fumes after they had become incapacitated, allowing them the opportunity to recover. When gasoline is sprayed into a den during rattlesnake roundups, there is a high probability that animals in that den come into physical contact with gasoline. In addition, loss of the righting response and general decrease in locomotory ability that results from exposure to gasoline fumes may not allow the least resistant of species tested to escape from fumes by exiting the den. This would be a particular problem if animals were driven to the back of a den rather than out of it by the introduction of gasoline.

Affects of gasoline exposure on the potential prey species examined in this study (crickets) may have both short-term and long-term consequences for populations of other species. Our results clearly demonstrate that some portion of the invertebrate prey population may be adversely affected by exposure to gasoline. If invertebrate populations are affected, decreases in prey availability to vertebrates that inhabit underground dens or burrows as well as vertebrates active on the surface could result in predators having to spend more time and energy foraging or extending the area that is being searched for prey. Decreases in the number of prey and potentially energy available to these organisms may have an effect on their survival and reproduction in affected habitats.

Exposure to gasoline fumes also had significant effects on the foraging behavior of two of the species tested. Exposure significantly affected the foraging efficiency of both *Crotaphytus collaris* and *Bufo woodhousei.* In foraging experiments with toads exposed for 10 minutes and lizards for 30 minutes, individuals of both species captured fewer prey animals and took a longer period of time to capture the first prey animal than did unexposed control individuals. Three of the *C. collaris* exposed for 30 minutes did not capture any prey animals during trials, although they repeatedly attempted to do so. Affected toads and lizards appeared to be generally less mobile and required more attempts to capture a given prey item. The decrease in foraging efficiency of animals exposed to fumes has obvious implications for their survival and reproduction. Increased latency to capture prey may increase the time and energy spent foraging, and this would be further increased if animals needed more capture attempts to make a successful capture. This, in combination with fewer total number of prey animals captured by individuals exposed to gasoline fumes, suggests that over the long term such animals may have less energy to channel into growth and reproduction.

Although the results of our study are preliminary, they strongly suggest potential problems for populations of the target species in rattlesnake roundups, western diamondback rattlesnakes (*Crotalus atrox*), as well as other vertebrate and invertebrate species in affected habitats. The data do not appear to support the assertion that *C. atrox* populations are unaffected, perhaps even increasing in density, by mass annual removal of individuals from populations. Although difficult to interpret, the data suggest a need for collection of more extensive quantitative information on the population ecology of rattlesnakes before a precise estimate of the impact of removal on the snake populations can be made. In addition, spraying of gasoline into dens may have direct effects on the health of individuals of other species in the habitat and indirect effects through decreases in quality (decreased prey availability, decreased availability of suitable dens or burrows) of those habitats for the resident species.

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LITERATURE CITED

Beavers, R. A. 1976. Food habits of the western diamond rattlesnake, *Crotalus atrox*, in Texas. Southwestern Nat., 20:503-515.

Fisher, R. A. 1930. The genetical theory of natural selection. Oxford Univ. Press, Oxford, England, 291 pp.

Fitch, H. S. 1970. Reproductive cycles of lizards and snakes. Misc. Publ. Mus. Nat. Hist., Univ. Kansas, 52:1-247.

Formanowicz, D. R., Jr., and E. D. Brodie, Jr. 1985. Unpalatability and toxicity of an introduced species (cinnabar moth larvae) to native predators. Amer. Midland Nat., 113:401-403.

Gloyd, H. K. 1940. The rattlesnakes, genera *Sistrurus* and *Crotalus*, a study in zoogeography and evolution. Spec. Publ. Chicago Acad. Sci., 4:1-270.

Kilmon, J., and H. Shelton. 1981. Rattlesnakes in America and a history of the Sweetwater Jaycees Rattlesnake Roundup. Shelton Press, Sweetwater, Texas, vi + 234 pp.

Klauber, L. M. 1972. Rattlesnakes: their habits, life histories, and influence on mankind. 2nd ed. 2 vols. Univ. California Press, Berkeley and Los Angeles. 1:xxx + 1-740 and 2:xvii + 741-1533.

Smith, H. M., and E. D. Brodie, Jr. 1982. A guide to field identification, reptiles of North America. Golden Press, New York, 240 pp.

Sweetwater Jaycees. 1986. 1986 program.

Tennant, A. 1984. The snakes of Texas. Texas Monthly Press Inc., Austin, 561 pp.

Tinkle, D. W. 1962. Reproductive potential and cycles in female *Crotalus atrox* from northwestern Texas. Copeia, 1962:306-313.

FRESHWATER BIVALVES OF MEDINA LAKE, TEXAS: FACTORS PRODUCING A LOW-DIVERSITY FAUNA

Raymond W. Neck
Texas Parks and Wildlife Department, 4200 Smith School Road, Austin, Texas 78744

Abstract.—The freshwater bivalve fauna of Medina Lake, Texas (a reservoir on the Medina River of the San Antonio River drainage), consists of three species of native unionids, one species of native fingernail clam, and the introduced Asiatic clam. The low-diversity fauna is the result of naturally low species diversity in the source-fauna (of the Medina River) adapted to lotic waters, steepness of reservoir bottom, and frequent major fluctuations in water elevation.

Surveys of various reservoirs in Texas (Neck, 1986*b*; unpublished studies) have revealed generally low species diversity but, at times, high population densities of freshwater bivalves. The severe drought of 1983-1984 resulted in drastic drops in water level in a number of these reservoirs. One of the more severely affected reservoirs was Medina Lake. Strecker (1931) gave no records for Medina Lake, and there are no known published records since his work. This survey was undertaken to determine the species present, to characterize the preferred microhabitats of the species and to analyze the factors that have produced the present fauna of Medina Lake. *Key words*: freshwater bivalves; Medina Lake, Texas.

Medina Lake (Fig. 1) is located in the Texas Hill Country on the mainstem of the Medina River in Medina and Bandera counties. The damsite is located 35 kilometers northwest of San Antonio and 14 kilometers north of the Balcones Fault Zone. Impoundment of water began on 7 May 1913 with completion of the dam by the Bexar-Medina-Atascosa Counties Water Improvement District Number 1 (Dowell and Petty, 1971). Spillway crest is at 324.4 meters (1064.2 feet) above mean sea level; at this elevation a total of 313 million cubic meters (254,000 acre feet) covers 2256 hectares (5575 acres). Lower Cretaceous limestones and dolomites of the Glen Rose Formation and limited areas of Pleistocene and Holocene terraces of the Medina River and tributaries are normally covered by reservoir waters.

Methods

Localities were selected from appropriate quadrangle maps published by the U. S. Geological Survey and were chosen to provide samples from various portions of the reservoir as well as various habitat types. Several localities were chosen on watercourses draining into Medina Lake to determine if these streams function as foci of recolonization following reservoir refill. Bivalves were counted along a two by 200 meter transect. Observations on factors affecting relative abundance of bivalves, both inter- and intrasite, were noted. Conversations with a local resident provided valuable information spanning a longer period of time. A survey of various Texas museums was undertaken to determine which species likely were present in the Medina River within and above the present reservoir limits at the time of impoundment. Limited published records (Strecker, 1931) of the fauna of the Medina River also were consulted. The field survey was performed in August 1984.

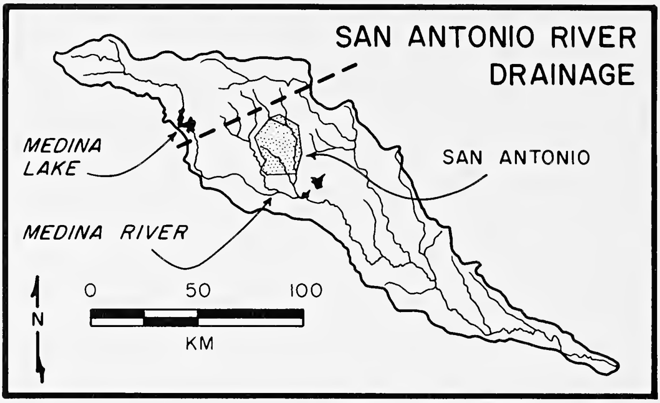

FIGURE 1. Map of San Antonio River drainage, Texas, including Medina Lake.

RESULTS

Faunal Survey

The bivalve fauna of Medina Lake is a low-diversity fauna that is heavily dominated by the nonnative Asiatic clam, *Corbicula fluminea* (Table 1). Native unionid species are rare.

Anodonta imbecilis Say, 1829, is the most abundant and widespread native unionid in Medina Lake. The largest specimen measured 68.5 mm in shell length. In Medina Lake, this species typically is found in mud accumulations on narrow, limestone shelves as well as in deep, firm mud. *Anodonta imbecilis* may be absent from the northern part of the reservoir. The periostracum is pale brown with the posterior rays being slightly darker brown and of only moderate prominence. The greenish blush found in many Texas populations of *A. imbecilis* was not observed in shells from Medina Lake. Nacre is white with only hints of iridescence. This population probably is referable to *horda* Gould, 1855, which may merit recognition as a subspecies.

Cyrtonaias tampicoensis (Lea, 1838) is the largest bivalve found in Medina Lake occurring in deep, firm mud. The largest shell had a length of 129.8 mm. The periostracum of young shells and umbonal portions of older shells are pale brown. Color of periostracum becomes dark brown in older individuals; faint greenish-brown rays are present on the posterior portion of some immature specimens. Nacre varies from white to light purple and salmon; such variation in color may occur in a single shell. This population is referable to *heermanni* Lea, 1861, a variety that is more compressed than most populations of *C. tampicoensis* in Texas. Field and museum specimen surveys indicate that this compressed form is more common in the upstream (piedmont-like) portion of the San Antonio River in the Texas Hill Country than in the downstream portion in the Coastal Plain.

TABLE 1. Results of bivalve transect counts at Medina Lake, Medina and Bandera counties, Texas, in August 1984. Each transect was two by 200 meters.

Locality	*Corbicula fluminea*	*Anodonta imbecillis*	*Cyrtonaias tampicoensis*	*Toxolasma texasensis*	*Sphaerium transversum*	Species totals
Elm Cove	18,475	1	3	0	0	3
Pebble Beach	15,391	5	0	0	0	2
Cedar Point	5,675	1	0	0	0	2
Sawmill Cove	19,229	7	0	0	0	2
Avalon Park	3,255	1	0	0	0	2
Fauries Cove	6,280	18	8	3	0	4
Tschirhart Cove	1,256	2	2	0	0	3
Leibold Camp	1,262	4	2	0	5	4
Wharton's Docks	138	0	0	0	0	1
Upper Reservoir	756	0	0	0	0	1
Alamo Beach	902	0	0	0	0	1
Red Cove	6,318	3	0	0	0	2
12 localities	12	9	4	1	1	—
79,002 individuals	78,937	42	15	3	5	—

Toxolasma texasensis (Lea, 1857) was found at only one locality, but the specimens recovered were larger than most specimens that I have seen from Texas. The largest specimen recovered (presumed female shell) measured 59.7 mm in shell length. The largest presumed male shell measured 56.3 mm in shell length. The periostracum is dark brown whereas the nacre is white with buff highlights. Moderate iridescence is present. The single site (no. 6) was below a normally inundated limestone bluff that would be an area of prime fish microhabitat.The few specimens recovered during this survey compare favorably to shells in the Strecker Museum referred to *mearnsi* Simpson, 1900, by Strecker (1931). However, the extreme variability of *T. texasensis* both between and within geographical areas appears to preclude the acceptance of a subspecific epithet.

Corbicula fluminea (Müller, 1774) is extremely abundant (and the only species found at all collection sites) in Medina Lake but has apparently only recently colonized this reservoir (see below). The largest specimen measured 45.0 mm in shell length. Although some variation in nacre and periostracum color was noted, all examined shells are referable to the "white form" (Hillis and Patton, 1982). Preferred microhabitat is a coarse-grained substrate of limestone and shell fragments with some clay overlying limestone bedrock in relatively shallow water. In general, *C. fluminea* was found in higher energy microhabitats than native unionids. Deep mud substrates supported populations of low density when compared to rocky substrates. The observed microhabitat occurrences are similar to those previously observed for Texas populations of *C. fluminea* (Neck, 1986*a*). *Corbicula fluminea* has not been reported from Medina Lake previously, although Britton (1982) recorded specimens taken from downstream parts of the Medina River in 1979.

Sphaerium transversum (Say, 1829) was represented in Medina Lake at a single site (no. 8). All shells were found *in situ* in a sand deposit in the protected area immediately downstream of an old trunk base of a bald cypress. Shells of *C. fluminea* also were present in this same deposit. Absence of *S. transversum* at other reservoir localities indicates that limestone and mud substrates under several meters of water in Medina Lake are not suitable for this fingernail clam.

Local Informant

Milton Leibold, a septuagenarian, has lived next to the present location of Medina Lake for his entire life. He was quite familiar with the bivalves of this reservoir and referred to the "soft mussel" (*A. imbecilis*) and the "hard mussel" (*C. tampicoensis*). He was not familiar with *T. texasensis* as being different from *C. tampicoensis*. The "small mussel" (*C. fluminea*) had only been seen in the last "four or five years" (questioned in 1984).

Leibold recounted that *A. imbecilis* made an excellent bait for trot lines. He had eaten both *A. imbecilis* and *C. tampicoensis* but wasn't particularly impressed with their taste. In 1983, he had caught channel catfish, *Ictalurus punctatus*, the entrails of which "were so full of the 'small mussel' [*C. fluminea*] that they rattled." He felt that *C. fluminea* was less abundant at the time of this survey (1984) as recently collected catfish did not have nearly as many shells in them.

Especially *A. imbecilis*, but also *C. tampicoensis*, were more common in previous years than presently. This decline "may have" been contemporaneous with the appearance and population explosion of *C. fluminea*. During approximately the same time period the fish fauna also had changed from domination by white bass (*Roccus chrysops*) to domination by large-mouth bass (*Micropterus salmoides*).

Museum Collections and Published Records

As part of a general survey of unionids in Texas, a survey of museum collections is being conducted. This survey has revealed a number of lots containing unionids from the Medina River but none from Medina Lake (except those in the Strecker Museum). Museum collections of Texas Christian University (TCU), The University of Texas at El Paso (UTEP), and Trinity University (TU) were examined. Occurrence of species records in these collections and the only known applicable published records (Strecker, 1931) are presented in Table 2. Specimens that were the basis of the Strecker (1931) records are present in the collection of the Strecker Museum, Baylor University.

Discussion

The most noticeable characteristic of the bivalve fauna of Medina Lake is the low species diversity. This low-diversity fauna is the result of several factors.

Table 2. Literature and museum records of unionids from San Antonio River (other than Medina River), Medina River, and Medina Lake.

	Water body		
Species	San Antonio River	Medina River	Medina Lake
Anodonta grandis	1, 2, 4*		
Anodonta imbecillis	1, 4	1	X
Amblema plicata	1, 2, 4	1, 2, 3	
Megalonaias nervosa	2, 4		
Quadrula quadrula apiculata	2, 3, 4	2, 3	
Quadrula aurea	1, 2, 4	1, 3	
Tritogonia verrucosa	1, 4	2, 3	
Cyrtonaias tampicoensis	1, 2, 4	1, 3	X
Lampisilis bracteata		4	
Lampsilis radiata hydiana	2, 4	3	
Lampsilis teres	1, 2, 4	1	
Toxolasma texasensis	1, 2, 4	1	X
Species totals	11	10	3

*Numbers refer to sources as follows: 1) Strecker, 1931; 2) collection at TCU; 3) collection at UTEP; 4) collection at TU.
X = records established in this study.

A small number of unionid species (10) is native to the entire Medina River drainage (Table 2). Four of the 10 (*Lampsilis teres, Tritogonia verrucosa, Quadrula guadrula apiculata, Lampsilis radiata hydiana*) require soft substrate that may not have been present in the portion of the Medina River now covered by Medina Lake. A fifth species (*Amblema plicata*) may have occurred in deeper pools of this portion of the river. Two species (*Quadrula aurea* and *Lampsilis bracteata*) are characteristic of clear, fast-running waters of the Texas Hill Country and would not be expected to survive in the lentic waters of Medina Lake. The three remaining species are presently found in Medina Lake. Several of the above species (*L. teres, L. r. hydiana Q. q. apiculata,* and *A. plicata*) are able to survive in some Texas reservoirs (Neck, 1986*b*; unpublished data). Reasons for their absence in Medina Lake are discussed in the following paragraphs.

Most of the bottom of Medina Lake consists of moderate and steep limestone slopes of the Glen Rose Formation. Most of the bivalve species native to the Medina River were unable to adapt to such habitats once they were inundated. As noted above, *Anodonta imbecilis* is able to survive in mud-limestone detritus accumulations on shelves of limestone. These accumulations are generally less than five centimeters in depth; no large unionids would be able to burrow and maintain proper orientation in such a microhabitat. Deeper, nonindurated substrates are restricted to flooded broad creek valleys. In these cove areas, *C. tampicoensis* and *T.*

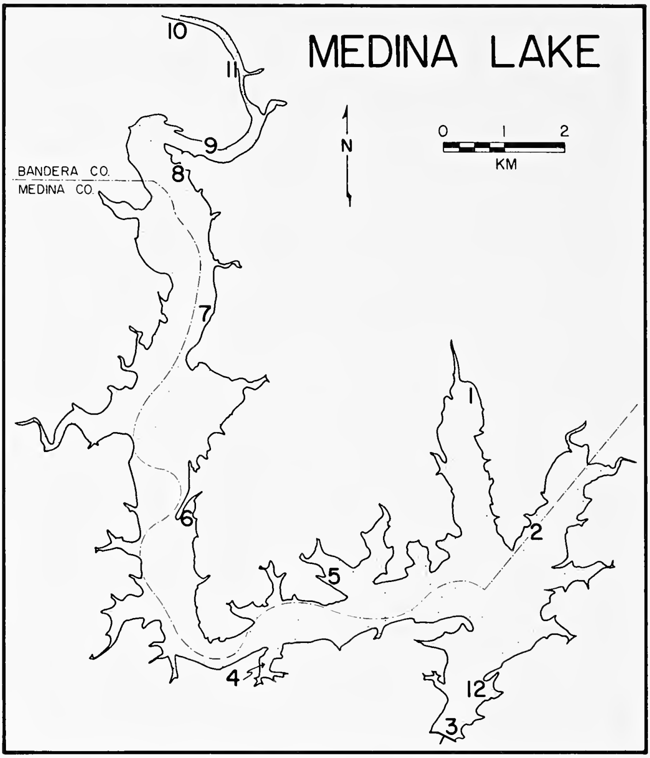

FIGURE 2. Map of Medina Lake, Texas, with collection sites indicated. Numbers are keyed to Appendix.

texasensis are able to survive; even *A. imbecilis* and *C. fluminea* have denser populations in these mud substrate areas than on limestone slopes.

An additional and probably more significant factor is the periodic occurrence of drastic drawdowns (Reeves et al., 1984), which expose vast amounts of reservoir bottom and cause death of numerous bivalves by thermal stress, desiccation and predation. The major causal factor for drawdowns is downstream demand for irrigation of truck crops. Droughts are frequent and further increase the normally high evaporation rates. Another important factor results from the location of Medina Lake in the recharge zone of the Edwards Aquifer (Garza, 1962), which is utilized for agricultural, industrial, and municipal needs of more than one million people in central Texas. Significant amounts of reservoir water enter the aquifer system. Such dynamic changes in water levels do not allow the bivalve fauna to reach an equilibrium of species diversity (White and White, 1977).

Habitat changes affect freshwater mussels both directly on the individual animals themselves and indirectly upon the freshwater fish fauna of the area. Freshwater fish act as a temporary host to the parasitic glochidium stage. No records of fish hosts are known for Texas freshwater mussels. Unpublished fishery surveys in the files of the Texas Parks and Wildlife Department reveal that Medina Lake still supports a diverse freshwater fish fauna, although the relative abundance of species undoubtedly has changed during the period of inundation. The effects of a change in a fish fauna as a factor in change in a related freshwater mussel fauna is unknown.

Acknowledgments

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Appendix

Collection sites are as follows (keyed to Fig. 2): 1) Samsel residence, Elm Cove; 2) Pebble Beach Park, Haby's Cove; 3) Cedar Point landing; 4) Sawmill Cove; 5) Avalon Park; 6) Fauries Cove; 7) Tschirhart Camp; 8) Leibold Camp; 9) Wharton's Docks; 10) Upper Reservoir; 11) Alamo Beach; and 12) Red Cove.

Literature Cited

Britton, J. C. 1982. Biogeography and ecology of the Asiatic clam, *Corbicula*, in Texas. Pp. 21-31, *in* Proceedings of the Symposium on Recent Benthological Investigations in Texas and Adjacent States (J. R. Davis, ed.), Texas Acad. Sci., Austin, 278 pp.

Dowell, C. L., and R. G. Petty. 1971. Dams and reservoirs in Texas, Part III. Texas Water Development Board Rept., 126:1-687.

Garza, S. 1962. Recharge, discharge, and changes in ground-water storage in the Edwards and associated limestones, San Antonio area, Texas. A progress report on studies, 1955-59. Texas Board Water Engin. Bull., 6201:1-42.

Hillis, D. M. and J. O. Patton. 1982. Morphological and electrophoretic evidence for two species of *Corbicula* (Bivalvia: Corbiculidae) in North America. Amer. Midland Nat., 104:74-80.

Neck, R. W. 1986*a*. *Corbicula* in public recreation waters of Texas: Habitat spectrum and clam-human interactions. Amer. Malacol. Bull., Spec. Ed., 2:179-184.

——. 1986*b*. Freshwater bivalves of Lake Tawakoni, Sabine River, Texas. Texas J. Sci., 38:241-249.

Reeves, R. D., R. W. Maclay, and G. B. Ozuna. 1984. Compilation of hydrologic data for the Edwards Aquifer, San Antonio area, Texas, 1981, with 1934-81 summary. Edwards Underground Water District Bull., 41:1-135.

Strecker, J. K. 1931. The distribution of the naiades or pearly fresh-water mussels of Texas. Baylor Univ. Mus. Spec. Bull., 2:1-71.

White, D. S., and S. J. White. 1977. Observations on the pelecypod fauna of Lake Texoma, Texas and Oklahoma, after more than 30 years impoundment. Southwestern Nat., 22:235-254.

GENERAL NOTES

POLYMORPHISMS IN CHROMOSOME 5 OF THE WHITE-FOOTED MOUSE, *PEROMYSCUS LUECOPUS* (RODENTIA: CRICETIDAE)

Frederick B. Stangl, Jr., and Robert J. Baker
The Museum and Department of Biological Sciences, Texas Tech University, Lubbock, Texas 79409

Within the white-footed mouse, *Peromyscus leucopus*, there are three marker chromosomes (pairs 5, 11, and 20—see Committee, 1977) that distinguish two widely distributed and biochemically differentiated chromosomal races (Baker et al., 1983; Nelson et al., 1987; Stangl and Baker, 1984*a*). The chromosomal variation that characterizes the two races is presumed to be two pericentric inversions (Baker et al., 1983), with an acrocentric morph (5 and 11 in the northeastern race, and 20 in the southwestern race) and a biarmed morph (5 and 11 in the southwestern race, and 20 in the northeastern race). This report is concerned with the frequency and types of chromosomal rearrangements in these three marker pairs of chromosomes that distinguish the two races.

Frequency and types of chromosomal rearrangements from the vicinity where these two races interface in Oklahoma (Stangl, 1986) is significant because of the hypothesis by Shaw et al. (1983) that hybrid zones are a primary source of new genetic information, including chromosomal rearrangements, and because any new rearrangement might lead to a misidentification of the status of individuals as to this hybrid origin.

We examined in detail the G- and C-banded morphology of chromosomes 5, 11, and 20 in the 269 individuals reported by Stangl (1986). Of the five to 10 different spreads examined for each specimen, no variation other than that which distinguishes the races was found in pairs 11 and 20. An euchromatic rearrangement and heterochromatic variation were noted in chromosome 5 (Fig. 1). The situation associated with these rearrangements is discussed below.

Euchromatic variation.—Four specimens were heterozygous for a condition where a block of euchromatin has been inserted proximal to the centromere of the acrocentric morph (Fig. 1C). Specimens with this rearrangement (TK voucher number, sex, condition of homolog, and collection locality) are as follows: TK 20741, female, acrocentric, 1.6 mi. E Vivian, in Mcintosh Co., Oklahoma; TK 20819, male, acrocentric, 4.5 mi. E Wetumka, in Hughes Co., Oklahoma; TK 20902, female, biarmed, 7.7 mi. E County Courthouse in Chickasha, Grady Co., Oklahoma; TK 20943, female, acrocentric, 2.1 mi. E Dustin, in Hughes Co., Oklahoma. This euchromatic rearrangement is unique for any thus far described for *Peromyscus* (for recent summaries, see Rogers et al., 1984; Smith et al., 1986; Stangl and Baker, 1984*b*), where some 30 species have been G- and C-banded. This rearrangement could have arisen by a reciprocal translocation or by an amlified chromosomal region.

Heterochromatic variation.—The acrocentric morph of chromosome 5 exhibited considerable quantitative variation in the amount of heterochromatin comprising short arms, from the apparent absence (Fig. 1A) to about 20 percent of the total length of the euchromatic arm (Fig. 1D). Such variation is difficult to quantify, as the ability to detect short arms depends, in many instances, on the degree of contraction of the chromosomes. Such a continuum of a character state, plus the problems associated with the stage of contraction, makes cytosystematic use of the presence or relative amounts of heterochromatin in chromosome 5 in *Peromyscus leucopus* difficult.

If a high number of new arrangements arise among individuals in the chromosomal hybrid zone, then we might expect to see several different types of rearrangements.

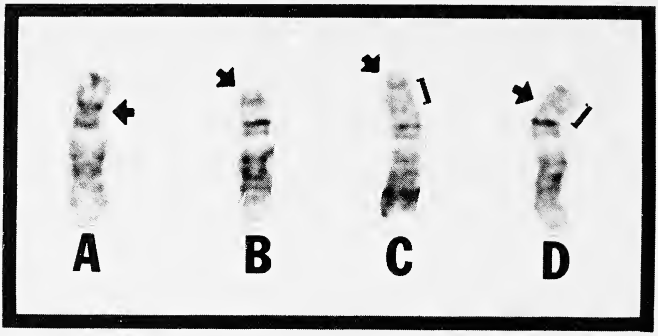

FIGURE 1.—Variation in chromosome 5 in *Peromyscus leucopus*, as determined by G-banding studies: A, biarmed (characteristic of southwestern cytotype); B, acrocentric (characteristic of northeastern cytotype); C, acrocentric with inserted euchromatin (brackets); D, acrocentric morph with heterochromatic short arms (brackets). Arrows indicate location of centromere.

However, our sample did not contain variations in cells from within an individual, and the unusual euchromatic insertion exhibited by the four specimens appeared to represent identical conditions. Therefore, the possibility that this observed chromosomal rearrangement arose in a single ancestral individual cannot be eliminated. However, it is clear that specific euchromatic rearrangements do arise repeatedly in the same species as documented by the reciprocal translocation of chromosomes 11 and 22 in unrelated human families (Fraccaro et al., 1980). It is also of interest to note that the four individuals with the euchromatic rearrangement were otherwise pure parental cytotypes.

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LITERATURE CITED

Baker, R. J., L. W. Robbins, F. B. Stangl, Jr., and E. C. Birney. 1983. Chromosomal evidence for a major subdivision in *Peromyscus leucopus*. J. Mamm., 64:356-359.

Committee for Standardization of Chromosomes for *Peromyscus* 1977. Standardized karyotype of deer mice, *Peromyscus* (Rodentia). Cytogenet. Cell Genet., 19:38-43.

Fraccaro, M., J. Lindstein, C. E. Ford, L. Iselius, A. Antonelli, P. Aula, A. Aurias, A. D. Bain, M. Bartsch-Sandoff, F. Bernardi, L. F. Buchanan, A. H. Cameron, A. de la Chapelle, G. Ciuffa, C. Cuoco, B. Durillaux, G. Dutton, M. A. Ferguson-Smith, D. Francesconi, J. P. Gernaedts, G. Gimelli, J. Guerguen, E. Garsner, A. Hagemejer, F. J. Hansen, P. E. Holings, T. W. J. Hustinx, A. Kaakmen, J. J. P. van de Kamp, H. von Koskull, J. Lejeune, R. H. Lindebaum, H. R. McCreanor, M. Mikkelsen, F. Mitelman, B. Nicoletti, I. Nislby, A. Nilsson, B. Noel, E. Padavoni, F. Pasquali, J. de Pater, C. Pederson, F. Peteson, E. B. Robson, J. Rotman, M. Ryynanen, E. Sachs, J. Salat, R. H. Smythe, I. Stabell, I. Subrt, P. Vampirelli, G. Wessner, L. Zergollern, and O. Zuffardi. 1980. The 11q; 22q: European collaborative analysis of 43 cases. Human Genet., 56:21-51.

Nelson, K., R. J. Baker, and R. L. Honeycutt. 1987. Mitochondrial DNA and protein differentiation between hybridizing cytotypes of the white-footed mouse, *Peromyscus leucopus*. Evolution, 41:864-872.

Rogers, D. S., I. F. Greenbaum, S. J. Gunn, and M. D. Engstrom. 1984. Cytosystematic value of chromosomal inversion data in the genus *Peromyscus* (Rodentia: Cricetidae). J. Mamm., 65:457-465.

Shaw, D. D., P. Wilkinson, and D. J. Coates. 1983. Increased chromosomal mutation rate after hybridization between two subspecies of grasshoppers. Science, 220:1165-1167.

Smith, S. A., R. D. Bradley, and I. F. Greenbaum. 1986. Karyotypic conservatism in the *Peromyscus mexicanus* group. J. Mamm., 67:584-586.

Stangl, Jr., F. B. 1986. Aspects of a contact zone between two chromosomal races of *Peromyscus leucopus* (Rodentia: Cricetidae). J. Mamm., 67:465-473.

Stangl, Jr., F. B., and R. J. Baker. 1984*a*. A chromosomal subdivision in *Peromyscus leucopus*: implications for the subspecies concept as applied to mammals. Pp. 139-145, *in* Festschrift for Walter W. Dalquest in honor of his sixty-sixth birthday (N. V. Horner, ed.). Dept. Biol., Midwestern State Univ., Wichita Falls, Texas, xx + 163 pp.

———. 1984*b*. Evolutionary relationships in *Peromyscus*: congruence in chromosomal, genic, and classical data sets. J. Mamm., 65:643-654.

Current address of Stangl: *Department of Biology, Midwestern State University, Wichita Falls, Texas 76308.*

THE TEXAS MOUSE, *PEROMYSCUS ATTWATERI* (RODENTIA: CRICETIDAE), IN HOOD AND JOHNSON COUNTIES, TEXAS

Chris T. McAllister

Renal-Metabolic Laboratory (151-G), Veterans Administration Medical Center,
4500 S. Lancaster Road, Dallas, Texas 75216, and Department of Biological Sciences,
University of North Texas, Denton, Texas 76203

The Texas Mouse, *Peromyscus attwateri* J. A. Allen, 1895, ranges from southeastern Kansas and southwestern Missouri southward through northern Arkansas and eastern Oklahoma to southern Texas (Schmidly, 1973, 1974; Hall, 1981). In Texas, the species reaches the southern limit of its known distribution along the extreme southern edge of the Balcones Escarpment in Uvalde County (Schmidly, 1973). Based on three specimens examined by Schmidly (1973), the easternmost localities of record for *P. attwateri* in the state (from north to south) are 2 mi. S Marysville, Cooke County, 7 mi. N Iredell, Bosque County, and 20 mi. NW Austin, Travis County.

Between 27 March and 19 May 1988, six adult (two males and four females) *P. attwateri* were collected 17.5 km. SE Granbury, off FM 2174, at Fort Spunky, Hood County. The trap site was an abandoned gravel pit (elevation, 244 meters) in the Cross Timbers-Grand Prairie (oak-hickory forest community) of north-central Texas. Habitat of the area includes disturbed upland prairie grasslands and juniper-covered limestone hills (cedar-glade), with stony and gravelly soils dominated by *Schizachyrium scoparium, Andropogon gerardii, Panicum virgatum, Bouteloua curtipendula, Stipa leucotricha, Juniperus virginiana, Prosopis glandulosa, Quercus fusiformis, Q. texana, Opuntia rafinesquei*, and *Yucca* sp. Unfortunately, the landowner completely cleared the area for cattle grazing, and, thus far, no additional *P. attwateri* have been collected there. As reinterated by Jones et al. (1987), land-use practices continue to impact the distribution of terrestrial mammals in the state.

On 12 March 1989, a single adult female Texas mouse was trapped 3.5 km. ENE Nemo, off county road 406, at the Ken Fry Ranch, Johnson County (elevation, 259 meters). This site is 7.3 km. south-southeast of the first locality along a limestone escarpment characterized by similar vegetation. These two localities represent new county records for *P. attwateri* and are 37 kilometers north-northeast and 31 kilometers northeast, respectively, of the nearest previous locality of record in Bosque County (Schmidly, 1973). Most importantly, these records help to partially fill a distributional hiatus between extreme north-central populations and those from the western Cross Timbers (see Schmidly, 1973).

Other rodent associates trapped with *P. attwateri* included *P. leucopus texanus* (Woodhouse, 1853), *P. maniculatus pallescens* (J. A. Allen, 1896), *Neotoma micropus micropus* Baird, 1855, *Reithrodontomys montanus griseus* V. Bailey, 1905, *R. fulvescens laceyi* J. A. Allen, 1896, *Sigmodon hispidus texianus* (Audubon and Bachman, 1853), *Baiomys taylori taylori* (Thomas, 1887), *Perognathus flavus merriami* (J. A. Allen, 1892), and *Chaetodipus hispidus hispidus* (Baird, 1858).

The Texas mouse is typically a species associated with rocky outcroppings of dolomite and limestone rock that include juniper cover (Garner, 1967; Schmidly, 1973; Jones et al., 1987). The sites listed herein are characterized as such and because this kind of habitat (ecological requirement) extends eastward some eight kilometers to near Cleburne State Park, it would not be surprising to find *P. attwateri* ranging farther into south-central Johnson County.

Voucher specimens of *P. attwateri* are deposited in the Arkansas State University Museum of Zoology. I thank V. R. McDaniel for curatorial assistance, K. L. Fry and G. Roberts for allowing me to collect on their properties, E. G. Zimmerman for confirming rodent identifications, and D. J. Schmidly for helpful suggestions. I also acknowledge the Texas Parks and Wildlife Department for providing Scientific Collecting Permit no. SP044-1.

Literature Cited

Garner, H. W. 1967. An ecological study of the brush mouse, *Peromyscus boylii*, in western Texas. Texas J. Sci., 19:283-291.

Hall, E. R. 1981. The mammals of North America. John Wiley and Sons, New York, 2nd ed., 2:vi + 601-1181 +*90*.

Jones, C., R. D. Suttkus, and M. A. Bogan. 1987. Notes on some mammals of north-central Texas. Occas. Papers Mus., Texas Tech Univ., 115:1-21.

Schmidly, D. J. 1973. Geographic variation and taxonomy of *Peromyscus boylii* from Mexico and the southern United States. J. Mamm., 54:111-130.

———. 1974. *Peromyscus attwateri.* Mamm. Species, 48:1-3.

RANGE EXTENSIONS FOR *ISOSTICHOPUS BADIONOTUS* SELENKA, 1867 AND *HOLOTHURIA* (*HALODEIMA*) *GRISEA* SELENKA, 1867 (ECHINODERMATA: HOLOTHUROIDEA).

Chris Pomory

Texas A&M University, Biology Department, College Station, Texas 77843

Holothurians of the coast of Texas are poorly studied. Previous records have been given by Burke (1974), Pawson and Shirley (1977), and Miller and Pawson (1984).

A specimen of *Isostichopus badionotus* was collected from the wreck of the *V. A. Fogg* at a depth of 30 meters approximately 50 mi. S Galveston, Texas (28° 36′ N, 94° 48′ W), on 26 July 1987. The specimen is 100 mm in length with an overall coloration of pale tan. The dorsal surface has numerous dark brown warts. The ventral surface has a distinct sole with three bands of darker podia. The ossicles match descriptions given by Miller and Pawson (1984) and Deichmann (1954).

I. badionotus has a wide range from Ascension Island (Pawson, 1978) throughout the Caribbean (Clark 1922, 1933, 1942; Pawson, 1976) to the Flower Gardens of Texas (Burke, 1974). This documentation extends the known range of *I. badionotus* 70 miles farther to the northwest.

A specimen of *Holothuria* (*Halodeima*) *grisea* was collected from the Port Mansfield rock jetty on the Texas coast (26° 33′ N, 97° 16′ W) on 27 July 1986. The specimen is 30 mm in length with an overall coloration of mottled gray. The dorsal surface has many low warts. The ventral surface is covered by numerous yellow podia.

H. grisea has been reported from the Caribbean as far north as Florida and along the Central American coast (Clark 1933). Deichmann (1954) doubted whether it occurred in the northern Gulf of Mexico. It was not reported by Burke (1974) for the Flower Garden reefs of Texas. Thus, coastal Texas is a considerable extension of its known range. The specimen is small, because the species is reported to reach 250 mm; it was collected near shore underneath rocks at low tide. It is probably not a year-round inhabitant of coastal Texas. which is subject of temperature fluctuations.

I wish to thank M. K. Wicksten, Texas A&M University for reviewing the manuscript and D. L. Pawson, Smithsonian Instituion for identification of *H. grisea.*

Literature Cited

Burke, T. E. 1974. Echinoderms. Pp. 312-331, *in* Biota of the West Flower Garden Bank (T. J. Bright and L. H. Pequegnat, eds.), Gulf Publ. Co., Houston, Texas, 435 pp.

Clark, H. L. 1922. The holothurians of the genus *Stichopus.* Bull. Mus. Comp. Zool., Harvard Univ., 65:39-74.

———. 1933. A handbook of the littoral echinoderms of Porto Rico and the other West Indian Islands. Sci. Surv. Porto Rico, Virgin Islands, 16(1):1-147.

———. 1942. The echinoderm fauna of Bermuda. Bull. Mus. Comp. Zool., Harvard Univ., 89:367-391.

Deichmann, E. 1954. The holothurians of the Gulf of Mexico. Pp. 381-410, *in* The Gulf of Mexico, its origin, waters and marine life (P. S. Galtsoff, ed.), U.S. Fish Wildlife Serv., Fish. Bull., 55(89):1-604.

Miller, J. E., and D. L. Pawson. 1984. Holothurians (Echinodermata: Holothuroidea). Mem. Hourglass Cruises, 7:1-79.

Pawson, D. L. 1976. Shallow-water sea cucumbers (Echinodermata: Holothuroidea) from Carrie Bow Cay, Belize. Proc. Biol. Soc. Washington, 89:369-382.

———. 1978. The echinoderm fauna of Ascension Island, South Atlantic Ocean. Smithsonian, Contrib. Mar. Sci., 2:1-31.

Pawson, D. L., and T. C. Shirley. 1977. Occurrence of the subgenus *Holothuria* (*Holothuria*) in the Gulf of Mexico (Echinodermata: Holothuroidea). Proc. Biol. Soc. Washington, 90:915-920.

FIRST SPECIMEN OF A HOG-NOSED SKUNK (*CONEPATUS MESOLEUCUS*) FROM BEXAR COUNTY, TEXAS

Jerry W. Dragoo, Daniel B. Fagre, David J. Schmidly, and Linda B. Penry

Department of Wildlife and Fisheries Sciences, Texas A&M University,
College Station, Texas 77843 (JWD, DBF, DJS) and Texas Animal Damage Control
Service, 651 S Main, San Antonio, Texas 78204 (LBP)

We recently acquired a female hog-nosed skunk (*Conepatus mesoleucus mearnsi* Merriam, 1902), TCWC 49679, obtained on 25 July 1988 in the back yard of the home of Mr. and Mrs. Edward F. O'Hara in southwestern San Antonio. This specimen documents the occurrence of *C. mesoleucus* in Bexar County, Texas.

We have examined specimens of Texas skunks in approximately 40 museums but have found among them no *C. mesoleucus* from Bexar County. Hog-nosed skunks were reported from Bexar County before the turn of the century (Allen, 1896), but these reports were based on sight records not specimens. Allen (1896) published excerpts from H. P. Attwater's field notes for mammals in Bexar County and noted that several hog-nosed skunks (*C. mapurito*) had been killed there. Allen (1894) referred to hog-nosed skunks from Aransas County as *C. mapurito*, but made no distinction between the two currently recognized species (*C. mesoleucus* and *C. leuconotus*) that occur in southern Texas. Bailey (1905) maintained that records reported by H. P. Attwater from San Antonio probably were referable to *C. mesoleucus.*

Since these early reports, Bexar County has been located on the southwestern edge of the distribution of *C. mesoleucus* (Davis, 1960; Hall and Kelson, 1959). However, Raun and Wilks (1961) reported a specimen, tentatively identified as *C. mesoleucus*, from 8 mi. (12.9 km.) NW Jourdanton, Atascosa County (24 kilometers south of the locality reported here and outside the otherwise known range of both species) and commented that this specimen appeared to be morphologically intermediate between *C. mesoleucus* and *C. leuconotus.* On the basis of their record, recent authors (Davis, 1966, 1974; Hall, 1981; Schmidly, 1984) have included Atascoas County within the range of *C. mesoleucus.* However, if Raun and Wilks (1961) were correct, Atascosa and Bexar counties may be an area of potential contact between these two taxa of skunks. A closer examination of more specimens of hog-nosed skunks from both counties is needed to determine the exact distribution of the two species in southern Texas and whether or not these taxa hybridize in this region.

Van Gelder (1968) considered specimens of *Conepatus* with fully erupted permanent dentition and with fused and undetectable basisphenoid-basioccipital sutures to be adults. Our specimen had no visible sutures, and all the teeth were extremely worn. Based on these characters we judge our specimen to be a mature adult.

The following cranial measurements (mm), which were described and illustrated by Van Gelder (1968) and were used by Hall and Kelson (1952) to illustrate size differences between *C. mesoleucus mearnsi* and *C. leuconotus texensis*, of this specimen are: condylobasal length, 65.50; zygomatic breadth, 45.50; mastoid breadth, 37.75; length of upper toothrow, 25.90; length of maxillary toothrow, 21.25; outside length of P4, 6.95; outside length of M1, 7.20; breadth of M1, 7.95. External measurements (mm) are as follows: total length, 627; length of tail, 186; length of hind foot, 66; length of ear, 25. The specimen weighed 1.9 kg. These measurements are comparable to those of other specimens of *C. m. mearnsi* reported by Hall and Kelson (1952). This female skunk was not lactating, had three pair of mammae, and showed no indication of having been suckled. We examined the uterus and found no embryos or placental scars.

We thank Sara A. Drumm for her initial contact with us and her subsequent offer to collect skunks from the San Antonio area. We also thank Bill Clay, Assistant to the State Director, Texas Animal Damage Control Service, for his assistance and cooperation in collecting skunks from San Antonio and southern Texas. Finally, we thank Tom E. Lee, Luis A. Ruedas, Gary S. Drew, John W. Bickham, and William H. Neill for reviewing early drafts of this manuscript. We acknowledge the support of Texas Parks and Wildlife Department to investigate the status of the Gulf Coast hog-nosed skunk. This paper represents contribution no. TA24329 of the Texas Agricultural Experiment Station.

LITERATURE CITED

Allen, J. A. 1894. On the mammals of Aransas County Texas, with descriptions of new forms of Lepus and Oryzomys. Bull. Amer. Mus. Nat. Hist., 6:165-198.

———. 1896. On mammals collected in Bexar County and vicinity, Texas by Mr. H. P. Attwater, with field notes by the collector. Bull. Amer. Mus. Nat. Hist., 8:47-80.

Bailey, V. 1905. Biological survey of Texas. N. Amer. Fauna, 25:1-222.

Davis, W. B. 1960. The mammals of Texas. Bull. Game and Fish Comm., Austin, 41:1-252.

———. 1966. The mammals of Texas. Bull. Game and Fish Comm., Austin, 41:1-267.

———. 1974. The mammals of Texas. Bull. Game and Fish Comm., Austin, 41:1-294.

Hall, E. R. 1981. Mammals of North America. John Wiley and Sons, New York, 2:vi + 601-1187 + *90.*

Hall, E. R., and K. R. Kelson. 1952. Comments on the taxonomy and geographic distribution of some North American marsupials, insectivores and carnivores. Univ. Kansas Publ., Mus. Nat. Hist., 5:319-341.

———. 1959. The mammals of North America. The Ronald Press Co., New York, 2:vii + 537-1083 + *79*.

Raun, G. G., and B. J. Wilks. 1961. Noteworthy records of the hog-nosed skunk (*Conepatus*) from Texas. Texas J. Sci., 13:204-205.

Schmidly, D. J. 1984. The furbearers of Texas. Bull. Texas Parks and Wildlife Dept., 111:1-55.

Van Gelder, R. G. 1968. The genus *Conepatus* (Mammalia, Mustelidae): variation within a population. Amer. Mus. Novit., 2322:1-37.

A NEW RECORD OF *TYMPANOCTOMYS* (OCTODONTIDAE) FROM MENDOZA PROVINCE, ARGENTINA

Ricardo A. Ojeda, Virgilio G. Roig, Elba P. De Cristaldo, and
Cecilia N. De Moyano
Zoologia y Ecologia Animal, Centro Regional de
Investigaciones Cientificas y Tecnicas, C.C. 507, 5500 Mendoza, Argentina

The natural history, distribution, and taxonomic status of the red vizcacha rat, *Tympanoctomys barrerae* (Lawrence, 1941) is poorly known (Olrog and Lucero, 1981). While some reviewers (Contreras et al., 1987; Honacki et al., 1982; Reig, 1987; Woods, 1984) have considered *Tympanoctomys* congeneric with *Octomys*, others (Cabrera, 1961; Mares and Ojeda, 1981; Olrog and Lucero, 1981; Yepes, 1942) have recognized it as a separate genus. We adopt here the latter view.

This species has been recorded from only a few places within the central-western portion of the Monte Desert of Argentina. The scanty records of *T. barrerae* include specimens from the following localities of Mendoza Province: La Paz (type locality; Museum of Comparative Zoology); Malargue (specimens housed at the Museo Argentino de Ciencias Naturales of Buenos Aires); Nihuil and Catitas (Yepes, 1942), and from the vicinity of Desaguadero (Torres-Mura et al., 1989). The IADIZA Mammal Collection in Mendoza, houses three specimens from the latter locality collected by one of us (RAO) and by L. Contreras. A recent record from the Province of La Pampa (Justo et al., 1985) completes the list of known localities for the species.

Figure 1.—Lateral view of museum skin of *Tympanoctomys barrarae* from MAB Reservation of Ñacuñan, Santa Rosa, Argentina. Note long, tuffted tail.

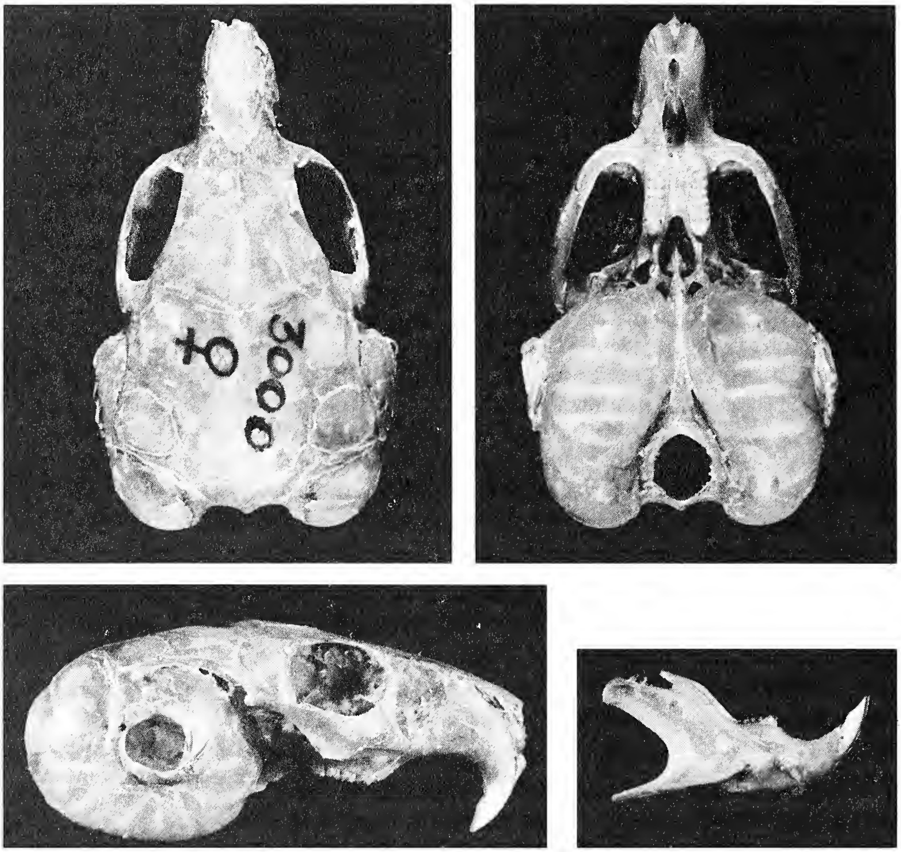

FIGURE 2.—Dorsal, ventral, and lateral views of skull, and lateral view of right mandible of *Tympanoctomys barrerae*, IADIZA 3000, female. See text for cranial measurements.

On 12 December 1987, during part of a long-term ecological research project on the vertebrates of the Monte Desert, a pregnant female was trapped on the MAB Reservation of Ñacuñan (34° 02′S, 67° 58′W), in the Department of Santa Rosa, Mendoza. The distance between the reservation and previously known locality records ranges from 75 to 230 kilometers. The individual, the general description and measurements of which are given below, was live-trapped in a Sherman trap baited with rolled oats. The dominant vegetation of the habitat included *Larrea cuneifolia, L. divaricata, Atriplex lampa*, and a variety of grasses and forbs (for example, *Chloris, Pappophorum, Plantago*). Scattered legumes such as *Prosopis flexuosa* and *Geoffroea decorticans* also were present (Ojeda, 1989). In this creosote bush-grass habitat, mean percent of plant coverage (shrubs, grasses and forbs combined) was 85 percent.

The assemblage of small mammals (less than 100 grams) that coexist in this habitat include *Graomys griseoflavus, Eligmodontia typus, Calomys musculinus, Akodon molinae* (Rodentia, Cricetidae), and *Marmosa pusilla* (Marsupialia, Didelphidae). Other medium and large (more than 100 grams) hystricognath rodents present in the area are *Galea musteloides, Microcavia australis, Dolichotis patagonum* (Caviidae), *Lagostomus maximus* (Chinchillidae), and *Ctenomys mendocinus* (Ctenomyidae). The specimen here reported as *T. barrerae* was deposited in the IADIZA Mammal Colleciton, Mendoza, Argentina (no. 3000).

The following measurements and description may prove to be useful for future comparisons: total length, 295 mm; tail, 155; hind foot (including claws), 34; ear from notch, 18.8; greatest length of skull, 39.6; condylobasal length, 35.9; least interorbital breadth, 8.2; zygomatic breadth, 19.2; length maxillary toothrow, 5.0; length mandibular toothrow, 5.0; bullar width, 11.4; bullar length, 18.4; greatest length mandible, 19.6; diastema length, 9.0; weight, 82 grams.

The dorsal pelage is buffy. The specimens from Desaguadero are more yellowish colored than the one from Ñacuñan. Hairs in the middorsal region are 15-19 mm long, and the underparts are white. The transition between the dorsal and ventral region is not as marked as in the specimens from Desaguadero. The tail is bicolored, well haired, and the tip is pencilled. The anterior portion of the tail (37 percent) is agouti colored, whereas the terminal portion is dark brown to reddish brown. Hairs at the tip of the tail are 19-25 mm long. The hind feet are covered with long whitish gray hairs. The ears are short, with a well-defined region of white hairs along the middle part of the inside edge. A preauricular tuft is present.

Although the Reservation of Ñacuñan has been actively trapped during the last 16 years, no record of the red vizcacha rat has been reported. This "unusual" record of a pregnant individual suggests either a low resident population, elusive habits, and an avoidance of box-like traps, or represents an immigrant from surrounding sandy habitats. Based on our field experience and that of various colleagues, closely related species, such as *Octomys mimax*, also exhibit trap shyness. Budin noted that they are (see Thomas, 1920, 1921)" . . . entirely unknown to the natives; rare and very difficult to trap."

This desert-adapted species is endemic to the Monte ecosystem, and its patchy distribution might reflect Pleistocene refugia dating from glacial and interglacial periods (Mares, 1973). The record from Ñacuñan expands the western distribution as well as the range of known habitats for *Tympanoctomys* (considered to inhabit sand dunes and salt pans—Yepes, 1942). Whether or not the occurrence of *Tympanoctomys* in the central Monte Desert is a recent colonization remains a matter of speculation.

We wish to thank J. Braun, L. Contreras, and J. Knox Jones, Jr., for reviewing the manuscript. Photographs were taken by Mr. Alvarez at the Centro Regional de Investigaciones Cientificas y Tecnicas de Mendoza. Field work was supported by a grant (PID no. 3011800/85) from the Consejo Nacional de Investigaciones Cientificas y Tecnicas de Argentina.

LITERATURE CITED

Cabrera, A. 1961. Catálogo de los mamíferos de America del Sur II. (Sirenia-Perissodactyla-Artiodactyla-Lagomorpha-Rodentia-Cetacea). Rev. Mus. Argentino Cien. Nat. "Bernardino Rivadavia," Zoologia, 4:309-732.

Contreras, L., J. C. Torres-Mura, and J. L. Yañez. 1987. Biogeography of octodontid rodents: an eco-evolutionary hypothesis. Pp. 401-411, *in* Studies in neotropical mammalogy: essays in honor of Philip Hershkovitz (B. D. Patterson and R. M. Timm, eds.). Fieldiana Zool., n.s., 39:vii + 1-506.

Honacki, J. H., K. E. Kinman, and J. W. Koeppl (eds.). 1982. Mammal species of the world. The Association of Systematics Collections, Lawrence, Kansas, ix + 694 pp.

Justo, E. R., C. I. Montalvo, and J. M. De Santis. 1985. Nota sobre la presencia de *Tympanoctomys barrerae* (Lawrence, 1941) en La Pampa (Rodentia: Octodontidae). Hist. Nat., Argentina, 28:243-244.

Mares, M. A. 1973. Climates, mammalian communities, and desert rodent adaptations: an investigation into evolutionary convergence. Unpublished Ph.D. dissertation, Univ. Texas, Austin, 345 pp.

Mares, M. A., and R. A. Ojeda. 1981. Patterns of diversity and adaptation in South American hystricognath rodents. Pp. 393-432, *in* Mammalian biology in South

America (M. A. Mares and H. H. Genoways, eds.), Spec. Publ., Pymatuning Lab. Ecol., Univ. Pittsburgh, 6:xii + 1-539.

Ojeda, R. A. 1989. Small mammal responses to fire in the Monte desert, Argentina. J. Mamm., in press.

Olrog, C. C., and M. M. Lucero. 1981. Guía de los mamíferos argentinos. Fundacion Miguel Lillo, Tucuman, Argentina, 151 pp.

Reig, O. A. 1987. Diversity patterns and differentiation of high Andean rodents. Pp. 404-439, *in* High altitude tropical biogeography (F. Vuilleumier and M. Monasterio, eds.), Oxford Univ. Press, 671 pp.

Thomas, O. 1920. On mammals from near Tinogasta, Catamarca, collected by Sr. Budin. Ann. Mag. Nat. Hist. ser. 9, 6:116-120.

———. 1921. On mammals from the Province of San Juan, western Argentina. Ann. Mag. Nat. Hist., ser. 9, 8:214-221.

Torres-Mura, J. C., M. L. Lemus, and L. C. Contreras. 1989. Dietary specialization of the rare South American desert rodent, *Tympanoctomys barrerae*. J. Mamm., in press.

Woods, C. A. 1984. Hystricognath rodents. Pp. 389-396, *in* Orders and families of Recent mammals of the world (S. Anderson and J. K. Jones, Jr., eds.). John Wiley and Sons, New York, xii + 686 pp.

Yepes, J. 1942. Zoogeografía de los roedores octodontidos de Argentina y descripción de un genero nuevo. Rev. Argentina Zoogeografia, 2:69-81.

DISTRIBUTIONAL RECORDS OF THE NORTHERN RICE RAT, *ORYZOMYS PALUSTRIS* (RODENTIA: CRICETIDAE)

THOMAS E. LEE, JR., AND LUIS A. RUEDAS
Department of Wildlife and Fisheries, Texas A&M University,
College Station, Texas 77843-2258

In January 1989, three specimens of the northern rice rat, *Oryzomys palustris*, were collected 0.4 mi. S, 0.06 mi. E Somerville, Burleson Co., Texas, and another was taken 2.3 mi. N, 3 mi. E Giddings, Lee Co., Texas. In Burleson County, rice rats were collected in a one-hectare cattail (*Typha latifolia*) marsh at the base of Lake Somerville Dam, 100 meters north of Yegua Creek. They were taken (over a 40 trap-night period) in association with cotton rats (*Sigmodon hispidus*, n = 2), white-footed mice (*Peromyscus leucopus*, n = 1), fulvous harvest mice (*Reithrondontomys fulvescens*, n = 5), and house mice (*Mus musculus*, n = 2). The rice rat from Lee County was obtained on the west bank of Yegua Creek, near Burleson County Rt. 132, in habitat dominated by cockle burr (*Xanthium* sp.). It was collected (50 trap nights) along with pygmy mice (*Baiomys taylori*, n = 5), white-footed mice (*P. leucopus*, n = 3), fulvous harvest mice (*R. fulvescens*, n = 5), and house mice (*M. musculus*, n = 1). The above specimens all are deposited in the Texas Cooperative Wildlife Collection at Texas A&M University.

These specimens of *O. palustris* were trapped outside the recorded range of this species (Davis, 1974; Hall, 1981; Schmidly, 1983). The specimen from Lee County extends the known distribution of the northern rice rat approximately 35 kilometers west from the previous westernmost locality in east-central Texas (7 mi. S, 4 mi. W College Station, Brazos County). These northern rice rats are the first recorded from Burleson and Lee counties. There are no records from surrounding counties (Austin, Grimes, Madison, Robertson, and Washington), which are presumably within the range of the species (Schmidly, 1983).

It is unclear whether *O. palustris* is presently expanding its range westward, or whether the documented range extension represents populations missed by previous collecting efforts. However, because the Brazos River appeared to represent the western limit of the range (Davis, 1974; Hall, 1981; Hall and Kelson, 1959) for many years, and only recently was that boundary extended from Walker and Colorado counties (Davis, 1974) to include Brazos County (Schmidly, 1983), we suggest that our specimens may represent a recent expansion along Yegua Creek. Such a phenomenon may have been aided by recent water management practices creating riparian habitat favorable to the northern rice rat.

We thank S. A. Smith for his thorough review of a previous draft of this manuscript.

Literature Cited

Davis, W. B. 1974. The mammals of Texas. Bull. Texas Parks and Wildlife Dept., 41:1-294.

Hall, E. R. 1981. The mammals of North America. John Wiley & Sons, New York, 2:vi + 601-1181 + *90*.

Hall, E. R., and K. R. Kelson. 1959. The mammals of North America. Ronald Press Co., New York, 2:viii + 547-1083 + *79*.

Schmidly, D. J. 1983. Texas mammals east of the Balcones Fault Zone. Texas A&M Univ. Press, College Station, xviii + 400 pp.

ADDITIONAL HERPETOLOGICAL RECORDS FOR TEXAS

Tracy S. Schafer and Stephen Kasper

Department of Biology, Midwestern State University, Wichita Falls, Texas 76308

Investigation of herpetological specimens in the Midwestern State University (MWSU) Collection of Reptiles and Amphibians has produced several noteworthy specimens that update currently known distributions in Texas as documented by Dixon (1987).

Ambystoma texanum.—The smallmouth salamander ranges throughout the eastern half of Texas where mesic situations prevail (Conant, 1975). On 26 February 1986, an adult male (MWSU 4192) was found dead in a swimming pool in Wichita Falls, Wichita County. This record extends the known range slightly westward.

Gastrophryne olivacea.—The Great Plains narrowmouth toad is a common grassland inhabitant throughout much of the state, excluding the Panhandle (Garrett and Barker, 1987). A single adult female (MWSU 4184) taken 7 mi. N Clarendon, Donley County, exhibited the pale gray color phase and was marked with scattered black spots. The specimen was taken on 10 July 1987, and represents the first record from the Texas Panhandle.

Hemidactylus turcicus.—The Mediterranean gecko was introduced in many localities along the Gulf Coast states, and since has expanded its range through accidental transport by man (Conant, 1975; Davis, 1974). A single juvenile (MWSU 4216) was found in Seymour Baylor County, on 22 November 1987. Two adults and two juveniles (MWSU 4239-4242) were taken on 2 April 1989 from an established breeding colony in the city of Wichita Falls, Wichita County, where they have withstood several hard winter freezes over the past four years. These records are the most northerly in the state.

Opheodrys aestivus.—A juvenile male rough green snake (MWSU 4177) was collected in riparian habitat along the Little Wichita River, 2 mi. N Scotland, Archer County, on 15 October 1986. This specimen constitutes a marginal western record.

New county records.—The following specimens are from within the known range, but represent county records: *Pseudacris clarki* (MWSU 4238), 2 mi. NW Lipscomb, Lipscomb County, 18 May 1988; *Bufo punctatus* (female, MWSU 4198), 7 mi. N Clarendon, Donley County, 10 July 1987; *Eumeces laticeps* (female, MWSU 4185), 12.5 mi. NW Bonham, Fannin County, 14 September 1985; *Cnemidophorus sexlineatus* (MWSU 4237), Texas Tech University Center at Junction, Kimble County, 18 February, 1989.

We thank Walter W. Dalquest and Frederick B. Stangl, Jr., for review of the manuscript and use of the specimens.

LITERATURE CITED

Conant, R. 1975. A field guide to reptiles and amphibians of eastern and central North America. Houghton Mifflin Co., Boston, 2nd ed., xviii + 429 pp.

Davis, W. K. 1974. The Mediterranean gecko, *Hemidactylus turcicus*, in Texas. J. Herp., 8:77-80.

Dixon, J. R. 1987. Amphibians and reptiles of Texas. Texas A&M Univ. Press, College Station, xii + 434 pp.

Garrett, J. M., and D. G. Barker. 1987. A field guide to reptiles and amphibians of Texas. Texas Monthly Press, Inc., Austin, 225 pp.

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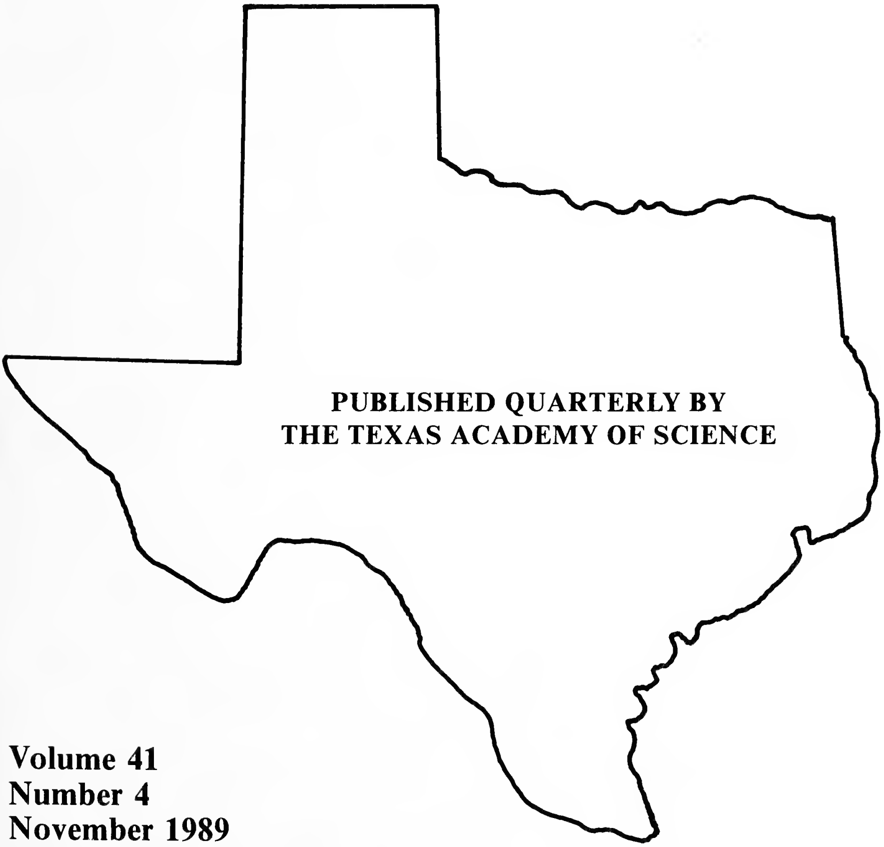

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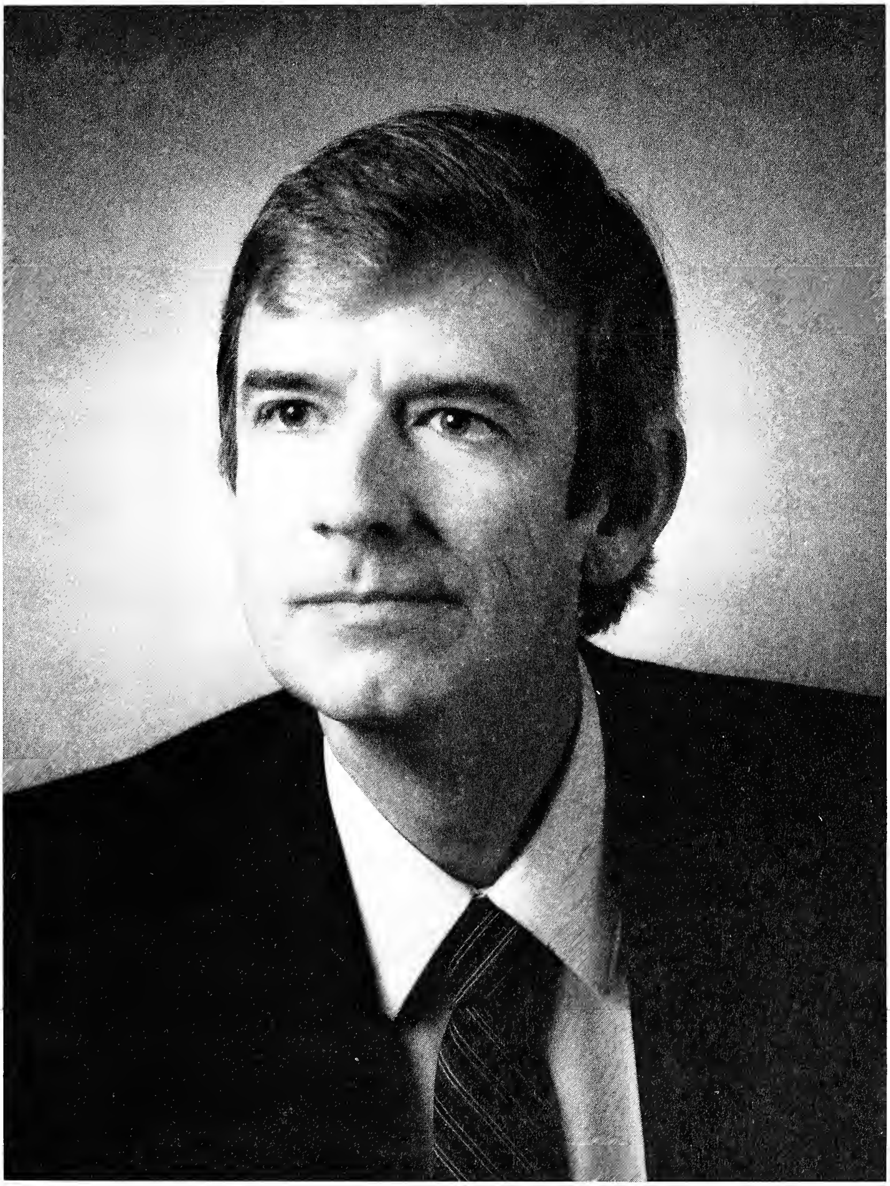

CARL B. COLLINS, JR.
Distinguished Texas Scientist, 1989.

CARK B. COLLINS, JR., was born in San Antonio, Texas, on 4 March, 1940. He received the B.S. with high honors, the M.A., and the Ph.D. in physics from the University of Texas at Austin in 1960, 1961, and 1963, respectively. While at the University of Texas he was awarded a Woodrow Wilson Fellowship in 1960 and National Science Foundation Cooperative Fellowships in 1960, 1961, and 1962.

From 1962 to 1964, Dr. Collins was a Physics Instructor at the University of Texas at Austin. In 1964, he joined the Southwest Center for Advanced Studies, which was incorporated into the University of Texas at Dallas in 1969. He served as Head of the Graduate Program in Physics from 1972-1975 and is presently a Professor of Physics and Director of the Center for Quantum Electronics, which he founded in 1975, at the University of Texas at Dallas. His research involves various aspects of quantum electronics, in particular, high power laser development, kinetics studies in laser media, laser spectroscopy, and ultra short wavelength lasers. In these fields, he has published 125 papers and supervised 25 Ph.D.'s through to completion. Currently he is guiding 6 more in progress.

Dr. Collins is a member of Phi Beta Kappa and Sigma Xi, and is a senior Member of IEEE, and a Fellow of the American Physical Society. He has served as a frequent organizer of professional conferences since 1978. In 1985, he was instrumental in forming the Laser Science Topical Group and Conference Chairman of the First International Laser Science Conference organized by the Group. He served as the APS representative to the Joint Council on Quantum Electronics and recording member of the Steering Committee of the APS Group on Laser Science. Dr. Collins currently serves as the U.S. delegate to the International Union of Pure and Applied Physics of UNESCO, Commission on Quantum Electronics.

THIN-FILM DIAMOND

C. B. Collins, F. Davanloo, E. M. Juengerman, W. R. Osborn,
D. R. Jander, and T. J. Lee
*Center for Quantum Electronics, University of Texas at Dallas, P.O. Box 830688,
Richardson, Texas 75083-0688*

ABSTRACT.—The past few years have witnessed a renaissance in the preparation and study of thin films of carbon having diamondlike properties. However, while natural diamond is a well-defined substance, these diamondlike films are not. In many cases, different materials result from the different methods of preparation and this has contributed much complexity to the evaluation of the merits of the various techniques of growth. Reported here is the use of a unique laser plasma source able to deposit thin films of amorphic diamond at practical rates of growth. The beam from a pulsed Nd-YAG laser is focused at high power densities of 10^{12} W/cm^2 onto graphite feedstock in an ultrahigh vacuum environment. The resulting plasma ejects carbon ions able to migrate to the plane of deposition. In this way, diamondlike coatings have been applied to silicon, gold, germanium, glass, and plastic. Such films have interesting optical and electrical properties and can be grown at rates approaching one carat per day. *Key words*: thin-film diamond; amorphic diamond.

Diamond can be readily characterized as nature's perfect achievement in materials science. Its hardness, durability, and optical constants give diamond a unique level of value and appearance. However, in addition to these obvious properties, it is also the best conductor of heat and at the same time one of the best electrical insulators. If doped with traces of elements other than carbon, it becomes a semiconductor and there is a clear promise that future generations of microcircuitry will benefit from the enhanced capabilities of diamond for the thermal management of the waste heat in complex devices. Unfortunately, the same characteristics that give it value make it exceedingly difficult to fabricate.

The exploitation of diamond technology seems poised on the brink, awaiting the discovery of a viable method for growing layers of diamond film from molecular beams or with vapor deposition systems. Such techniques have supported the explosive development of other modern materials such as gallium arsenide and indium phosphide and should work for diamond. Surprisingly, successes to date have been rather limited.

Thin-film diamond was first grown 35 years ago by W. G. Eversole at Union Carbide Corp (Angus and Hayman, 1988). Since that time, effort has been underway continuously, with periodic alternations of intensity. The most recent of these might justifiably be considered a renaissance in the preparation and study of thin films of carbon having diamondlike properties. A diversity of new approaches has yielded a variety of products. However, whereas natural diamond is a well-defined substance, these diamondlike films are not. In many cases, different materials result from the different methods of preparation and this has contributed much complexity to the evaluation of the merits of the different techniques of growth.

GRAPHITE, DIAMOND, LONSDALEITE, AND AMORPHIC DIAMOND

While it is tempting to try to envision the bonding of carbon as an analog of silicon, such efforts are vitiated by the much greater complexity of carbon systems. From a structural viewpoint, Spencer et al. (1976) identified six allotropes of carbon, two for each of the numbers of dimensions through which the carbon atoms may bond. Those most important in the formation of thin films of diamondlike carbon (DLC) are the two-dimensional sp^2 bonds, which characterize graphite, and the three-dimensional sp^3 bonds, which give cubic diamond its unique properties.

The relationship between graphite and diamond can be appreciated from the conceptual transformation illustrated in Figure 1. However, this is only a conceptualization connecting the same final states; the real transformation, which favors other paths, is more difficult to draw. The fundamental structure in pure carbon is the planar cyclohexane net shown in the top panel. Carbon atoms lie at the vertices and three of the strong σ bonds project at equal angles within the plane to connect to nearest-neighbor carbons. These bonds are represented by the lines forming the sides of the hexagons. However, the valence of carbon is four and the remaining bond is a weak π orbital projecting perpendicular to the plane, both upward and downward from each atom.

The most ordered form of graphite can result from the stacking of the planar nets with alignment as shown in the middle panel of Figure 1 so that the π bond from a vertex in one layer can overlap the corresponding bond from the atom in the layer immediately below. While the position of an atom is fixed rather strongly within each plane, bonding between planes is weak giving graphite its lubricating ability. Breaking the π bonds is relatively easy and planes can slide over each other as long as they remain flat.

The transformation from graphite to diamond can be imagined to occur by a puckering of each ring in the net as shown in the middle and lower panels of Figure 1. Alternate atoms around each ring are displaced downward and upward toward nearest neighbors in the adjacent planes. As bond lengths are reduced they become σ bonds. At some point, as shown in the lower panel, all four bonds from an atom make equal angles. Atoms displaced upward in the figure would bond entirely to the next higher layer, not shown in the figure, so that again all bonds would be of σ character arranged at equal angles.

Actually, the puckering of aligned cyclohexane nets as shown in Figure 1 would give a rare form of diamond known as Lonsdaleite or hexagonal diamond. The dominant form naturally occurring is cubic diamond,

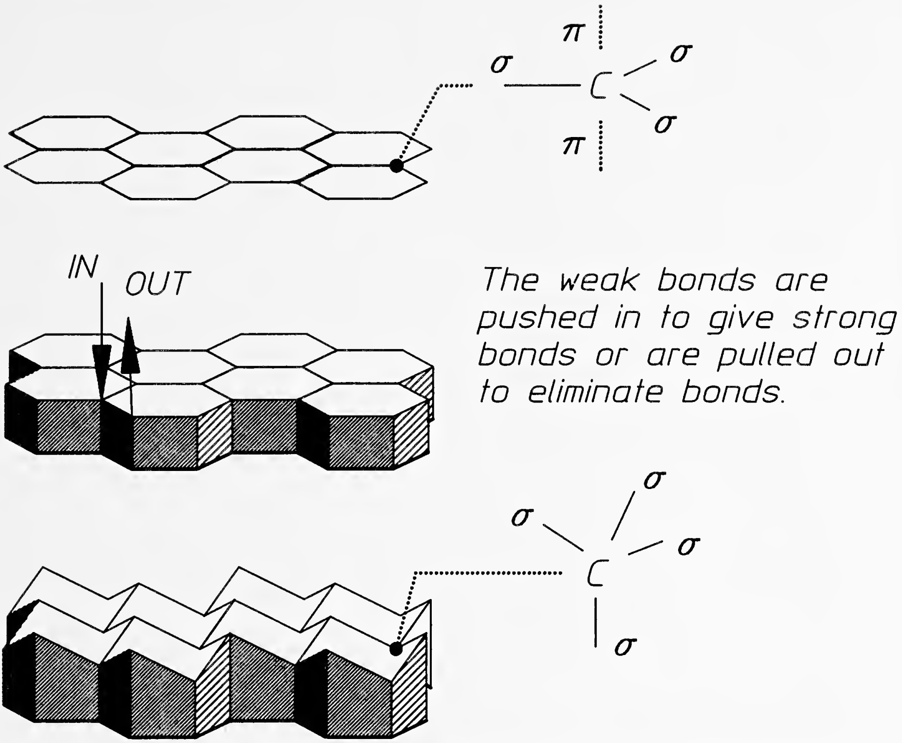

FIGURE 1. Schematic representation of the structural relationship between graphite and diamond. The net of cyclohexane rings in the top panel forms the fundamental conceptual basis. Carbon atoms lie at the intersections and σ bonds are represented by the lines forming the sides of the hexagons. Nets in parallel planes can be joined by weak π bonds to form graphite as shown in the middle panel. Puckering the rings as shown by the arrows leads to the diamond structure seen in the lower panel.

which results from the puckering of adjacent nets, but after they have been displaced with respect to each other as shown to the right of Figure 2. For comparison, the alignment typical of Lonsdaleite is shown to the left. In this figure, the puckering has been suppressed for clarity and again it must be recognized that these transformations are only conceptual. The structures are not naturally formed by alignment followed by puckering but rather grow by the placement of atoms into the aligned puckered positions. The conceptual processes shown would have to surmount activation barriers considerably elevated from the minimal values possible along other trajectories actually followed.

From Figure 2, the possibility for amorphic diamond can be readily appreciated. To each of the two forms shown, a fourth or higher cyclohexane net could be added for growth. It may be either aligned or staggered with respect to the uppermost layer shown. In either case, all bonds will still be of σ type at equal angles after the puckering process

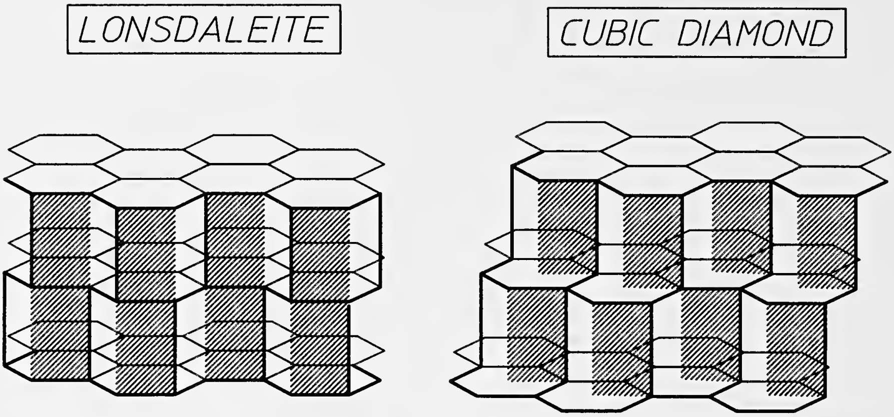

FIGURE 2. Schematic representation of the structural relationship between naturally occurring cubic diamond on the right and the rare hexagonal variant on the left. Line segments represent σ bonds and carbon atoms lie at the intersections. For simplicity, the puckering of the rings has not been shown. It would occur as the vertical bonds shown as heavy were reduced in length.

places the atoms into the proper lattice sites. If the planes are always either staggered or aligned, pure crystals of diamond or Lonsdaleite result, respectively. However, if there is an alternation of types every few layers, long range order will be lost, even though all bonds are still of the strong sp^3 type. This is the theoretical possibility for amorphic diamond. It is the search for this material that has motivated our work reported here.

SYNTHESIS PROCEDURES

The energy per atom of carbon in the different allotropes is a function of the various bond lengths and angles, reaching local minima identified with each of the stable or metastable forms. It is not only the lowest minima that can be stable, but local minima at higher energies also can have long metastable lifetimes if all reaction paths to lower states must surmount barriers larger than the thermal energies that might drive them. These energetics are shown schematically in Figure 3.

The bulk synthesis of diamond uses heat and pressure to proceed upward in energy over the barrier between graphite and diamond, and cubic diamond is the likely result. Most thin-film diamond traditionally has been made (Angus and Hayman, 1988) by chemical vapor deposition (CVD) from relatively low energy precursive radicals. Polycrystallites result and the usual yield consists of a bed of micron-sized crystallites embedded in a matrix of polymerized precursors containing from 20 to 60 percent hydrogen and termed diamondlike carbon (DLC) or a-C:H.

Although having many desirable properties, CVD diamond is a conglomerate material and so is not smooth enough for tribological uses,

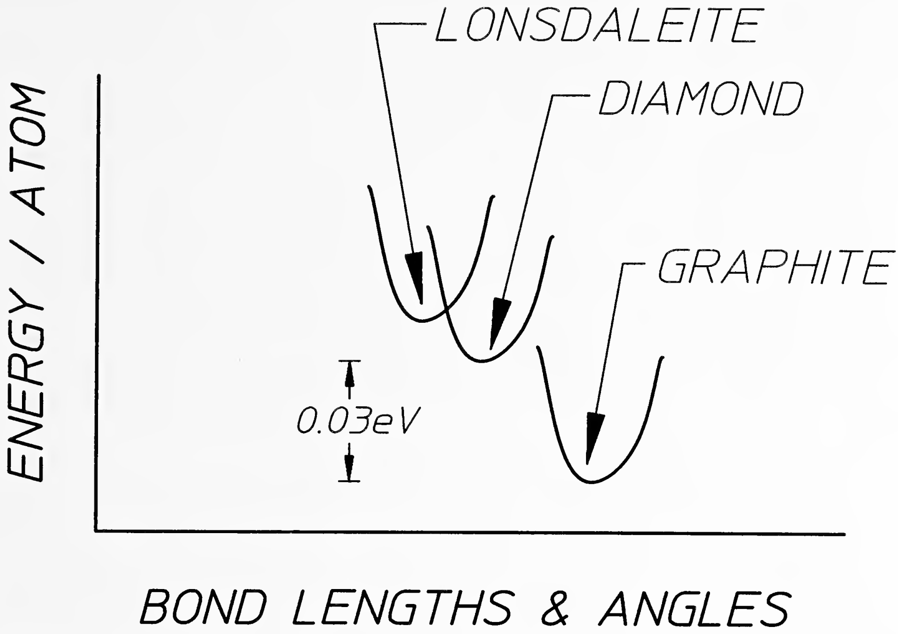

FIGURE 3. Hypothetical plot of the energy of a carbon atom in a lattice as a function of the variation of bond angles and lengths intended to illustrate the metastable relationship between the two diamond polytypes and graphite.

not uniform enough for optics, and not sufficiently impermeable for surface passivation. Perceived as the greatest problem is the high percentage of hydrogen in the intergranular polymer. It provides for the initiation of stress fractures and for the unbonding of the film from optical materials for the infrared (IR), such as germanium.

The least known technique for the synthesis of diamond involves the quenching of C^+ ions. On the scale of Figure 3, such ions lie at high energies and it is reasonable that with such excesses, diamond and londsaleite may be equally favored results of suddenly quenching these energies.

Denoted as a-C films, these unhydrogenated DLC films have received relatively little attention, although they have been known for quite some time. As early as 1971, Aisenberg and Chabot (1971), reported the quenching of a beam of C^+ ions in the presence of Ar and Ar^+ on a cold substrate to form an amorphic layer containing no hydrogen, yet having some diamondlike properties. Spencer et al. (1976) continued this line of development, attributing the favorable properties of the deposited layers to the selective destruction of exposed sp^2 bonds by the bombarding ions. However, with these early ion-beam methods the growth rates were extremely slow and the material they produced remained only a curiosity until relatively recent times.

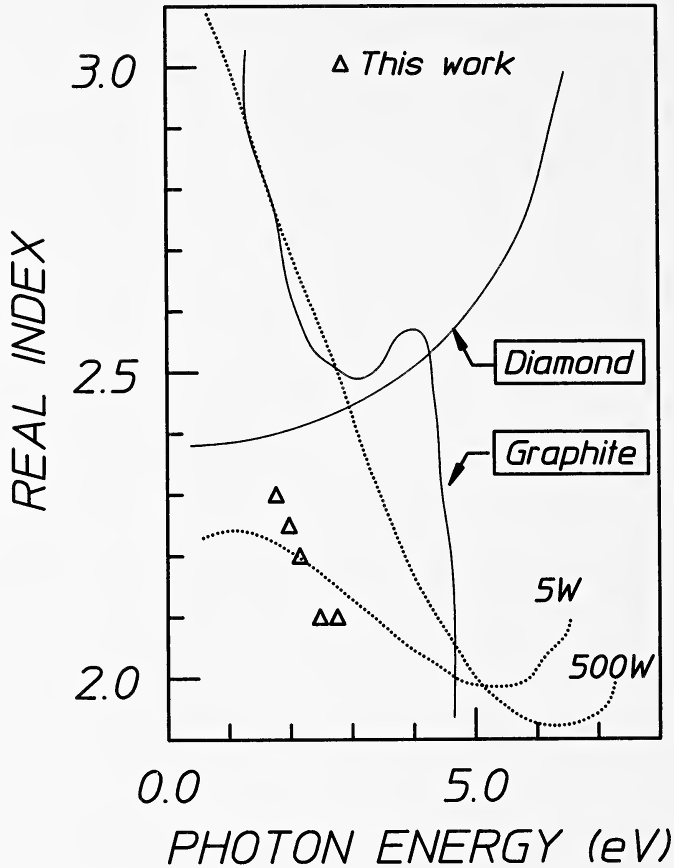

FIGURE 4A. Symbols plot the real and imaginary parts of the refractive indices of a-C films produced by the laser plasma source described in this work as functions of photon energy. Real parts plotted together with comparative values for diamond and graphite as indicated; dotted curves show the results reported by Savvides (1985, 1986) for films prepared with a sputtered ion source operated at the powers shown.

With a high fluence ion source, Miyazawa et al. (1984) brought growth rates up to about 360 A/h on a one centimeter-square substrate, whereas Savvides (1985, 1986) and Savvides and Window (1985) achieved 500 A/h on a 20 centimeter-square area with a sputtered source of carbon ions and atoms. Even higher growth rates were demonstrated at the cost of degraded film quality. The resulting availability of samples of a tangible scale together with the potential importance of such films in optical applications seems to have motivated an intensive study of their optical properties. Unlike the a-C:H materials these unhydrogenated DLC films were moderately clear in the visible wavelengths, and Miyazawa et al. (1984) recorded the observation of colored interference fringes. The

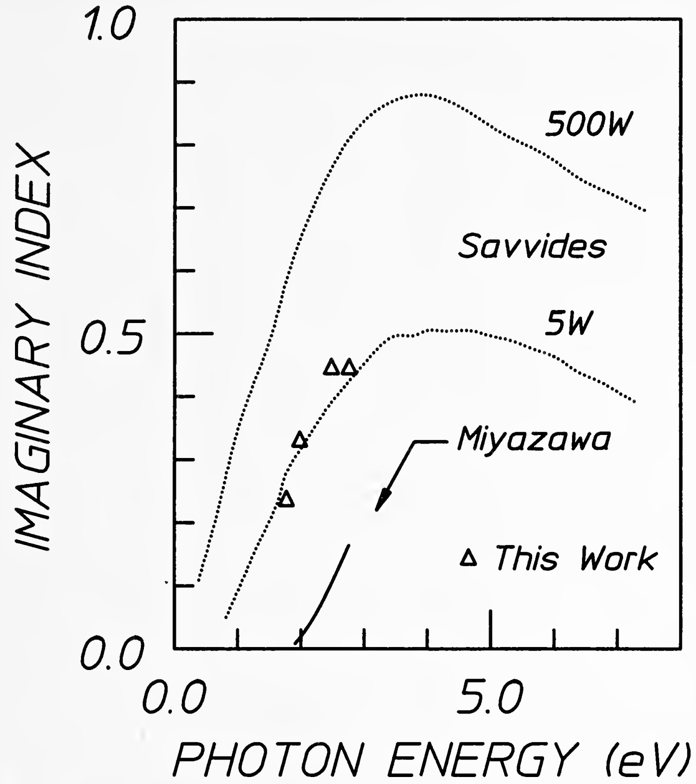

FIGURE 4B. Imaginary components of the refractive indices of a-C films reported by Savvides (1985, 1986) are shown by the dotted lines for the two powers used in his process, whereas results reported by Miyazawa et al. (1984) are plotted by the solid curve.

resulting indices of refraction reported by Miyazawa et al. (1984) and Savvides (1985, 1986) are collected in Figures 4A and 4B.

There is some suggestion in the literature that diamond formed by this type of ion quenching has some memory of the type and ordering of the carbon in the feedstock (Richter et al., 1986). Because it is the general intent to produce diamondlike material from inexpensive sources of carbon, it is unlikely that any structural information of benefit is to be derived from the source material. Thus, it is reasonable to expect that the quality of synthetic diamond films would depend upon the destruction of all memory of the feedstock. This suggests the desirability of the use of the highest possible process temperature (Collins, et al., 1989).

The greatest energy densities and consequently the highest temperatures are obtained in laser foci. Having no charges or material to compress, photon concentrations are routinely raised to extremely high values with commerically available lasers and simple geometrical optics. Our experiments have been designed to exploit these high temperatures to ionize the carbon feedstock for the deposition of thin-film diamond while erasing all memory of the bonding in the source material (Collins et al., 1989). The apparatus is shown schematically in Figure 5.

Roughly patterned after the laser plasma apparatus of Marquardt et al. (1985), Richter et al. (1986), Sato et al. (1987), and Wagal et al. (1988), the system we employed in this work was a Q-switched Nd-YAG laser to deliver 250 mJ to the focus at a repetition rate of 10 Hz. Because of an improved optical system it produces 5×10^{11} W/cm^2 in a 15 nsec pulse at the graphite target. This is sufficient (Marquardt et al., 1985) to achieve peak temperatures in excess of 500,000°K in the plume ablated from the graphite target. In previous work of Richter, Sato, Marquardt, and Wagal, much lower powers of 10^8, 10^9, 5×10^{10}, and a few $\times 10^{10}$ W/cm^2, respectively, were used. Whereas Sato et al. (1987) and Wagal et al. (1988) used supplementary electrodes for cleaning the substrate and for steering the ions, respectively, the system in Figure 5 incorporated an auxiliary discharge to further increase the plasma temperature by Joule heating in the small volume of the ablation plume.

RESULTS

The films produced with the laser plasma technique described in this work have a distinctive appearance. Displaying an optically smooth surface, there is no visible distortion of moirè patterns seen in reflection or in images transmitted through the films. Bright interference fringes can be seen in samples deliberately inclined to produce a wedge of thickness. In transmission, there is a visible brownish cast indicating a lossy part to the index of refraction such as seen in the materials characterized in Figures 4A and 4B.

The characterization of such thin lossy films as produced in this work is a severe challenge. For initial diagnostics, we concentrated upon 1) optical constants, 2) surface morphology, and 3) mass density.

The phenomenologies of these three diagnostics were examined over a wide range of process variables. All experiments were conducted in a UHV environment. The only variables of particular importance were the peak laser intensity in the ablation plume and the peak discharge current. Generally, lower current could be compensated by higher laser power. Consistent with this was the observation that cratering the graphite or defocusing the laser gave larger plumes and higher growth rates at the substrate but the resulting film had much greater loss and tended toward a form of graphite known as "glassy carbon" (Baranov et al., 1987). Characteristics of films deposited at the lower power densities of Richter et al. (1986), Sato et al. (1987), and Wagal et al. (1988) could not be plotted on the scale of Figure 4B because of their excessively lossy behavior.

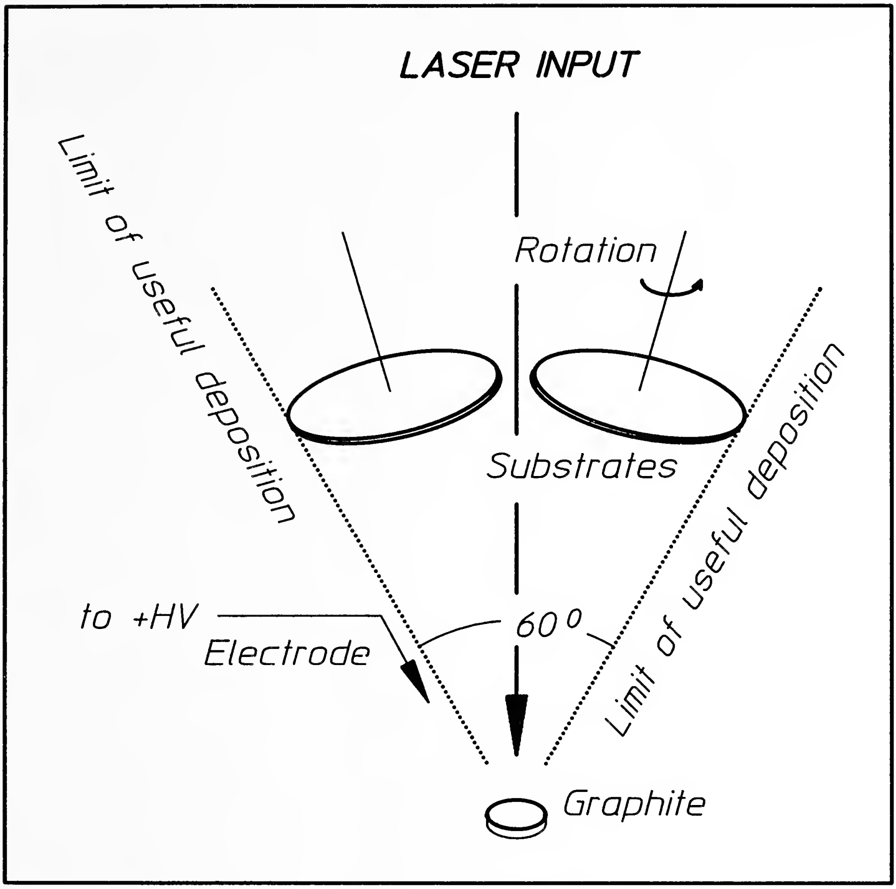

FIGURE 5. Schematic representation of the laser plasma source used in this work to prepare amorphic diamond films.

In this work, the determination of optical constants was accomplished by fitting measured reflectance spectra to textbook forms (Born and Wolf, 1980). However, the diversity in the types of optical constants that often are reported requires an explication of which of the possibilities is being used in a particular application. The propagation of light in the x direction normal to the surface of the film can be described by the expression,

$$A = A_o \exp\left[i\omega\left(t - \frac{n_r - in_i}{c}\right)x\right], \tag{1}$$

where A is the complex field amplitude for a particular polarization and n_r and n_i are the real and imaginary indices of refraction comprising our choice for the representation of optical constants with which to describe the film. Recalling that the intensity is A*A, then the loss of intensity encountered in propagating in the x direction can be seen to be,

$$I = I_o \exp\left(-\frac{4\pi n_i x}{\lambda_v}\right), \qquad (2)$$

where λ_v is the wavelength of the light in vacuum.

The imaginary part of the index, n_i in Equation (2) is an important diagnostic. Savvides (1985, 1986) has shown how, at small values, this extinction coefficient is reasonably proportional to the fraction of sp^2 bondings remaining in the film, provided the real part is reasonably constant. Purely diamondlike sp^3 bonding would give no loss at these photon energies. The lower curve in Figure 4B, identified by the 5 W of input power to the sputtering source in Savvides' system, provides a calibration that is identified with a 25 percent content of graphitic, sp^2 bonds. Though not computed previously, it can be seen that Miyazawa's films should have contained only about 10 percent of the sp^2 bonding and no detectable amounts of hydrogen.

Figure 6 shows typical data from which the optical constants were derived for a particle sample. The substrate was a Si wafer placed in reasonable proximity to the laser plasma source and radial expansion of the ejected material produced a domed profile of thickness, which could be appreciated by the visual appearance of bright Newton's rings of interferences. Optical constants were measured to be consistent across the 20 square centimeters over which thickness varied from 0.05 to 0.2 μm by fitting measured reflectivities at 6328A to curves computed for several choices of n_r and n_i as shown in Figure 6. As can be seen there, simple visual agreement gives a reasonably sensitive means of selecting between possibilities.

To date, about 50 samples have been made and the imaginary indices have ranged from 0.2 for films produced at the highest power densities to 0.8 for poor materials obtained by deliberately lowering the power density for the ablation and ionization of the feedstock.

While the optical constants are convincing in their demonstration that some new form of transparent carbon has been produced by this quenching of C^+ ions, it is the examination of the surface morphology that is most suggestive of an amorphic nature. Shown in Figure 7A is a photograph of the image of the surface of a typical film that was acquired with a scanning electron microscope (SEM) at a modest magnification of 3000. No detail is seen in this nor in similar SEM photographs at 30,000 magnification.

As can be seen in Figure 7B, efforts at deliberately destroying a film on a silicon substrate with a focused laser pulse of high intensity gave a thermal blistering of the film that has the appearance generally associated with the destruction of plastic coatings or paints. No shattering or

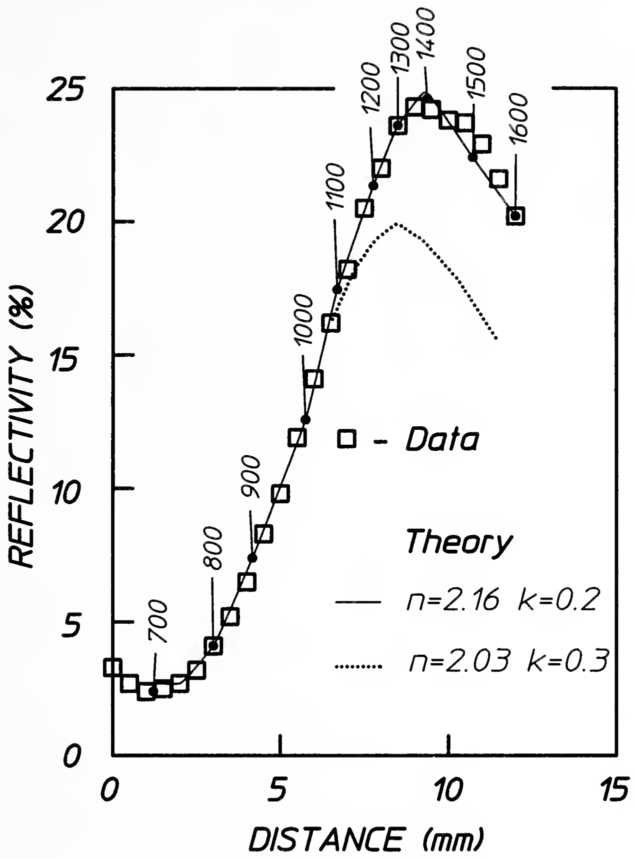

FIGURE 6. Comparison of reflectivities measured at 6328A wavelength from a film deposited on a silicon substrate with those computed from textbook expressions for two different values of optical constants. Those values of n and k refer to values of n_r and n_i, respectively, at 6328A. Reflectivities were measured with a HeNe laser and the abscissa records the displacement of the probing beam across the surface of the film. Corresponding thicknesses of the film at the positions plotted by the filled points are shown above the curve.

crazing of the surface is seen and the peeling of parts of the layer is quite evident. A structureless or amorphic composition is clearly in evidence.

To contrast with the smooth, amorphic structure suggested by the previous photographs, the deliberate misalignment of the ablation plume allowed the transport of some structured seeds from the feedstock, which were able to nucleate the aberrant growths seen in Figures 8A and 8B. In Figure 8A, the characteristic curls of turbostratic graphite are shown growing from the underlying plane. In Figure 8B, the seed itself can be seen to the right of the figure, partly buried by the amorphic material subsequently delivered, but also nucleating the faster growth of the sheets

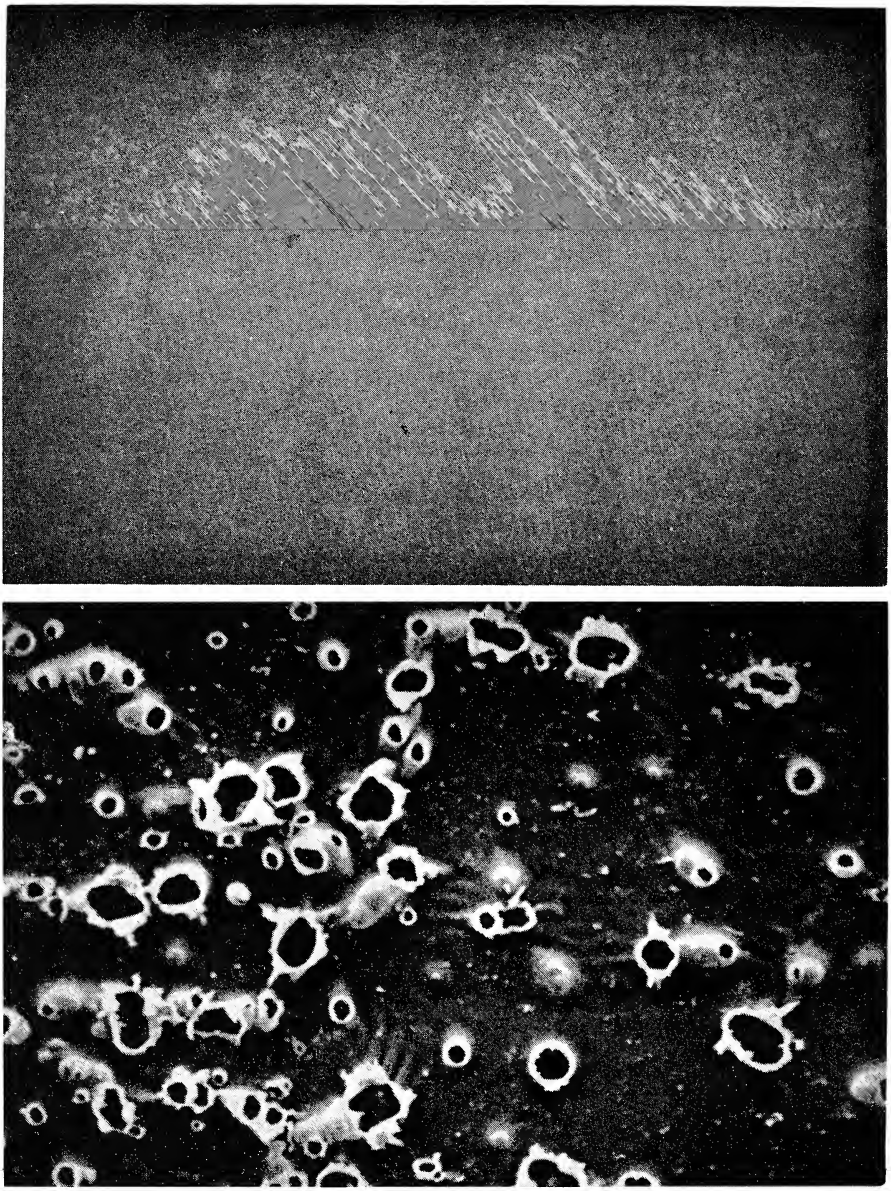

FIGURE 7. Scanning electron microscope (SEM) images at a magnification of 3000 × of the surface of an amorphic diamond film deposited onto a silicon substrate. A, absence of perceptible structure in the film as usually deposited. B, blistering deliberately produced with a focused beam from a Nd YAG laser.

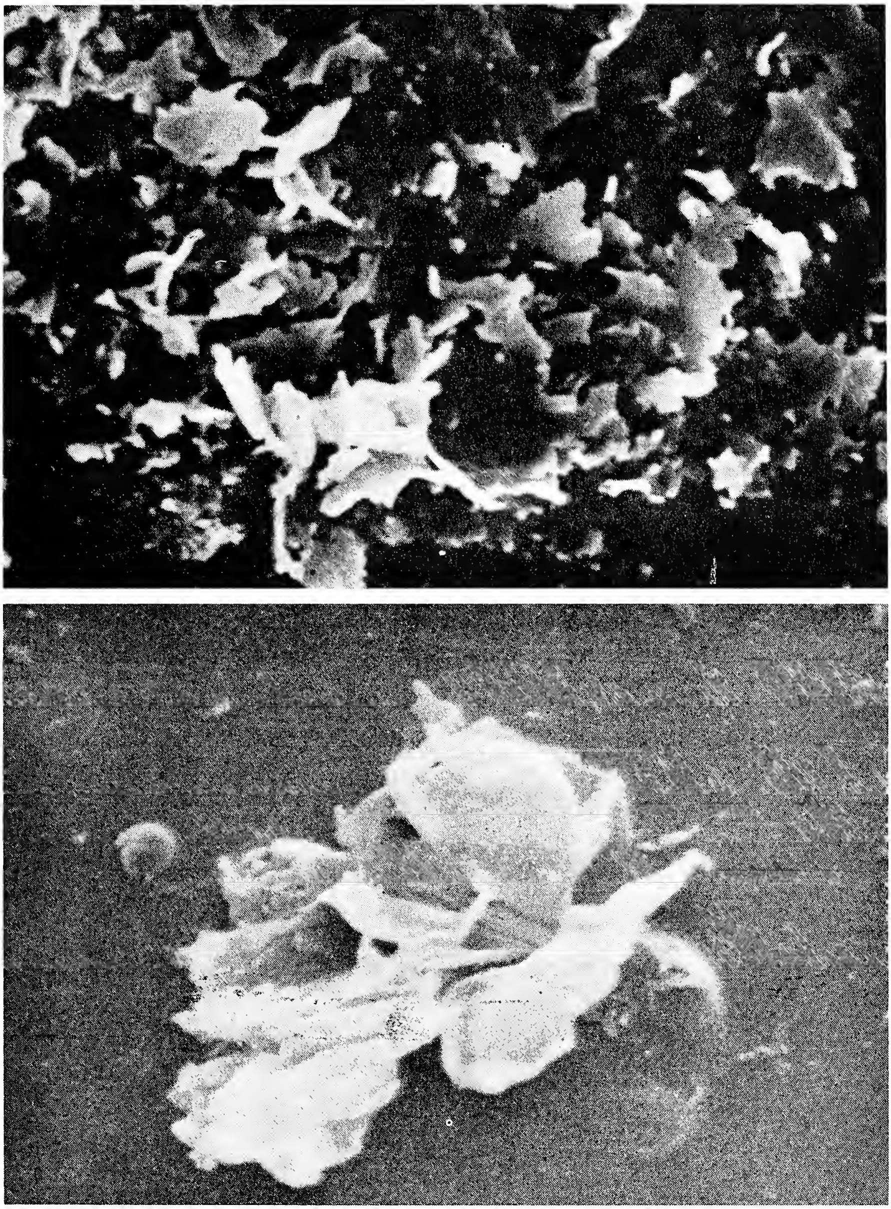

FIGURE 8. Scanning electron microscope images of the surfaces of two different amorphic diamond films showing the aberrant growth of graphite nucleated by undigested seeds carrying structural information that were deliberately introduced from the source material. A, the horizontal dimension of the field shown represents about 20 μm of the surface. B, the seed partially buried to the right of the graphitic growth is about 1 μm in diameter.

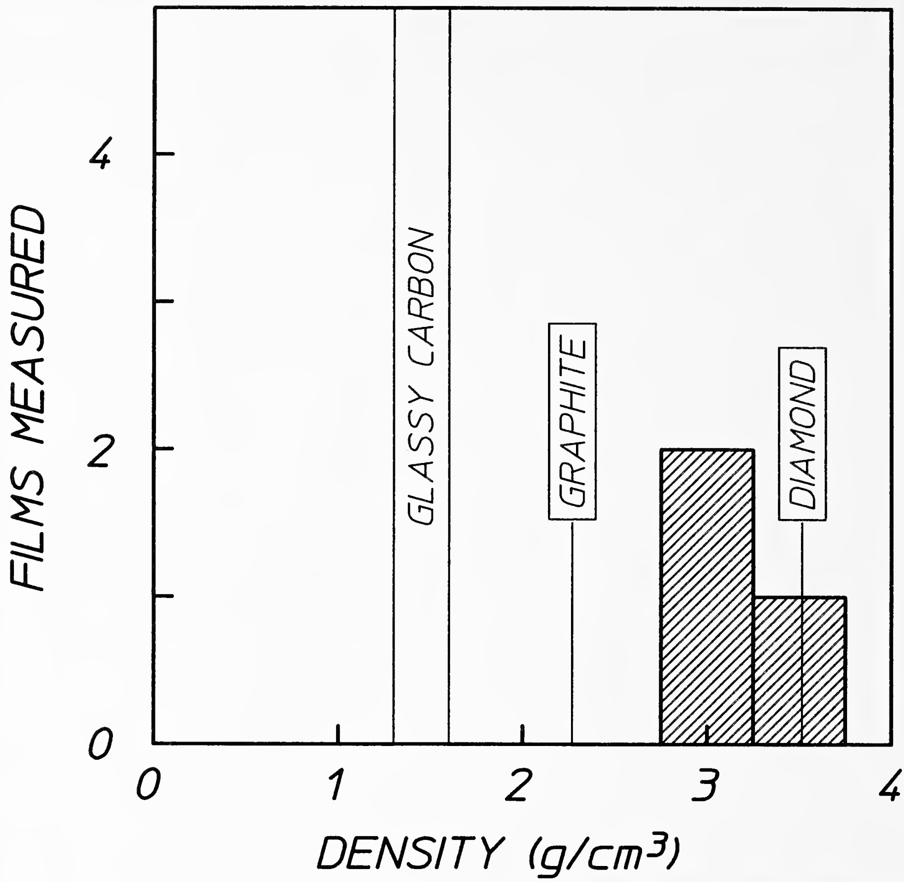

FIGURE 9. Histogram of the number of films measured to have various possible values of mass density. Only these three samples were measured. The densities of natural diamond, graphite, and glossy carbon are shown for comparison.

of graphite developing to the left. Proper alignment of the ablation plume sufficed to digest all structural information from the feedstock so that the smooth material of Figure 7A could be reproducibly obtained.

The densities of these films were sampled in the course of a few depositions onto substrate packages including a masked sample of thin polyimide film. Direct measurements with a microbalance of the mass deposited together with the volume computed from profile measurements gave the results plotted in Figure 9. As can be seen, the densities of those few films that were examined approached the value of natural diamond and showed a marked contrast to previous reports for glassy carbon (Baranov et al., 1987).

CONCLUSIONS

The laser pulse energies used here were not particularly different from those employed previously, but the power densities developed at the graphite feedstock were much greater in the present work. The fact that a smaller growth rate was observed supports the expectations that a tighter focus gives a higher temperature to a smaller amount of carbon material. This in turn strengthens the perception of Miyazawa et al. (1984) that the carbon ions are the critical precursors of sp^3 bonding, but refute his conclusion that the concurrent transport of electons is detrimental. At these densities, the ablated material must be traveling as largely neutral plasma.

Losses indicate that the proportion of sp^2 bonding in our material is comparable to the best of Savvides' samples and can be reduced further with lasers of even higher power that are commercially available. In contrast to all previous methods used to deposit a-C from quenched ions, our technique yields practical rates of growth. It is believed that this material can be reasonably described as ultrafine-grained diamond with 25 percent impurities and that those sp^2 inclusions serve no necessary role.

ACKNOWLEDGMENT

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LITERATURE CITED

Aisenberg, S., and R. Chabot. 1971. Ion-beam deposition of thin films of diamondlike carbon. J. Appl. Phys., 42:2953-2958.

Angus, J. C., and C. C. Hayman. 1988. Low-pressure, metastable growth of diamond and "diamondlike" phases. Science, 241:913-921.

Baranov, A. V., A. N. Bekhterev, Y. S. Bobovich, and V. I. Petrov. 1987. Interpretation of certain characteristics in Raman spectra of graphite and glassy carbon. Opt. Spectrosc. (USSR), 62:612-616.

Born, M., and E. Wolf. 1980. Optics of metals. Pp. 611-633, *in* Principles of optics, 6th ed., Pergamon, Oxford.

Collins, C. B., F. Davanloo, E. M. Juengerman, W. R. Osborn, and D. R. Jander. 1989. Laser plasma source of amorphic diamond. Appl. Phys. Lett., 54:216-218.

Marquardt, C. L., R. T. Williams, and D. J. Nagel. 1985. Deposition of amorphous carbon films from laser-produced plasmas. Mat. Res. Soc. Symp. Proc., 38:325-335.

Miyazawa, T., S. Misawa, S. Yoshida, and S. Gonda. 1984. Preparation and structure of carbon film deposited by a mass-separated C^+ ion beam. J. Appl. Phys., 55:188-193.

Richter, A., H. J. Scheibe, W. Pompe, and K. W. Brzezinka. 1986. About the structure and bonding of laser generated carbon films by Raman and electron energy loss spectroscopy. J. Non-Cryst. Solids, 88:131-144.

Sato, T., S. Furuno, S. Iguchi, and M. Hanabusa. 1987. Deposition of diamondlike carbon films by pulsed-laser evaporation. Japanese J. Appl. Phys., 26:L1487-L1488.

Savvides, N. 1985. Four-fold to three-fold transition in diamondlike amorphous carbon films: a study of optical and electrical properties. J. Appl. Phys., 58:518-521.

———. 1986. Optical constants and associated functions of metastable diamondlike amorphous carbon films in the energy range 0.5-7.3 eV. J. Appl. Phys., 59:4133-4145.

Savvides, N., and B. Window. 1985. Diamondlike amorphous carbon films prepared by magnetron sputtering of graphite. J. Vac. Sci. Technol., A3:2386-2390.

Spencer, E. G., P. H. Schmidt, D. C. Joy, and F. J. Sansalone. 1976. Ion-beam-deposited polycrystalline diamondlike films. Appl. Phys. Lett., 29:118-120.

Wagal, S. S., E. M. Juengerman, and C. B. Collins. 1988. Diamondlike carbon films prepared with a laser ion source. Appl. Phys. Lett., 53:187-188.

HELIX ORIENTATION IN A DNA CIRCLE

Carl R. Wasmuth
Department of Biology, Texas A&M University, College Station, Texas 77843-3258

Abstract.—A fractional variation in occurrence (F_v) value for a trinucleotide is the ratio of the variation amplitude associated with periodicity in the occurrence of that trinucleotide along nucleosome core DNA sequences to its average occurrence along the sequences. If plus or minus signs are appropriately assigned to individual F_v values on the basis of F_v phase group, then the calculations for fitting a simple cosine curve to a plot of trinucleotide F_v value versus trinucleotide position in a double-stranded DNA circle will yield the values of two parameters. One parameter is a phase angle that determines the orientation of the DNA helix. The other parameter is related to the net directional flexibility in the ring. It is found that the phase angle for orientation calculated from trinucleotide F_v values for a 169-base-pair DNA circle is in close agreement with a value obtained from available data indicating the pattern of DNase I cleavage. It also is found that the agreement among the orientation phase angles obtained in separate calculations from the mono-, the di-, and the trinucleotide F_v values tends to improve as the net directional flexibility in the ring increases toward a higher level. The computation methods are shown to be of further value in assessing DNA directional flexibility effects in DNA-loop-protein complexes. *Key words*: DNA bending; directional flexibility; DNA circle.

In a recent study, the effects of certain regional changes in DNA sequence upon the potential for site-specific recombination in a ColE1 plasmid were interpreted in terms of a local requirement for DNA bending (Summers and Sherratt, 1988). This interpretation was based in part on the use of fractional variation in occurrence (F_v) values (Satchwell et al., 1986), which are values associated with sequence-dependent directional flexibility in duplex DNA. In this paper, F_v values in a format similar to that devised by Summers and Sherratt (1988) for the recombination study are used in calculating the preferred direction of helix curvature in a 169-base-pair (bp) circular DNA molecule. Such a preference would be found as a particular rotational orientation of the molecule with respect to its circular helix axis (Fig. 1).

Values of F_v are individually identified with specific short DNA sequences and were originally obtained by Satchwell et al. (1986) in an investigation of the periodicity in the occurrence of short DNA sequences in 177 different nucleosome core DNAs from chicken erythrocytes. The F_v value for a short sequence was defined as the ratio of its maximum periodic variation in occurrence to its average occurrence along the 177 core DNAs. Thus, an F_v value of 0.45 for GGC/GCC at a periodicity of 10.20 bp and a phase angle of 12 degrees would indicate that beginning at a site (12 × 10.20/360) bp away from a common reference point in each of the 177 DNAs, the trinucleotide GGC/GCC occurrence every 10.20 bp had been found on the average to be 1.45 times greater than its average occurrence along the sequences and that this periodic variation had been found to be at a maximum at a phase angle of 12 degrees.

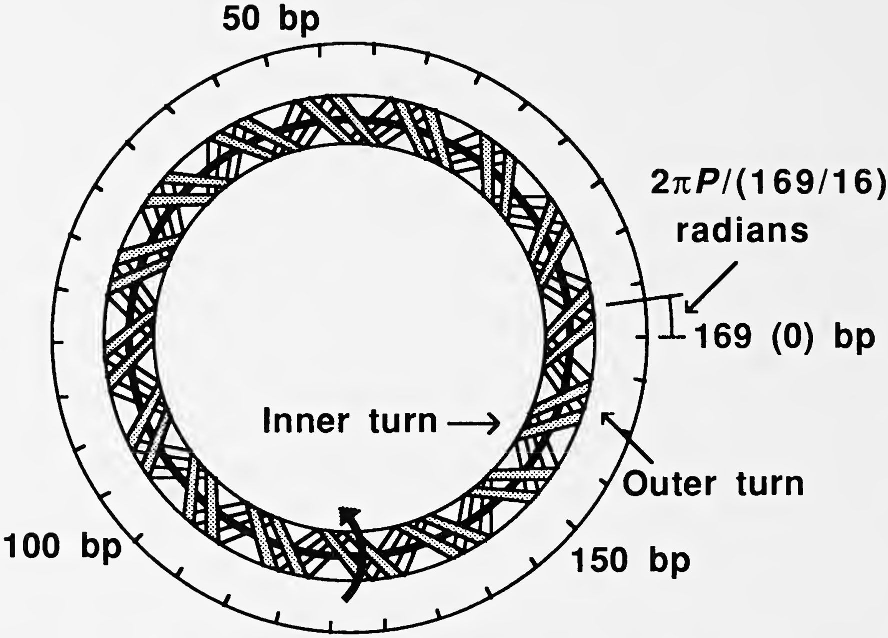

FIGURE 1. DNA circle. The DNA is the numbered sequence shown in Figure 2. The phase angle, ϕ_o, corresponding to the helix orientation is $2\pi P/(169/16)$ radians where P is the distance in bp from bp 169 (0) to the center of the narrow groove in its outermost position within the single helix period interval of 0 to 169/16 bp. The value of P for the helix orientation shown is approximately that calculated as P_{exp} (3.45 bp) from the pattern of DNase I cleavage as described in the text. A radian scale (not drawn) for reading the value of ϕ_o from the figure would show $2\pi/(169/16)$ radians per bp on the bp scale on the basis of 2π radians per turn of the 16-turn helix.

The occurrence of such variations with characteristic phase angles was interpreted to be associated with the winding of the DNA helices around the core histone octamers. For a near average value of the variation period, 10.20 bp, the phase angles associated with the dinucleotide and the trinucleotide F_v values were found to be clustered into two groups that on the average were approximately 180 degrees apart. The positions of the 10 dinucleotides and 40 trinucleotides in the first phase angle group, which tended to be C or G rich, or both, were interpreted to occur relatively more frequently at the outer turns of the narrow groove of the winding helix. The six dinucleotides and 24 trinucleotides in the other group, which tended to be A or T rich, or both, were interpreted to occur relatively more frequently at the inner turns of the narrow groove. The approximately 10-bp periodicity was interpreted to correspond to the periodicity in the turns of the helix (Satchwell et al., 1986).

These interpretations seemed to point to a relationship between F_v values and directional flexibility in double-stranded DNA (Satchwell et al., 1986; Summers and Sherratt, 1988). As an approximation, it may be stated that bending of DNA generally is eased to the degree that short sequences in the A- and T-rich group with higher F_v values are located close to the inner edge of the bend obtained, and that short sequences in the C- and G-rich group with higher F_v values are located close to the outer edge.

With the assignment of plus signs to the F_v values of the trinucleotides found more frequently at outer narrow groove turns and minus signs to the other F_v group, Summers and Sherratt (1988) prepared plots of trinucleotide F_v value versus trinucleotide position for some plasmid DNA sequences. In agreement with the approximation relating F_v values and directional flexibility stated above, these plots showed DNA runs with a possible potential for easily assuming a particular bending configuration arising from DNA-protein association as patterns of alternating positive and negative F_v regions having an appropriate periodicity. A less complex example of DNA bending is that found in the 169-bp circle in which directional flexibility would be expressed as a preferred orientation of the helix with respect to its circular axis. Because the 169-bp circle is a comparatively simple system, it seemed possible that fitting a simple cosine curve to a plot of trinucleotide F_v versus circle trinucleotide position would show the preferred positioning of the base pair sequence with respect to the locations of the inner and the outer turns of the narrow groove of the helix and thus the orientation of the helix. The results of this approach are reported here.

RESULTS AND DISCUSSION

The 169-bp circle was one prepared by Drew and Travers (1985). Through the use of DNase I, an enzyme with 3′ cleavage specificity, they found sites in the circle at 14, 24, 35, 45, 56, 66, 77, 87, 98, 108, 119, 129, and 140 bp that were each between a pair of sites of maximum cleavage and sites at 9, 19, 30, 40, 51, 61, 72, 82, 93, 103, 114, 124, 135, and 145 bp that were each between a pair of sites of minimum cleavage. The two sites comprising each pair of cleavage loci were found by Drew and Travers (1985) to be located on separate strands just outside of adjacent base pairs. They assigned the former series of 13 loci to the outside of the circle and the latter series of 14 to the inside. They interpreted the spacing between the loci as being consistent with a helix period of 169/16 bp. Their zero reference point was between base pairs 0 and 1, where base pair 1 is the first C·G in the sequence C·G, C·G, G·C, G·C, T·A, T·A. The complete sequence of the circle is shown in Figure 2.

To express the helix orientation of the DNA circle as a quantity that could be compared to the results of calculations of orientation from F_v values, a phase angle for orientation was calculated from the data of Drew and Travers (1985). The orientation phase angle, ϕ_o, in radians is defined as $2\pi P/w$, where w is the helix period and P is the location in

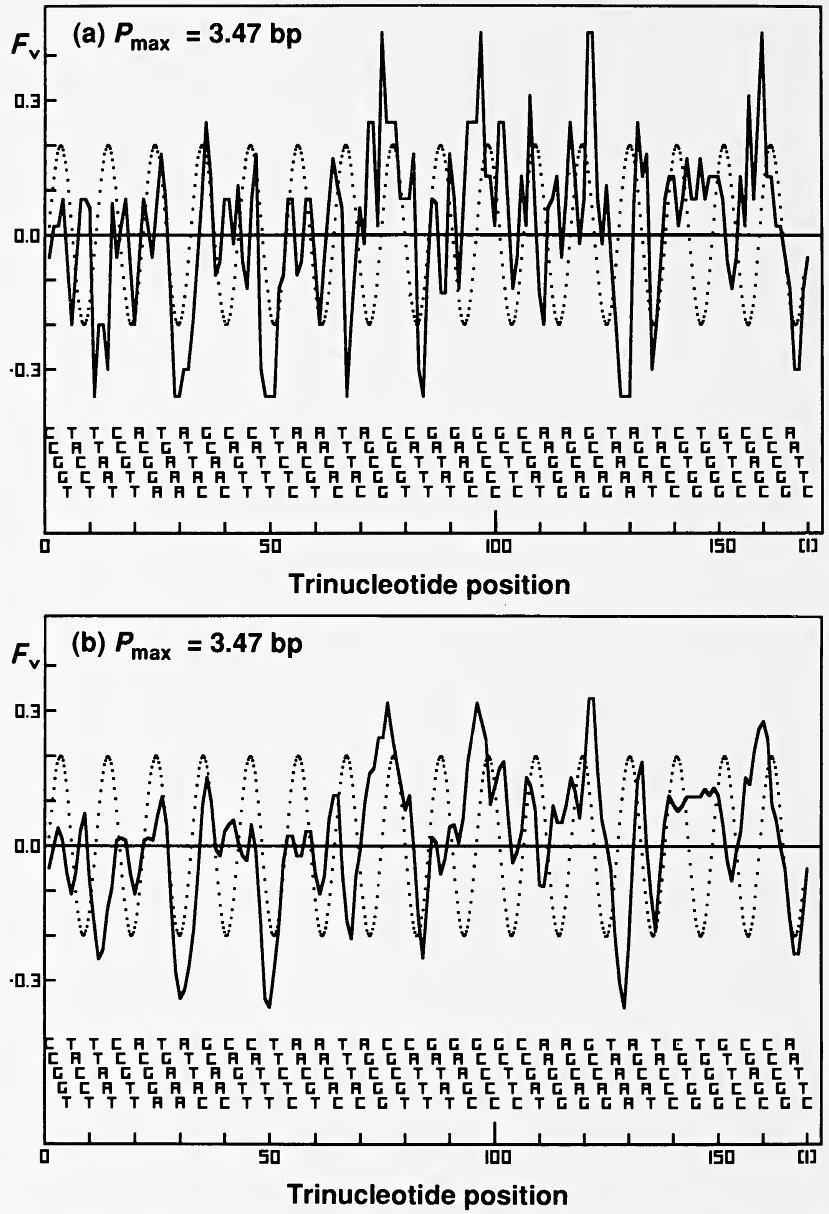

FIGURE 2. Plots (solid lines) of F_v versus position in a 169-bp DNA circle where F_v is a) trinucleotide F_v, b) trinucleotide F_v averaged with the F_v values of the two nearest overlapping trinucleotides, c) dinucleotide F_v, d) mononucleotide F_v. The dinucleotide and the trinucleotide F_v values used were those corresponding to a period of 10.20 bp (Satchwell et al., 1986) except that the F_v values for CG and GC were averaged as were the F_v values for AT and TA. The F_v values for CG/GC and AT/TA were then + 0.205 and − 0.095, respectively. The circular DNA sequence shown is aligned with each bp

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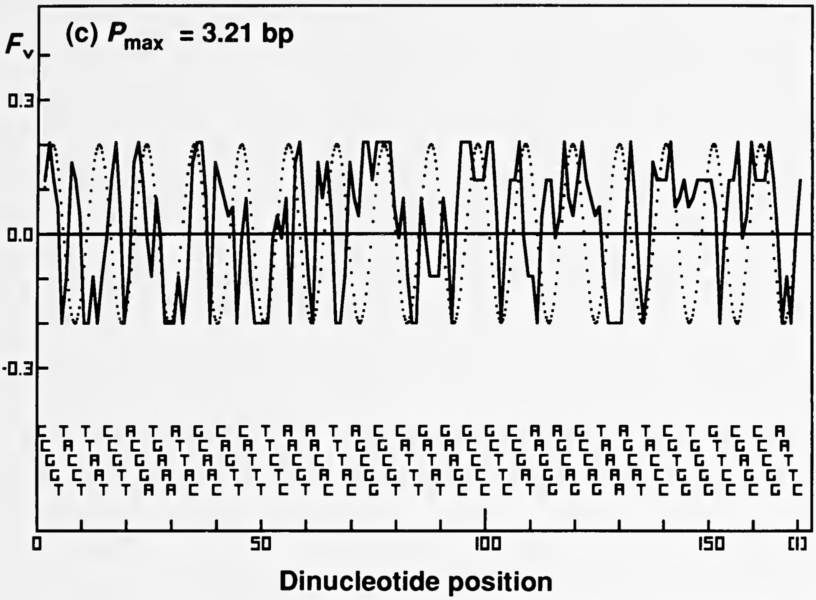

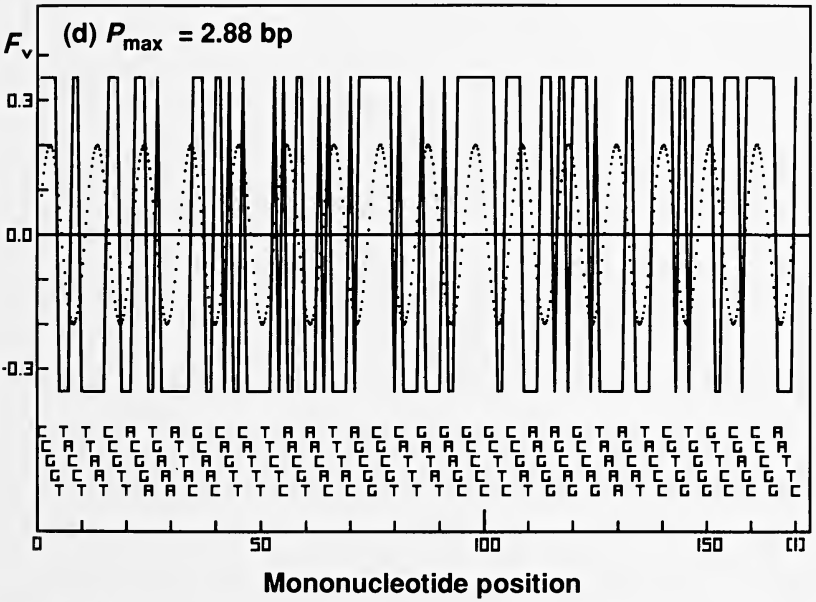

scale such that the center of each base letter symbol lies above its bp position on the scale. Base pair number 1 is repeated at the right end of each bp scale. With this sequence alignment, the F_v values were plotted at 1-bp intervals against the positions of the centers of trinucleotides (beginning at bp 1), of dinucleotides (beginning at bp 1.5), and of mononucleotides (beginning at bp 1). The calculated value of P that gives the best fit of a cosine curve with a phase angle of $2\pi P/(169/16)$ radians and a period of 169/16 bp is listed with each plot as $P_{\max}$. The amplitude of each of the fitted cosine curves (dotted lines) was adjusted to a value of 0.2 for display in this figure.

bp, relative to bp 0, of the center of the narrow groove in its outermost position between 0 and the helix period (here, 169/16) on the bp scale (Fig. 1). If one starts from the approximations of a constant periodicity and a constant spacing between base pairs in terms of bp per degree in the 360-degree circle, then P as P_{exp} for the preferred helix orientation can be calculated through an averaging method by first subtracting the appropriate integral number of half periods from each of the positions of the 27 sites listed above. Because each of the 27 positions was between two cleavage sites symmetrically located with respect to the midway point between two adjacent base pairs, and because the cleavage sites were interpreted to be situated on opposite sides of an inside (or an outside) turn of the base-pair chain, it would be expected that each of the 27 positions, each obtained by averaging a pair of cleavage positions, would be that midway site (midway between adjacent base pairs) that would be closest, within its particular half period of (169/16)/2 bp, to the inside or, alternatively, to the outside of the DNA circle. The zero reference point would then be at 0.5 bp on the base-pair scale in Figures 1 and 2. Thus, with the addition of 0.5 bp to each position to shift the zero reference point to 0.0 on the scale, $P = (1/27)[(0.5)(27) + 14 - w + 24 - 2w + \cdots + 140 - 13w + 9 - w/2 + 19 - 3w/2 + \cdots + 145 - 27w/2] = 3.45 \pm 0.05$ bp $= P_{\text{exp}}$, where $w = 169/16$ bp.

The value of ± 0.05 bp was obtained by a probable error calculation. Consideration was also given to the error associated with the availability of the data in the form of integers in determining the positions of the particular 27 innermost or outermost sites along the 169-bp circular DNA. The error arising from this effect alone varies with P and is calculated as:

$$P' - (1/27) \sum_{a=1}^{27} [\mathrm{R}(P' + aw/2) - aw/2], \text{ where } P' = P - 0.5 \text{ bp}, w = 169/16 \text{ bp},$$

16 bp, and $\mathrm{R}(P' + aw/2)$ is $P' + aw/2$ rounded off to the nearest integer. This error in P was calculated to be less than 0.002 bp at a P value of 3.45 bp and no greater than 0.05 bp in the range of $P = 3.1$ to $P = 4.0$ bp.

Phase angles for helix orientation were calculated from F_{v} values through determinations of the value ($P_{\max}$) of P that would maximize J for $\mathrm{J} = \sum_{n=r}^{s} F_{\text{v}} \cos[(2\pi/w)(n - P)]$ or for dinucleotide F_{v} values, $J = \sum_{n=r+0.5}^{s+0.5} F_{\text{v}} \cos[(2\pi/w)(n - P)]$, where $w = 169/16$ bp, $r = 1$ bp, and $s = 169$ bp for the 169-bp circle. Summations are for 1-bp increments in n, where, under this constraint, n is then the position in the base-pair scale of the center of a tri-, di-, or mononucleotide with the fractional variation in occurrence value F_{v}. A P value obtained as $P_{\max}$ in bp units is converted into the corresponding value of the phase angle, ϕ_o, for helix orientation by multiplying the P value by $360/w$ degrees/bp or by $2\pi/w$ radians/bp. The orientation phase angles are reported in this paper in the form of unconverted P values, however, in order that comparisons can be made in terms of bp units.

The results for the DNA circle are displayed in Figure 2 (A-D). Plots of F_v versus n of the kind prepared by Summers and Sherratt (1988) are shown together with plots of $\cos \{[2\pi/(169/16)]\,(n\text{-}P_{max})\}$ versus n for the P_{max} values obtained by maximizing J. The di- and trinucleotide F_v values used were those derived for a period of 10.20 bp as listed by Satchwell et al. (1986) with the exceptions noted in Figure 2. The F_v values of -0.35 for A/T and $+0.35$ for C/G were arbitrarily assigned with the restriction that the latter F_v was set higher than the former. For the DNA circle, the P_{max} obtained from mononucleotide F_v values was found to be dependent not upon the signs or magnitudes of the two F_v values but rather only upon which one is the greater. An F_v value for A/T greater than that for C/G would yield an orientation phase angle value different by exactly 180 degrees.

The P value ($P_{max} = 3.47$ bp) calculated from the trinucleotide F_v values is in close agreement with the experimental value ($P_{exp} = 3.45$ bp) obtained from DNase I cleavage results. The relative sizes of the deviations of the P_{max} values calculated for the tri-, di-, and mononucleotides from the experimental value are in the order that would be predicted. The error in the P_{max} value obtained from trinucleotide F_v values would be expected to be the least because more fine structure effects would be expected to be incorporated into the calculation. According to this logic, a further degree of refinement would be attained through the inclusion of the effects on directional flexibility arising from sequences longer than trinucleotides wherever these effects are found to be appreciably different from the total of the isolated effects from the constituent trinucleotides of the longer sequence. Where the occurrence of specific longer sequences associated with such differences is low, directional flexibility approximations derived from trinucleotide F_v values would be expected to be useful. Little is known about the quantitative effects of longer sequences; but it is noted, for example, that AAAAA/TTTTT, which is thought to have a preferred location centered about midway between an inside turn and an outside turn of the minor groove in curved DNA (Travers and Klug, 1987), occurs only two times in the 169-bp circle sequence.

The averaging of the trinucleotide F_v value at each position with those of its two nearest overlapping trinucleotides, which was done in the plots reported by Summers and Sherratt (1988), is shown for the circle sequence in Figure 2B. For the DNA circle, this kind of averaging affects

TABLE 1. Average differences between P_{max} values for 169-bp circles. Sequences for the 169-bp DNA circles were generated from random numbers such that each of the four bases had an equal probability of appearing in any position.

	Average difference[1] between			
$J_{max,T}$ range[1]	$P_{max,T}$ and $P_{max,D}$ bp	$P_{max,T}$ and $P_{max,M}$ bp	$P_{max,D}$ and $P_{max,M}$ bp	Number of sequences
2.0000-2.9999	0.74	0.91	0.56	300
3.0000-3.9999	0.44	0.54	0.36	300
4.0000-4.9999	0.38	0.44	0.27	300
5.0000-5.9999	0.28	0.33	0.22	300
6.0000-6.9999	0.26	0.30	0.20	150
7.0000-7.9999	0.16	0.20	0.14	50

[1] The first sequences generated within a particular range of $J_{max,T}$ (J_{max} calculated from trinucleotide F_v values) were used in determining average P_{max} differences. The generation of more than 12,000 sequences was required for obtaining the 50 sequences in the $J_{max,T}$ range of 7 to 8. The $J_{max,T}$ values and the trinucleotide, dinucleotide, and mononucleotide P_{max} values were calculated as described in the text and in the legend for Figure 2 except that no F_v averaging for overlapping trinucleotides was done as in Figure 2B.

the maximum J value but has no apparent effect on the value of P at maximum J.

Because dinucleotide rather than trinucleotide F_v listings might be considered for use in the calculation of preferred helix orientations, the agreement between P_{max} values obtained from dinucleotide F_v values with those from trinucleotide F_v values was examined for 169-bp circles having DNA sequences generated from random numbers. The results are shown in Table 1. The average agreement was found to improve with increasing $J_{max,T}$ (J_{max} calculated from trinucleotide F_v values) and thus with increasing directional flexibility in the $J_{max,T}$ range of 2 to 8. For comparison, the 169-bp circle with $P_{exp} = 3.45$ bp has a trinucleotide J_{max} of 3.48 and a difference between $P_{max,T}$ and $P_{max,D}$ of 0.26 bp, which in this instance is less than the average difference (0.44 bp) in the $J_{max,T}$ range of 3 to 4. It was also found that the order of the sizes of the average difference among $P_{max,T}$, $P_{max,D}$, and $P_{max,M}$ was constant within the $J_{max,T}$ range examined. The greatest P_{max} difference found, that between $P_{max,T}$ and $P_{max,M}$, corresponds to the greatest difference in the level of complexity in the calculation of P_{max}.

The existence of a preferred helix orientation found through the use of DNase I for a 169-bp circle and the agreement of that orientation with the value of P obtained ($P = 3.47$ bp $= P_{max}$) by maximizing trinucleotide J are indications that the maximum value of J found ($J_{max} = 3.48$) is sufficiently large for the circle to show a preferred orientation. Expressed as a quantity per base pair or $J_{bp,max}$ for comparison purposes as shown in Table 2, the value is 0.0206 bp^{-1}. Different segments of the circle do not have the same P_{max} and $J_{bp,max}$ values when examined individually,

TABLE 2. Calculated P and J_{bp} values for selected DNA sequences. The sequence P and J_{bp} values were calculated from trinucleotide F_v values as described in the text for the r to s intervals listed.

DNA sequence, bp r-s	P_{max}, bp	$J_{bp,max}$ bp^{-1} × 10^2	P, bp	$J_{bp,P}$ bp^{-1} × 10^2
169 bp circle, bp 1-169[1,4]	3.47	2.06		
Segment, bp 1-42	4.94	3.97	3.47	+2.55
Segment, bp 43-84	2.16	4.38	3.47	+3.13
Segment, bp 85-126	2.66	1.36	3.47	+1.21
Segment, bp 127-169	4.19	1.52	3.47	+1.38
Segment, bp 2-138	4.02	2.16	3.47	+2.05
Random sequences, bp 1-42[2,4]		3.0		
Random sequences, bp 1-84		2.2		
Random sequences, bp 1-168		1.5		
Sequence in *araC* regulatory region[3,4]				
Segment, bp 1-157	8.7	4.4		
Segment, bp 9-149	9.0	4.8		
Sequence with λ operator sites[3,4]				
Segment, bp 1-62	4.49	4.25		
Segment, bp 9-54	4.29	5.47		

[1] The sequence for the DNA circle is that shown in Figure 2.

[2] Random DNA sequences were generated from random numbers such that each of the four bases had an equal probability of appearing in any position. Average $J_{bp,max}$ values were calculated from 800, 400, and 200 sequences numbered 0-43, 0-85, and 0-169 bp, respectively.

[3] The sequence is shown in Figure 3.

[4] The reference point for P in every sequence was set at bp 0. The periods for the four kinds of sequences in the order that they appear in the table were set at 169/16, 10.5, 158/15, and 63/6 bp, respectively. The numerators of the latter two fractions show the base-pair distances between center points of the operator sequences, whereas the denominators show the integral number of periods within these base-pair distances most closely corresponding to a period of 10.5 bp.

however. Their contributions to the maximum of J for the entire circle would actually each be expressed as ($J_{bp.P}$) × (number of segment base pairs), where $J_{bp,P}$ is derived from J_P, the summation J through the segment sequence for the P value in this instance of 3.47 bp. The value of $J_{bp,P}$ thus could be positive or negative depending upon the sequence in the segment.

If a large segment is taken out of the circle and allowed to wind around a histone octamer, then the phase angle for bending would be expected to be more closely dependent upon the P_{max} for the part of the segment actually in contact with the octamer rather than upon the P_{max} for the entire circle. This kind of experiment was done by Drew and Travers (1985). As determined by DNase I, the positions of the base pairs in the inside and the outside turns of the 10-133 bp portion appeared to be nearly the same for the circle as for a histone-octamer-DNA complex prepared from a large segment of the circle. Small differences were

(a)
TTTCTGCCGTGATTATAGACACTTTTGTTACGCGTTTTTG
TCATGGCTTTGGTCCCGCTTTGTTACAGAATGCTTTTAAT
AAGCGGGGTTACCGGTTTGGTTAGCGAGAAGAGCCAGTAA
AAGACGCAGTGACGGCAATGTCTGATGCAATATGGACAA

(b)
CCAGGGGTAAAATAGTCGGAATTCCCGGGGATCCGTCAAT
TCCACATGCAACCATTATCACCGC

FIGURE 3. Nucleotide sequences: a) sequences in *araC* regulatory region, bp 0 to bp 158, representing *araO*$_1$ center *araO*$_2$ center sequence (Smith and Schleif, 1978; Miyada et al., 1980; Lee et al., 1987); b) sequence with λ operator sites, bp 0 to bp 63, representing operator center to operator center sequence (Hochschild and Ptashne, 1986). The parts of the operators that appear in the sequences are underlined.

attributed mainly to differences in periodicity as discussed by Drew and Travers (1985) and further by Travers (1987) and Travers and Klug (1987). It can be seen from Table 2, however, that the differences also would be expected to be low because $P_{\max}$ for the circle is not greatly different from $P_{\max}$ calculated for bp 2-138 of the 1-139 bp large segment portion actually thought to be in contact (Drew and Travers, 1985) with the histone octamer.

Possible instances of cooperativity in DNA loop formation from the binding of regulatory proteins to a pair of DNA regulatory sites have been described (Hamilton and Lee, 1988). If the directional flexibility of the loop DNA sequence and the curvature of the loop were both appreciable, then the directional flexibility would be expected to make a positive or negative contribution to the stability of the loop complex and possibly have some influence on its configuration. It is interesting to note that the 157-bp sequence extending between two operator centers in an *E. coli araC* regulatory region that has been thought (Hamilton and Lee, 1988; Huo et al., 1988) to take part in loop formation has a $J_{\mathrm{bp,max}}$ value of 0.044 bp^{-1}, which is substantially higher than the average value for random sequences of its size generated from random numbers (Table 2 and Fig. 3).

It is also interesting that the 46-bp sequence (9-54 bp segment, Table 2) that forms a loop when the bordering two λ operator sequences bind to λ repressor (Hochschild and Ptashne, 1986) has a high $J_{\mathrm{bp,max}}$ value (Table 2 and Fig. 3). The P value for the loop can be estimated roughly from the DNase I analysis provided (Hochschild and Ptashne, 1986) to lie between 3 bp and 4 bp with reference to bp 0. The corresponding $J_{\mathrm{bp},P}$ values would be + 0.039 bp^{-1} and + 0.054 bp^{-1}. Here a positive value would result in stabilization of the loop-protein complex and thereby would contribute to the equilibrium constant for its formation. For the future, it is suggested that J_{bp} calculations would be of value in devising

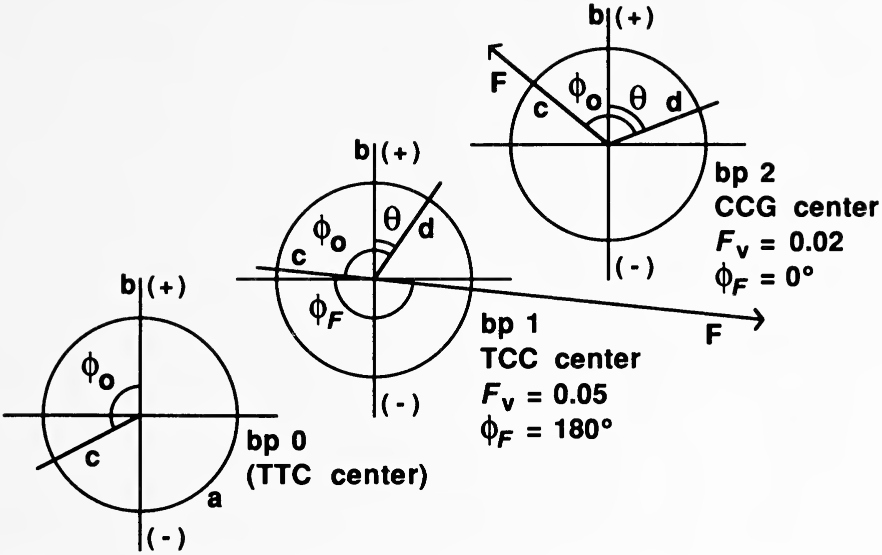

FIGURE 4. Cross sections of a 169-bp DNA circle at bp centers showing: a, helix envelope; b, radial line from DNA circle center; c, line marking center of narrow groove; d, reference line $2\pi n/(169/16)$ radians away from line b; F, vector corresponding to F_v; ϕ_o, helix orientation phase angle; ϕ_F, F_v-associated phase angle; θ, $2\pi n/(169/16)$. The negative end of line segment b is directed toward the center of curvature. The complete DNA sequence of the circle is that shown in Figure 2. The ϕ_o value used corresponds to the P_{max} valve of 3.47 bp calculated from trinucleotide F_v values for the complete sequence.

model systems for kinetics and equilibrium studies of this kind of loop formation.

By treating F_v as a vector (Drew and Calladine, 1987), the results presented in this paper can be obtained by computation methods equivalent to those shown above. Vectors for the first two base pairs of the circle sequence are shown in Figure 4, where the positive or negative signs assigned to trinucleotide F_v values by Summers and Sherratt (1988) are replaced by F_v-associated phase angle values of $\phi_F = 0$ degrees and $\phi_F = 180$ degrees, respectively. A value of 0 degrees means that the greatest trinucleotide preference is for a position at an outer turn (Fig. 1) of the helix of curved DNA, whereas 180 degrees means that the greatest preference is for an inner turn position. The preference of a trinucleotide for a particular position is taken to be proportional to $F_v \cos \alpha$ where α, which equals $[(2\pi/w)\ (n\text{-}P) - \phi_F]$, is the deviation from the favored 0-degree or 180-degree outer turn or inner turn position. The summation Σ $F_v \cos \alpha$ through the DNA sequence of the circle is then equal to J and is also equal to the summation of the components of the F_v vectors along the b axis in Figure 4. If the helix is oriented such that J equals J_{max}, then the resultant vector, $\mathbf{F}_r$, from a F_v vector summation is aligned with the b axis, and $\phi_{o,\max}$, which equals $2\pi P_{\max}/w$, is the angle of alignment of $\mathbf{F}_r$ (and the b axis) with line c at the reference position for helix orientation (bp 0). The magnitude of $\mathbf{F}_r$ is $J_{\max}$. For a DNA-loop-protein complex, J_P represents the value of the b-axis component of $\mathbf{F}_r$, where P expresses the orientation of the helix in the DNA loop.

Acknowledgment

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Literature Cited

Drew, H. R., and C. R. Calladine. 1987. Sequence-specific positioning of core histones on an 860 base-pair DNA. J. Mol. Biol., 195:143-173.

Drew, H. R., and A. A. Travers. 1985. DNA bending and its relation to nucleosome positioning. J. Mol. Biol., 186:773-790.

Hamilton, E. P., and N. Lee. 1988. Three binding sites for AraC protein are required for autoregulation of *araC* in *Escherichia coli.* Proc. Nat. Acad. Sci., 85:1749-1753.

Hochschild, A., and M. Ptashne. 1986. Cooperative binding of λ repressors to sites separated by integral turns of the DNA helix. Cell, 44:681-687.

Huo, L., K. J. Martin, and R. Schleif. 1988. Alternative DNA loops regulate the arabinose operon in *Escherichia coli.* Proc. Nat. Acad. Sci., 85:5444-5448.

Lee, N., C. Francklyn, and E. P. Hamilton. 1987. Arabinose-induced binding of AraC protein to *araI*$_2$ activates the *araBAD* operon promoter. Proc. Nat. Acad. Sci., 84:8814-8818.

Miyada, C. G., A. H. Horwitz, L.G. Cass, J. Timko, and G. Wilcox. 1980. DNA sequence of the *araC* regulatory gene from *Escherichia coli* B/r. Nucleic Acids Res., 8:5267-5274.

Satchwell, S. C., H. R. Drew, and A. A. Travers. 1986. Sequence periodicities in chicken nucleosome core DNA. J. Mol. Biol., 191:659-675.

Smith, B. R., and R. Schleif. 1978. Nucleotide sequence of the L-arabinose regulatory region of *Escherichia coli* K12. J. Biol. Chem., 253:6931-6933.

Summers, D. K., and D. J. Sherratt. 1988. Resolution of ColEl dimers requires a DNA sequence implicated in the three-dimensional organization of the *cer* site. EMBO J., 7:851-858.

Travers, A. A. 1987. DNA bending and nucleosome positioning. Trends Biochem. Sci., 12:108-112.

Travers, A. A., and A. Klug. 1987. The bending of DNA in nucleosomes and its wider implications. Phil. Trans. Royal Soc. London, ser. B, 317:537-561.

FRESHWATER BIVALVES OF LAKE ARROWHEAD, TEXAS: APPARENT LACK OF LOCAL EXTIRPATION FOLLOWING IMPOUNDMENT

Raymond W. Neck

Texas Parks and Wildlife Department, 4200 Smith School Road, Austin, Texas 78752

Abstract.—Survey of the freshwater bivalves of Lake Arrowhead, Clay Co., Texas (Little Wichita River of the Red River drainage) revealed eight species of native unionids and the introduced Asiatic clam. Impoundment of the Little Wichita River apparently resulted in no species extirpation as all native populations were adapted to sluggish waters.

Key words: freshwater bivalves; unionids; Lake Arrowhead, Texas.

The Red River (of the South, lower Mississippi drainage) supports a freshwater bivalve fauna with a species diversity that is high for the geographical region (Strecker, 1931:50-52). Although many taxonomic questions still exist, the fauna of the lower part of the Red River is relatively well known (Isley, 1924; Strecker, 1931), and the bivalve fauna of Lake Texoma has been intensively studied (Riggs and Webb, 1956; Valentine and Stansbery, 1971; White and White, 1977). The fauna above Lake Texoma is poorly known but is generally assumed to be limited both in species diversity and abundance.

Most records for the upper part of the Red River in Texas are given by Strecker (1931) who listed only two species for the mainstream of the Red River (*Lampsilis teres* and *Potamilus laevissimus* in Cooke County). Only limited records exist for tributary streams which are minor in length and volume of water transported. Pease River (Texas) records include only the above-mentioned two species and *Uniomerus tetralasmus.* The Wichita River (Texas) is somewhat longer and should support several species but only *P. laevissimus* is known from this stream. The farthest upstream record in the Red River drainage is of *U. tetralasmus* from the Prairie Dog Town Fork in Palo Duro Canyon in the Texas Panhandle (Clarke, 1938).

Survey of Texas museum collections has added a few additional Texas localities (Neck, unpublished data) but only of previously reported species. Collections examined include those housed in the Strecker Museum, Dallas Museum of Natural History, Fort Worth Museum of Science and History, Texas Christian University, Trinity University, University of Texas at El Paso, Corpus Christi Museum, and Houston Museum of Natural History.

Isely (1924) reported on extensive collections from Oklahoma, including one tributary of the Red River (Cache Creek, Cotton Co., Oklahoma) that had eight unionid species: *Quadrula quadrula, Quadrula pustulosa, Leptodea fragilis, Lampsilis teres, Potamilus purpuratus, Potamilus laevissimus, Tritogonia verrucosa,* and *Truncilla donaciformis.*

This regionally diverse fauna was able to survive because of "considerable" spring water. Smaller and intermittent streams on the Oklahoma side of the Red River have an unionid fauna of only a few species (Isely, 1924).

No analysis of the bivalve fauna of any particular area in the Red River drainage of Texas above Lake Texoma (Fig. 1) is known. Purposes of this survey of Lake Arrowhead were as follows: 1) establish species records for the Little Wichita River; 2) determine which species survive under reservoir conditions in the upper drainage of the Red River; and 3) examine preferred microhabitats of the species present. All records presented below are new records for the Little Wichita River, and provide a major addition to knowledge of bivalves in the Red River drainage above Lake Texoma.

Study Site

The Little Wichita River arises in Baylor County, Texas, and flows into the Red River in Clay County. Under normal flow the river is slow-moving and characterized by large amounts of suspended silt and clay of a reddish hue. No literature or museum records of bivalves from the Little Wichita River are known. Preliminary investigations of the Little Wichita River revealed a low-density fauna, which was difficult to sample accurately given time and access restrictions.

Lake Arrowhead (Fig. 2) is a 5468-hectare (13,500-acre) reservoir with a capacity of 281 million cubic meters (228,000 acre feet) at spillway level. Impoundment of waters of the Little Wichita River began in October 1966 (Dowell and Breeding, 1967). Drainage area above the dam is 2155 square kilometers (832 square miles). Low water levels in summer 1984 and availability of access points allowed a survey of the freshwater bivalves of Lake Arrowhead on 29 August 1984.

Methods and Results

Localities were chosen from available maps to include variable habitats (as to substrate, wave exposure, and portion of lake) within constraints of access. Seven localities were sampled by examination of exposed reservoir substrate, predator middens, and debris left by fisherman.

A total of nine species, including one introduced clam, was recovered from Lake Arrowhead (Table 1). Native unionids are rather generally distributed in this reservoir. Five of the eight unionid species were found at four or more sites. This distributional pattern indicates that preferred microhabitats are generally distributed in Lake Arrowhead.

Annotated List of Recovered Species

Anodonta grandis Say, 1829, is common throughout Lake Arrowhead. The only sample site that did not support this species was an exposed site with a hard clay substrate (site no. 5). Specimens were common in rock riprap of road crossings. The largest specimen recovered was 138 mm in shell length. Shells of *A. grandis* from Lake Arrowhead have a dark brown periostracum and white to pinkish nacre. A slight curve is present in the hinge line. The umbos are high and ornamented with curved ridges.

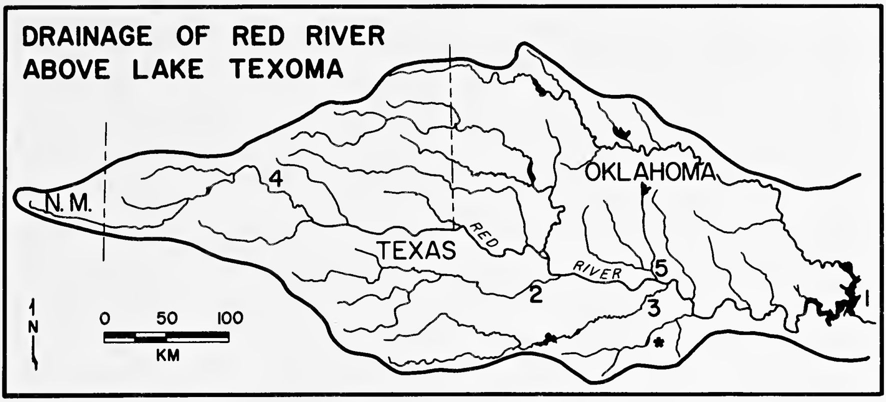

FIGURE 1. Map of upper Red River drainage, Texas and Oklahoma. Asterisk indicates location of Lake Arrowhead. Numbers indicate lake and streams as follows: 1) Lake Texoma; 2) Pease River, Texas; 3) Wichita River, Texas; 4) Prairie Dog Town Fork, Red River, Texas; 5) Cache Creek, Oklahoma.

Anodonta imbecilis Say, 1829, also was found in all but one site, which was an upper reservoir location (site no. 1) with more riverine characteristics than the other sites. *A. imbecilis* is the most abundant bivalve in Lake Arrowhead with the exception of *Corbicula fluminea*. Specimens were present in rock riprap of road crossings. The largest recovered specimen was 72.6 mm in shell length. Umbonal regions were horn-brown and the remaining periostracum was greenish brown.

Uniomerus tetralasmus (Say, 1830) was recovered as broken remains of a single valve, in debris left by fisherman, at only one locality on Lake Arrowhead (site no. 3). This species normally is found in sluggish and intermittent waters and generally does not persist in permanent lakes as large as Lake Arrowhead. These factors suggest that the single specimen may have been brought to the reservoir from a nearby stock pond by a fisherman and utilized for fish bait.

Quadrula quadrula apiculata Say, 1829, was found in several parts of the reservoir, but was more common on shores with exposure to prevailing southerly winds which produce currents that cause subaqueous accumulations of the sandy substrate favored by this species. The largest specimen recovered was 90.1 mm in shell length. Pustules are reduced or absent on the anterior portion of valves. The peripheral portions of larger shells (beyond the third growth line) have greatly reduced pustules.

Lampsilis teres (Rafinesque, 1820) was found only at one sampling location (site no. 7) on Lake Arrowhead. Although the soft substrate generally preferred by this species occurs in various parts of the reservoir, Lake Arrowhead seems to provide only marginal habitat for *L. teres*. The single valve recovered was recently dead and measured 124.6 mm in shell length. The periostracum was yellow with brownish staining.

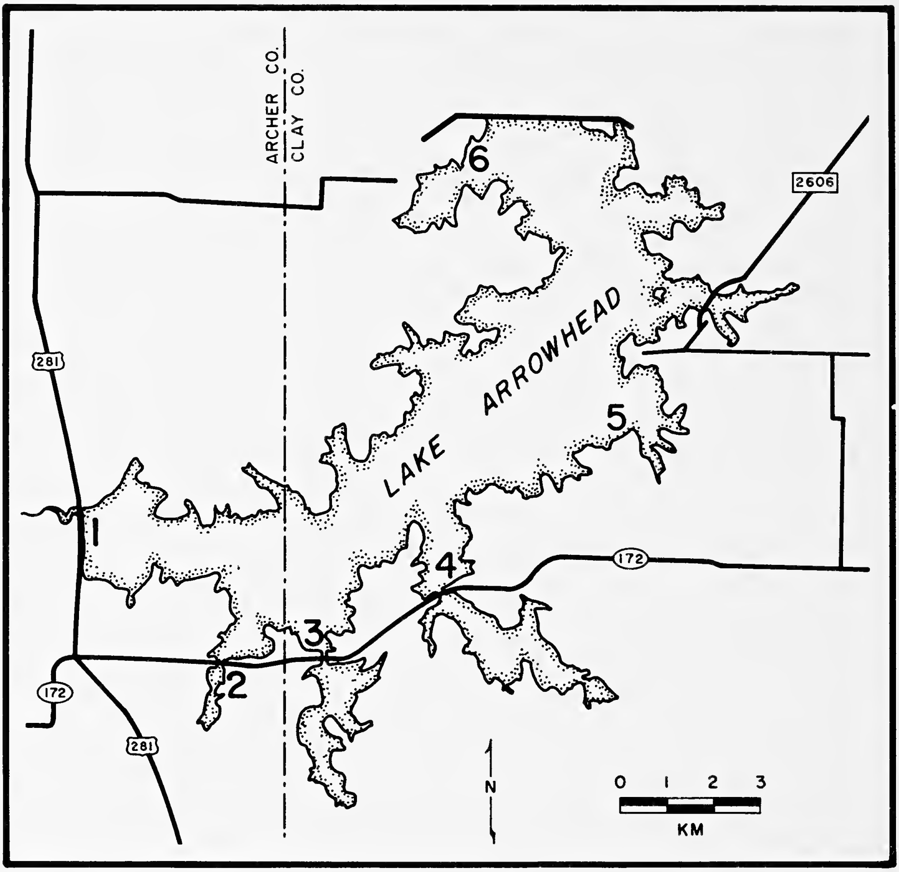

FIGURE 2. Map of Lake Arrowhead, Texas, with collection sites. Numbers refer to sites listed in appendix.

Leptodea fragilis (Rafinesque, 1820) was present at five locations and was generally found in areas with deep sand or silty sand. The largest specimen measured 133.1 mm in shell length. Shells are rather obese and long in relation to height when compared to specimens from central Texas. In general shape, the shells resemble those of specimens from the rivers of eastern Texas. The periostracum is a horn yellow with fine, green rays present on juveniles. Nacre is whitish with purplish highlights dorsally, the purple especially intense at the posterior muscle scars. The joined valves typically exhibit a gap at the ventro-anterior margin for protrusion of the foot.

Potamilus laevissimus (Lea, 1830) is common and widely distributed in Lake Arrowhead. This species was most common in deep sand or silty sand although one large, long-dead pair of valves was found embedded in a rocky clay bottom. The largest specimen measured 140.6 mm in shell

TABLE 1. Occurrence of bivalves at various collection sites of Lake Arrowhead, Clay, and Archer counties, Texas (X = present).

	Site number*						
Species	1	2	3	4	5	6	7
Anodonta grandis	X	X	X	X		X	X
Anodonta imbecilis		X	X	X	X	X	X
Uniomerus tetralasmus			X**				
Quadrula quadrula				X	X	X	X
Lampsilis teres							X
Leptodea fragilis	X	X	X	X		X	
Potamilus laevissimus	X		X		X	X	X
Toxolasma parvus			X			X	
Corbicula fluminea			X	X	X	X	X
Species site total	3	3	7	5	4	7	6

* See Figure 2 for site location.

** May not represent living population in Lake Arrowhead (see text).

length. Fresh valves exhibit a highly lustrous mauve nacre that fades to violet as valves weather. Shells fade to a whitish purple and eventually become nearly white with an underlying iridescence. Paired valves exhibit a noticeable gap at both ends that is more pronounced posteriorly. The periostracum is a dark brown.

Toxolasma parvus (Barnes, 1823) is the smallest unionid in Lake Arrowhead. The periostracum is a silky, dark brown and the nacre is white. Recorded at only two sites(nos. 3 and 6), *T. parvus* could be underrepresented in samples because of its small size. The largest recovered specimen measured only 17.9 mm in shell length.

Corbicula fluminea (Muller, 1774) is widely distributed in Lake Arrowhead and is the most common bivalve in this reservoir. Shells were typically small in size; the largest specimen measured only 25.4 mm in shell length. Presence of small (less than 5 mm) specimens indicates successful reproduction. *Corbicula fluminea* was found on rock riprap and soft substrates varying from clay loam to silty sand. However, specimens were noticeably less common on a hard clay substrate subportion of the Lake Arrowhead State Recreation Area when compared to adjacent areas with a sandy clay mixture. All specimens observed are referable to the "white form" (Hillis and Patton, 1982).

DISCUSSION

Apparently, no unionid species native to the Little Wichita River have been extirpated from the portion now under Lake Arrowhead; however, the rarity of *L. teres* in the lake may be an indication of loss in the future. Lack of evidence for extirpation of species probably relates to the fact that these species are well adapted to sluggish streams. Conditions of substrate and water chemistry of the river were similar in part to those found in Lake Arrowhead. Population densities of some species may be somewhat higher following impoundment due to increased area of benthic substrate.The greatest faunal diversity occurred in areas of mixed clay and sand substrate.

Records of unionids from Lake Texoma (summarized by White and White, 1977) allow comparison with the fauna reported herein for Lake Arrowhead. Unionid species typical of moving waters (for example, *Obliquaria reflexa*) probably are present in Lake Texoma, but not in Lake Arrowhead, because selected areas of Lake Texoma contain "riffle-like" conditions (White and White, 1977). Presence of perennial tributaries with permanent populations of unionids also favors occurrence of such species in Lake Texoma.

Impact of human activities upon the bivalves of Lake Arrowhead is not restricted to the immediate effects of impoundment. One non-native species, *Corbicula fluminea*, has established populations in Lake Arrowhead. The small size of the observed shells probably is due to recent introduction, although the shorter growth period (see White and Burky, 1984), when compared to the rest of Texas, may be a contributory factor. Lake Arrowhead represents a western extension of the range of *C. fluminea* in the Red River drainage (see Britton, 1982).

Four other observations concerning the bivalves of Lake Arrowhead can be made. First, the unionid populations of the drainage of the Little Wichita River appear to be physically and genetically isolated from other populations of these species in other rivers and creeks of the upper portion of the Red River. As few (if any) unionids appear to live in the mainstem of the Red River (Isely, 1924; Strecker, 1931; White and White, 1977; Neck, unpublished records). Secondly, all species known from the Red River drainage above Lake Texoma are present in Lake Arrowhead. Thirdly, suitable habitat would appear to exist in Lake Arrowhead for *Amblema plicata*, but no records in the Red River system are known for this species from or above Lake Texoma. Finally, primary mortality factors affecting bivalves in Lake Arrowhead appear to include fluctuations of water levels, predation by raccoons, and human utilization for fish bait.

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APPENDIX

Collection localities are as follows (numbers keyed to Figure 2): 1) U.S. Highway 281 and Lake Arrowhead; 2) first cove crossing (West Little Post Oak Creek) on Farm to Market Road 172 east of U.S. 281; 3) second cove crossing (East Little Oak Creek) on Farm to Market Road 172 east of U.S. 281; 4) third cove crossing (Deer Creek) on Farm to Market Road 172 east of U.S. Highway 281; 5)exposed shoreline 0.2 km west of Halsell Cemetery; 6) Lake Arrowhead State Recreation Area; and 7) Farm to Market Road 2606 and Lake Arrowhead.

Literature Cited

Britton, J. C.1982.Biogeography and ecology of the Asiatic clam, Corbicula, in Texas. Pp. 21-31, *in* Proceedings of the Symposium on recent benthological investigations in Texas and adjacent states (J.R. Davis, ed.). Texas Acad. Sci., Austin, 278 pp.

Clarke, W. T. Jr. 1938. List of mollusks from drift debris of Paladora [sic] Creek, Texas. The Nautilus, 52:14-15.

Dowell, C. L., and S. D. Breeding. 1967. Dams and reservoirs in Texas. Texas Water Development Board Rept., 48:1-267.

Hillis, D. M., and J. D. Patton.1982. Morphological and electrophoretic evidence for two species of *Corbicula* (Bivalvia: Corbiculidae) in North America. Amer. Mid. Nat., 108:74-80.

Isely, F. B. 1924. The freshwater mussel fauna of eastern Oklahoma. Proc. Oklahoma Acad. Sci., 4:43-118.

Riggs, C. D., and G. R. Webb. 1956. The mussel population of an area of loamy-sand bottom of Lake Texoma. Amer. Midland Nat., 56:197-203.

Strecker, J. K. 1931. The distribution of the naiades or pearly fresh-water mussels of Texas. Spec. Bull. Baylor Univ. Mus., 2:1-71.

Valentine, B. D., and D. H. Stansbery. 1971. An introduction to the naiads of the Lake Texoma region, Oklahoma, with notes on the Red River fauna (Mollusca: Unionidae). Sterkiana, 42:1-40.

White, D. S., and S. J. White. 1977. Observations on the pelecypod fauna of Lake Texoma, Texas and Oklahoma, after more than 30 years impoundment. Southwestern Nat., 22:235-254.

White, P. A., and A. J. Burky. 1984. Low temperature tolerance of winter-acclimated *Corbicula fluminea*. Amer. Malacol. Bull., 3:94 (abstr.).

GEOGRAPHIC DISTRIBUTION OF COMMERCIAL BOBCAT HARVESTS IN TEXAS, 1978-1986

Robert D. Bluett, Michael E. Tewes, and Bruce C. Thompson
Caesar Kleberg Wildlife Research Institute, Campus Box 218, Texas A&I University, Kingsville, Texas 78363, and Texas Parks and Wildlife Department, 4200 Smith School Road, Austin, Texas 78744

Abstract.—Fifty-four percent of bobcats harvested in Texas from 1978 through 1986 were taken in the Trans-Pecos Mountains and Basins, on the South Texas Plains, and on the Edwards Plateau. Numbers of bobcats harvested per season increased linearly in the Pineywoods ($P = 0.0239$), Post Oak Savannah ($P = 0.0002$), Blackland Prairies ($P = 0.0014$), and Edwards Plateau ($P = 0.0354$). Regional harvest densities (number of bobcats harvested per 100 square kilometers) were greatest in the Pineywoods ($\bar{x} = 2.81$), Cross Timbers and Prairies ($\bar{x} = 2.78$), and South Texas Plains ($\bar{x} = 2.77$). Populations may have been overharvested in some local areas. Illegal transport of pelts from Mexico to Texas may have contributed to high harvest densities in Maverick, Presidio, and Val Verde counties.
Key words: bobcat; *Felis rufus*; furbearer; harvest; Texas.

Harvest estimates provide the foundation for furbearer management policies and decisions in most western states (Melchior et al., 1987). Managers use harvest estimates to determine the commercial value of fur harvests, evaluate management alternatives, and monitor the distribution and status of furbearer populations (Erickson, 1982).

Efforts to manage bobcat (*Felis rufus*) harvests increased during the 1970s because of federal export restrictions stemming from the 1973 Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Gluesing et al., 1987). Since 1977, state resource agencies have been required to demonstrate to the Office of Scientific Authority (U.S. Fish and Wildlife Service) that annual bobcat harvests will not limit species survival (Gluesing et al., 1987). Minimum requirements for a non-detriment finding include information about the number and distribution of bobcats harvested in a state (Mech, 1978).

Texas Parks and Wildlife Department (TPWD) has collected data on annual bobcat harvests since 1976. Tagging of pelts prior to purchase, sale, or transport outside the state has been required since 1978. We analyzed tagging data collected from 1978 through 1986 to identify trends in the number and distribution of bobcats harvested in Texas.

Study Area and Methods

Texas encompasses 691,030 square kilometers in the south-central United States (Kingston and Crawford, 1987). About 19 percent of bobcats harvested in the United States are taken in Texas (Funderburk, 1986).

Distribution of harvest was obtained from pelt-tagging data summarized by TPWD in unpublished reports. We calculated annual (1979-1986) harvest densities (number of bobcats harvested per 100 square kilometers) for each county by dividing the number of bobcats harvested per year by total county area exclusive of cropland. County data were not

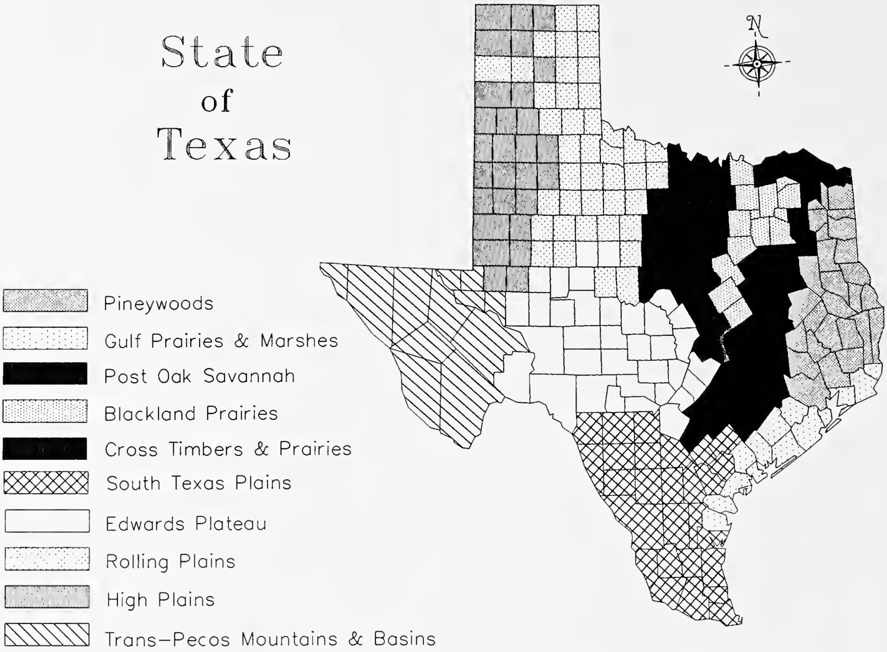

FIGURE 1. Texas counties grouped by ecological region (adapted from Gould, 1969, by the Texas Parks and Wildlife Department).

available for 1978. We ommitted cropland from density estimates because cropland provides unsuitable habitat for bobcats (Rolley, 1983) and is unevenly distributed in Texas (Texas Agric. Stat. Serv., 1985). County data were grouped by ecological region using TPWD's classification system (Fig. 1).

We used cluster analysis (PROC FASTCLUS) to identify groups of counties with similar harvest densities. We specified a maximum of 20 clusters during the first run and created a dendrogram (PROC TREE) from which we determined the optimal number of clusters for later analyses. We used canonical discriminant analysis (PROC CANDISC) to compute canonical variables for plotting clusters. All analyses were performed with SAS (SAS Inst., Inc., 1988).

We obtained data on the total area within each county from Kingston and Crawford (1987). Cropland area within each county was obtained from the Texas Agricultural Statistics Service (1985). We calculated descriptive statistics ($\bar{x}$, SD, range) for regional harvests and used simple linear regression to test for trends ($H_o : b_1 = 0$) in the number of bobcats harvested per year (1978-1986) in each ecological region.

RESULTS

Fifty-four percent of bobcats harvested from 1978 through 1986 were taken in the Trans-Pecos Mountains and Basins, on the South Texas Plains, and on the Edwards Plateau (Table 1). Numbers of bobcats harvested per season increased linearly from 1978 through 1986 ($n = 9$) in the Pineywoods ($r^2 = 0.54$, $P = 0.0239$), Post Oak Savannah ($r^2 = 0.87$, $P = 0.0002$), Blackland Prairies ($r^2 = 0.79$, $P = 0.0014$), and Edwards Plateau ($r^2 = 0.49$, $P = 0.0354$). No linear trend existed for

TABLE 1. Descriptive statistics for the number of bobcat pelts tagged annually (1978-1986) for international export in 10 ecological regions of Texas.

Region	Percent of estimated statewide bobcat habitat in region[a]	Harvest statistics			
		$\bar{x}$	SD	Max.	Min.
Pineywoods	9.9	1,420	291	1,828	862
Gulf prairies and Marshes	2.4	353	110	590	235
Post Oak Savannah	10.5	1,157	292	1,622	725
Blackland Prairies	2.4	433	149	662	226
Cross Timbers and Prairies	8.2	1,271	338	1,821	731
South Texas Plains	12.9	2,518	463	3,312	1,981
Edwards Plateau	19.5	2,111	531	3,108	1,445
Rolling Plains	13.1	1,584	590	2,959	970
High Plains	5.1	133	70	271	26
Trans-Pecos	16.0	2,918	681	4,098	1,832
Statewide	100.0	13,897	2,541	19,477	10,684

[a] From Bluett and Tewes (1988).

annual harvests in other regions ($P > 0.05$) or for statewide bobcat harvests ($r^2 = 0.25$, $P = 0.1701$).

Regional harvest densities were greatest in the Pineywoods, Cross Timbers and Prairies, and South Texas Plains (Table 2). Mean harvest densities for individual counties ranged from 0.00 to 10.64 bobcats per 100 square kilometers (Fig. 2). Maximum harvest densities ranged from 0.00 to 16.21 bobcats per 100 square kilometers (Fig. 3).

Preliminary data analysis indicated three to five clusters of harvest densities. High harvest densities in Maverick ($\bar{x} = 10.03$ bobcats per 100 square kilometers) and Presidio ($\bar{x} = 10.64$ bobcats per 100 square

TABLE 2. Descriptive statistics for numbers of bobcats harvested per 100 square kilometers (1979-1986) in Texas counties (exclusive of cropland) grouped by ecological region.

Ecological region	Number of counties	Harvest[a] per 100 square kilometers			
		$\bar{x}$	SD	Max.	Min.
Pineywoods	27	2.81	2.03	9.56	0.00
Gulf Prairies and Marshes	15	1.37	1.43	8.44	0.00
Post Oak Savannah	32	2.07	1.66	8.44	0.00
Blackland Prairies	14	2.42	2.05	8.12	0.00
Cross Timbers and Prairies	23	2.78	2.12	10.40	0.00
South Texas Plains	27	2.77	2.58	16.21[b]	0.00
Edwards Plateau	35	1.69	1.82	9.03	0.00
Rolling Plains	41	2.10	2.01	11.21	0.00
High Plains	28	0.24	0.51	3.28	0.00
Trans-Pecos	12	2.51	2.96	15.70[b]	0.00

[a] Determined from number of pelts tagged for international export.

[b] Maximum harvest density may be biased by tagging of bobcat pelts transported illegally from Mexico to Texas.

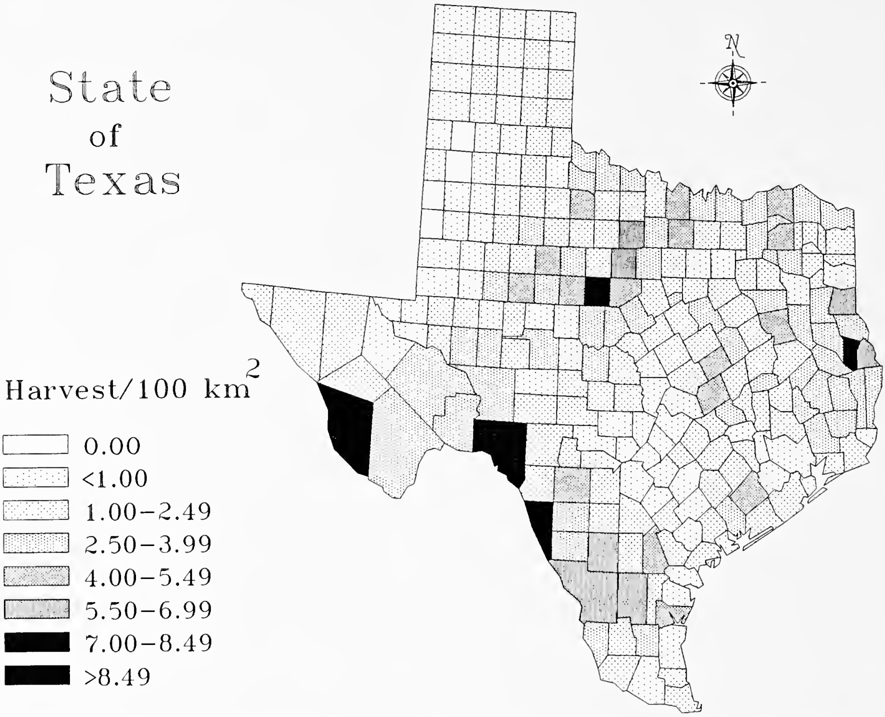

Figure 2. Mean number of bobcats harvested per 100 square kilometers of suitable habitat in Texas counties from 1979 to 1986.

kilometers) counties formed a distinct group of outliers when we specified a maximum of five and four clusters. Val Verde, San Augustine, and Callahan counties were added to this group when we reduced the maximum number of clusters to three.

Discussion

Harvest data indicate that bobcats occur throughout Texas and use most or all major habitat types within the state. The wide range of harvest densities we observed probably resulted from variation in harvest effort and bobcat density. Greatest harvest densities occurred in counties dominated by mesquite (*Prosopis glandulosa*)-lotebush (*Zizephus obtusifolia*), mesquite-juniper (*Juniperus* sp.), mesquite-blackbrush (*Acacia rigidula*), mesquite-granjeno (*Celtis pallida*), and post oak (*Quercus stellata*) habitats.

No bobcats were reported to have been harvested in Castro, Cochran, Lamb, and Yoakum counties. Lack of harvest probably resulted from low harvest effort. Few licensed furtakers (1.84 furtakers per 100 square kilometers) were present on the High Plains during the study period

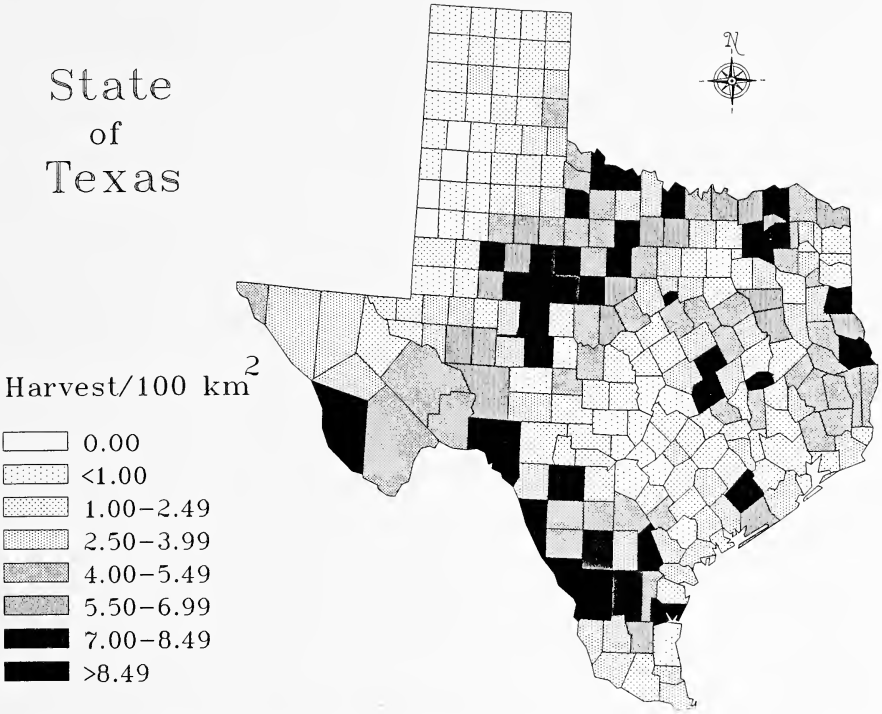

FIGURE 3. Maximum number of bobcats harvested per 100 square kilometers of suitable habitat in Texas counties from 1979 to 1986.

(Texas Parks and Wildlife Dept., unpublished data). Bobcats were harvested in adjacent counties with similar types and amounts of habitat.

Harvest rates may have been excessive in local areas during some seasons. Many managers consider a harvest rate of less than 20 percent of the autumn population to be safe for bobcats (Rolley, 1987; W. Berg, Minnesota Dept. Nat. Resources, personal communication). Using an estimate of 0.4 to 0.8 bobcats per square kilometers on the South Texas Plains (W. Andelt, Colorado State Univ., personal communication), harvest exceeded 20 percent of the minimum estimated population in Kleberg, Live Oak, and Uvalde counties in 1986, and in Webb county in 1982.

Bluett and Tewes (1988) estimated a density of 0.3-0.6 bobcats per square kilometers of habitat in the Pineywoods. Using the most conservative estimate of bobcat density, harvest exceeded 20 percent of the autumn population in Sabine and Panola counties during four seasons, and in San Augustine county during all eight seasons. High harvest rates in Sabine and San Augustine counties may have been associated with high harvest effort in large areas of national forest open to public hunting and trapping.

Investigations conducted by TPWD and federal law enforcement officials indicate bobcat pelts are sometimes transported illegally into Texas from Mexico. Major highways cross the Mexican border in three of five counties identified as outliers (Maverick, Presidio, and Val Verde). We believe that tagging of pelts harvested in Mexico contributed to high harvest densities calculated for these counties.

Management Implications

Although regional bobcat harvests seem within recommended levels (Bluett and Tewes, 1988), excessive harvest may occur in some local areas of Texas. Additional data about bobcat densities and harvest effort are needed to interpret variation in bobcat harvests. An increase in annual harvests in the Pineywoods, Blackland Prairies, Post Oak Savannah, and Edwards Plateau regions suggests these should receive management priority.

Transport of untagged bobcat pelts into the United States is a clear violation of CITES and the Lacey Act. Efficiency of state and federal efforts to control illegal transport of bobcat pelts might be increased by focusing enforcement activity in border counties with outlying harvest densities and seeking cooperation from the government of Mexico.

Cluster analysis is an effective data reduction technique that may have broader applications as a management and law enforcement tool. The FASTCLUS procedure is particularly sensitive to outliers and handles large data sets efficiently (SAS Inst., Inc., 1988:494). Results should be interpreted cautiously because no statistical tests can be used to verify them. However, we believe that results from cluster analysis provide a basis for further investigation if they are consistent with past experience and make good ecological sense.

Harvest may be excessive in some areas of Texas that are open to public hunting and trapping. Establishing refugia within large public properties might increase long-term yield and recreational opportunity by protecting populations from which dispersers could occupy vacant home ranges outside refugia (Bailey, 1981). Closing relatively small areas to bobcat hunting and dry-land trapping seems preferable to reducing season length for bobcats within a longer general furbearer season because incidental capture of bobcats in traps set for other species could hinder enforcement efforts.

Acknowledgments

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LITERATURE CITED

Bailey, T. N. 1981. Factors of bobcat social organization and some management implications. Pp. 984-1000, *in* Proceedings of the worldwide furbearer conference (J. A. Chapman and D. Pursley, eds.), Worldwide Furbearer Conf., Inc., Frostburg, Md., 2:viii + 653-1552.

Bluett, R. D., and M. E. Tewes. 1988. Evaluation of bobcat harvest relative to estimated population size and habitat base in Texas, 1978-1986. Texas Parks Wildlife Dept., Austin, 203 pp.

Erickson, D. W. 1982. Estimating and using furbearer harvest information. Pp. 53-65, *in* Midwest furbearer management (G. C. Sanderson, ed.), Symposium, North Central Section, Central Mountains and Plains Section, and Kansas Chapter, The Wildlife Society, Wichita, Kansas, 195 pp.

Funderburk, S. 1986. International trade in U.S. and Canadian bobcats, 1977-1981. Pp. 489-501, *in* Cats of the world: biology, conservation, and management (S. D. Miller and D. D. Everett, eds.), Nat. Wildlife Fed., Washington, D.C., xi + 501 pp.

Gluesing, E. A., S. D. Miller, and R. M. Mitchell. 1987. Management of the North American bobcat: information needs for nondetriment findings. Trans. North Amer. Wildlife Nat. Resour. Conf., 51:183-192.

Gould, F. W. 1969. Texas plants: a checklist and ecological summary. Texas A&M Univ., Texas Agric. Exp. Sta., College Station, 121 pp.

Kingston, M., and M. G. Crawford. 1987. 1988-1989 Texas almanac and state industrial guide. The Dallas Morning News, Dallas, Texas, 640 pp.

Mech, L. D. 1978. Report of the working group on bobcat, lynx, and river otter. Nat. Sci. Found., Washington, D.C., 15 pp.

Melchior, H. R., N. F. Johnson, and J. S. Phelps. 1987. Wild furbearer management in the western United States and Alaska. Pp. 1117-1128, *in* Wild furbearer management and conservation in North America (M. Novak, J. A. Baker, M. E. Obbard, and B. Malloch, eds.), Ontario Trappers Assoc., North Bay, Ontario, xviii + 1150 pp.

Rolley, R. E. 1983. Behavior and population dynamics of bobcats in Oklahoma. Unpublished Ph.D. dissertation, Oklahoma State Univ., Stillwater, 98 pp.

———. 1987. Bobcat. Pp. 671-681 in Wild furbearer management and conservation in North America (M. Novak, J. A. Baker, M. E. Obbard, and B. Malloch, eds.), Ontario Trappers Assoc., North Bay, Ontario, xviii + 1150 pp.

SAS Institute, Inc. 1988. SAS/STAT user's guide, release 6.03 edition. SAS Inst., Inc., Cary, North Carolina, 373 pp.

Texas Agricultural Statistics Service. 1985. 1985 Texas county statistics. Texas Dept. Agric., Austin, 273 pp.

THE KAWAGUCHI Y^H OPERATOR AS AN EXTENSOR QUOTIENT

P. S. Morey, Jr.
Department of Mathematics, Texas A&I University, Kingsville, Texas 78363

Abstract.—In his 1940 paper on higher order differential geometry, A Kawaguchi defined several operators, which have become known as "Kawaguchi operators." These operators, applied to an absolute extensor of sufficient differentiability, produce an extensor of the same type as the original or sometimes, a tensor, although the range of the nontensor index may be changed. Kawaguchi showed his Y^H operators to be extensors by induction; in this paper we show this by use of the extensor contraction and quotient laws. *Key words*: tensors; extensors; Kawaguchi operators; quotient law.

One of the main reasons for the usefulness of tensors in mathematical physics is that the tensor transformation law is linear; that is, the sum of two tensors of the same type is a tensor of the same type and the product of a nonzero number and a tensor is a tensor of the same type as the original. This means that if a certain geometric object (point, arc, surface, for example) makes a particular tensor zero in one coordinate system, the same geometric object will make the same tensor zero in all coordinate systems that can be obtained from the given one by allowable coordinate transformations. Thus, Albert Einstein set a contraction of the Riemann-Christoffel tensor equal to zero, for space containing no matter, to obtain the dynamical equations in the General Theory of Relativity. A solution to these equations (for example, the orbit of Mercury around the sun) would be the same regardless of the coordinate system used to describe that orbit.

The introduction of time (or some other parameter) as a variable is a necessity to setting up dynamical equations, because tensors are essentially timeless (or more generally, parameterless). If one introduces parametric arcs into the original model, another difficulty is encountered, because derivatives of tensors are no longer linear. To overcome the nonlinearity problem, H. V. Craig (1937), by combining the original tensor with the derivatives of the tensor, produced a set of quantities with a linear transformation law. But the resulting transformation law contained derivatives of the transformation coefficients, and hence these quantities were no longer tensors. He referred to these new quantities as "extensors."

Craig showed that these quantities obey much the same laws as do tensors; that is, sum, product, contraction, and quotient laws. Of course, extensors have properties that tensors do not possess. One of these is "rank," in which the components of an extensor may be divided naturally into sets of N quantities (N is the dimension of the space), depending on the valve of the Greek (nontensor) indices.

Still another distinguishing property of extensors is that a given extensor of sufficient differentiability may be differentiated a certain number of times with respect to the curve parameter, multiplied by the correct coefficient, and summed over a particular range to give an extensor of the same type as the original, or sometimes a tensor. Kawaguchi (1940), in a 152-page mathematics research paper, defined several of these operators, which have become known as "Kawaguchi operators." The present author (see Morey, 1967, 1981, 1982, 1987; Morey and Hardy, 1974), because of his work on "horizontal contractions," has shown some of Kawaguchi's original operators to be special cases of more general operators as well as developing several new operators.

The purpose of the present paper is to show that one of the original Kawaguchi operators may be derived by a completely different method from that used by Kawaguchi in his original paper, namely by use of the extensor quotient law instead of by induction.

NOTATION

The notation of this paper is essentially that of extensor analysis, as given in Craig (1943). In particular, enclosed Greek or enclosed numerical superscripts indicate differentiation with respect to the curve parameter (here denoted by t). Reference is made to three coordinate systems, x, $\tilde{x}$, and $\bar{x}$. Letters toward the first of the alphabet (a to h) are associated with the plain (unbarred) coordinate system x, those toward the middle (i to p) with the wave system $\tilde{x}$, and those toward the end (r to z) with the barred system $\bar{x}$, with a similar association for the Greek indices. Also,

$$X^{a}_{r} = \partial x^{a} / \partial \bar{x}^{r}$$

and

$$\begin{aligned} X^{Aa}_{Pr} &= \binom{A}{P} X^{a\,(A-P)}_{r} = \partial x^{a(A)} / \partial \bar{x}^{r\,(P)}, && A \geq P, \\ &= O, && A < P. \end{aligned}$$

Here A and P are the upper case Greek letters alpha and rho, respectively, with range on each Greek index from O to M, M > O, and the last partial derivative indicates a formal operation in which $\partial \bar{x}^{r\,(P)} / \partial \bar{x}^{s(\Sigma)}$ is zero unless r = s and P = Σ, in which case it is one. For details, see Craig (1943, 1964, 1965).

The usual Einstein summation convention applies to lower case Latin (tensor) indices. Namely, if such an index is repeated within a single term, once as a superscript and once as a subscript, it is assumed that there is a sum generated by that index over its range (1 to N, where N is the dimension of the space under consideration). For lower case Greek (extensor) indices, this same type of repetition generates a sum from zero to some positive integer M, unless the contrary is indicated by the presence of a summation sign (Σ) giving the range. Note that extensor indices within a given symbol do not have to have the same range, which is different from tensor indices, which must have range the dimension of the space. Also note that upper case indices, whether repeated or not, do not generate sums. In addition, the convention is used that indices inside binomial, multinomial, and related coefficients do not generate sums unless the contrary is specified by the presence of a summation sign. Also, at times "no summation" may be indicated by writing $\sim\Sigma$ after the expression in question. Also quantities bearing an out-of-range index are defined to be zero. This convention, which will apply to quantities differentiated a negative number of times, is for convenience in use of the summation convention.

EXTENSOR PRELIMINARIES

Before going to the main theorems, some definitions and theorems of extensor analysis are reviewed. Because the extensor transformation law for the general case is cumbersome, it will be stated for a special case, which is sufficiently typical to suggest unambiguously the general case. Note that throughout this paper, it is assumed that M is a positive integer.

Definition.—Let there be given an N-dimensional space, a coordinate system in that space, and the set of all coordinate systems that can be obtained from the given one by allowable coordinate transformations of class M, $M > O$. This set of coordinate systems is known as the "collection of tensor analysis."

Definition.—If there is given at a certain point P of a parameterized arc of class c^M, $M > O$, one set of labelled quantities $E^{\alpha a}_{\beta b \cdot c}$ for each coordinate system of the collection of Tensor Analysis, and if further, these quantities are either numbers or vectors and are such that the components $E^{\alpha a}_{\beta b \cdot c}$ associated with any one coordinate system x are related to the components $\bar{E}^{\rho r}_{\sigma s \cdot t}$ belonging to any other coordinate system $\bar{x}$ according to the transformation equation

$$\bar{E}^{\rho r}_{\sigma s \cdot t} = J^W (x/\bar{x})\, E^{\alpha a}_{\beta b \cdot c}\, X^{\rho r}_{\alpha a}\, X^{\beta b}_{\sigma s}\, X^{c}_{t}\,,$$

then these labelled quantities are the components of an extensor of excontravariant order one, excovariant order one, covariant order one, and weight W. Here $J(x/\bar{x})$ is the Jacobian determinant of the x's with respect to the $\bar{x}$'s.

If $E^{\cdot\cdot\cdot}_{\cdot\cdot\cdot}$ is an extensor of excontravariant order P, excovariant order Q, contravariant order R, covariant order S, and weight W, then $E^{\cdot\cdot\cdot}_{\cdot\cdot\cdot}$ is an extensor of type [P, Q, R, S, W]. Also, if $W = O$, $E^{\cdot\cdot\cdot}_{\cdot\cdot\cdot}$ is termed an absolute extensor (or tensor, if $P = O$ and $Q = O$).

The following theorems will be stated without proofs. Proofs may be found in Craig (1943, 1964, 1965).

Theorem 1.—The extensor transformation law is transitive; that is, the result of transforming from a coordinate system x to a coordinate system $\bar{x}$ through a coordinate system $\tilde{x}$ is the same as transforming directly from the x to the $\bar{x}$ system.

Corollary.—The extensor transformation law is reflexive; that, if the extensor transformation equation is solved for the plain components as a function of the barred components, the resulting transformation equation is of the same type as the original.

Theorem 2.—The extensor transformation law is linear; that, the sum of two extensors of the same type is an extensor of the same type, and the product of a nonzero number and an extensor is an extensor of the same type.

Theorem 3 (Product Rule).—If $E^{\cdots}_{\cdots}$ is a set of numbers and an extensor of type [p, q, r, s, w] and $F^{\cdots}_{\cdots}$ is a set of numbers and an extensor of type [P, Q, R, S. W], then $E^{\cdots}_{\cdots}F^{\cdots}_{\cdots}$ is an extensor of type [p+P, q+Q, r+R, s+S, w+W]. If $E^{\cdots}_{\cdots}$ and $F^{\cdots}_{\cdots}$ are vectors then their dot (cross) product is a number (vector) and an extensor of type [p+P, q+Q, r+R, s+S, w+W].

Theorem 4 (Contraction Law).—If $E^{\alpha a \ldots}_{\beta b \ldots}$ is an extensor of type [P+1, Q+1, R, S, W], then, for θ an integer and $O \leq \theta \leq M$, and $F^{\cdots}_{\cdots}$ defined by

$$F^{\cdots}_{\cdots} = \sum_{\alpha=\theta}^{M} \binom{\alpha}{\theta} E^{(\alpha-\theta)\, a \cdots}_{\alpha\, a \cdots} ,$$

then $F^{\cdots}_{\cdots}$ is an extensor of type [P, Q, R, S, W].

Theorem 5 (Craig).—If V^a is an absolute tensor of contravariant order one and a class c^M function of t, then for range on α from O to M, $V^{a(\alpha)}$ is an extensor of type [1, 0, 0, 0, 0].

Theorem 6 (Kawaguchi's theorem).—If V_b is an absolute tensor of covariant order one and a class c^M function of t, then $\binom{M}{\beta} V_b{}^{(M-\beta)}$ $(\sim\Sigma)$ is an extensor of type [0, 1, 0, 0, 0,].

Theorem 7 (Quotient laws, special cases.—1) If $E^{\cdots}_{\beta b \ldots} V^{b(\beta)}$ is an extensor of type [P, Q, R, S, W], V^b is an arbitrary absolute tensor of contravariant order one and a class c^M function of t, and $E^{\cdots}_{\cdots}$ is independent of V^b, then $E^{\cdots}_{\beta b \ldots}$ is an extensor of type [P, Q+1, R, S, W]. 2) If $\sum_{\alpha=O}^{M} E^{\alpha a \ldots}_{\ldots} \binom{M}{\alpha} V_a{}^{(M-\alpha)}$ is an extensor of type [P, Q, R, S, W], V_a is an arbitrary absolute tensor of covariant order one and a class c^M function of t, and $E^{\cdots}_{\cdots}$ is independent of V_a, then $E^{\alpha a \ldots}_{\ldots}$ is an extensor of type [P+1, Q, R, S, W].

THE KAWAGUCHI Y^H OPERATORS

Kawaguchi (1940) defined the Y^H operators and showed by induction that these operators produce extensors of the same type as the original, although the new Greek index has a higher range. The original theorems are here restated using the notation of Craig (1943) and the present author, then proved by use of the extensor quotient laws. Also, by use of the convention that quantities containing an out-of-range index are assigned the value zero, the three summation statements for each Kawaguchi operator, which depend on the value of the final index, can be combined into one summation.

Theorem 8.—Suppose $E_{\beta b}$ is an absolute excovariant extensor and a class c^L function of *t*, with range on β from O to M, L > O, M > O. Then, for range on H from O to L and on α from O to M+H, the quantities defined by

$$Y\ El_{\alpha a} = \sum_{\gamma=O}^{H} \binom{H}{\gamma} E_{(\alpha-\gamma)a}^{\cdot\,\cdot\,(H-\gamma)},$$

are the components of an extensor of the same type as the original.

Proof.—Note that the derivative of an invariant with respect to the curve parameter is itself an invariant. If V^a is an arbitrary, absolute, contravariant tensor and a class c^{L+M} function of *t*, then by theorem 5, $V^{a(\delta)}$, $O \leq \delta \leq M$, is an absolute excontavariant extensor. By theorem 4, $I = E_{\delta a}V^{a(\delta)}$ is an absolute invariant, and hence $I^{(H)}$ is also. By the Leibnitz rule for differentiation of a product,

$$I^{(H)} = [\, E_{\delta a}V^{a(\delta)} \,]^{(H)} \,.$$

$$= \sum_{\gamma=O}^{M} \binom{H}{\gamma} E_{\delta a}^{(H-\gamma)} V^{a(\delta+\gamma)} \,.$$

We next set $\delta = \alpha - \gamma$, with range on α from γ to $M + \gamma$, so that

$$I^{(H)} = \sum_{\gamma=O}^{H} \sum_{\alpha=\gamma}^{\gamma+M} \binom{H}{\gamma} E_{(\alpha-\gamma)a}^{\cdot\,\cdot\,(H-\gamma)}\ V^{a(\alpha)} \,.$$

By the convention that quantities bearing an out-of-range index are assigned the value zero, if $\alpha < \gamma$ or $\alpha > \gamma + M$, $E_{(\alpha-\gamma)a} = O$, and thus the range of summation on α can be changed from O to M + H without altering the value of the summation, then reverse the order of summation on α and γ, to obtain

$$I^{(H)} = \sum_{\alpha=O}^{M+H} \left[\sum_{\gamma=O}^{H} \binom{H}{\gamma} E_{(\alpha-\gamma)a}^{\cdot\,\cdot\,(H-\gamma)} \right] V^{a(\alpha)} \,.$$

By the extensor quotient law, the quantities inside of the last brackets are the components of an extensor of type [0, 1, 0, 0, 0] with range on α from O to M + H.

In the case of the excontravariant operator, there is a difference between the Kawaguchi operator and the results of the contraction and quotient process. However, it will be shown that one is a constant multiple of the other, so that we can use the results of theorem 2.

Theorem 9.—Suppose $E^{\beta b}$ is an absolute excontravariant extensor and a class c^L function of *t*, with range on β from O to M, L > O, M > O.

Then, for range on H from O to L and on α from O to M + H, the quantities defined by

$$Y^H E|^{\alpha a} = \sum_{\gamma=O}^{H} \binom{M+H}{\alpha}^{-1}\binom{H}{\gamma}\binom{M}{\alpha-\gamma}E^{(\alpha-\gamma)a(\gamma)}$$

are the components of an extensor of type [1, 0, 0, 0, 0].

Proof.—Apply the same proceedure as used in the proof of theorem 8. If V_a is an arbiitrary absolute covariant tensor and a class c^{L+M} function of *t*, then by theorem 6, $\binom{M}{\delta}V_a{}^{(M-\delta)}$ $(\sim\Sigma)$, $O < \delta < M$, is an absolute excovariant extensor. By theorem 4,

$I = \sum_{\delta=O}^{M} E^{\delta a}\binom{M}{\delta}V_a{}^{(M-\delta)}$ is an absolute invariant, and hence $I^{(H)}$ is also. By the Leibnitz rule for the differentiation of a product,

$$I^{(H)} = \left[\sum_{\delta=O}^{M} E^{\delta a}\binom{M}{\delta}V_a{}^{(M-\delta)}\right]^{(H)}$$

$$= \sum_{\gamma=O}^{H}\sum_{\delta=O}^{M}\binom{H}{\gamma}E^{\delta a(\gamma)}\binom{M}{\delta}V_a{}^{(M+H-\gamma-\delta)} .$$

Next set $\delta = \alpha - \gamma$, with range on α from γ to M + γ, so that

$$I^{(H)} = \sum_{\gamma=O}^{H}\sum_{\alpha=\gamma}^{M+\gamma}\binom{H}{\gamma}E^{(\alpha-\gamma)\ a\ (\gamma)}\binom{M}{\alpha-\gamma}V_a{}^{(M+H-\alpha)} .$$

By the convention that quantities bearing an out-of-range index are assigned the value zero, if $\alpha < \gamma$ or $\alpha > M + \gamma$, $E^{(\alpha-\gamma)a} = O$, and thus the range of summation on α can be changed from O to M + H without altering the value of the summation, then reverse the order of summation on α and γ, multiply and divide by $\binom{M+H}{\alpha}$, to obtain

$$I^{(H)} = \sum_{\alpha=O}^{M+H}\left[\sum_{\gamma=O}^{H}\binom{M+H}{\alpha}^{-1}\binom{H}{\gamma}\binom{M}{\alpha-\gamma}E^{(\alpha-\gamma)a(\gamma)}\right]\binom{M+H}{\alpha}V_a{}^{(M+H-\alpha)} .$$

By the extensor quotient law, the quantities inside of the last brackets are the components of an extensor of type [1, 0, 0, 0, 0] with range on α from O to M + H.

In Kawaguchi (1940:44), the $Y^H E|^{\alpha a}$ operator. is defined as follows (again, using the notation of this paper and the convention for out-of-range indices):

$$Y^H E|^{\alpha a} = H!\sum_{\alpha=O}^{M+H}\binom{\alpha}{\gamma}\binom{M+H-\alpha}{H-\gamma}E^{(\alpha-\gamma)a(\gamma)} .$$

Comparing this with the results of theorem 9, the only difference is in the binomial coefficients. Using the definition for these coefficients, those of the last formula become (with the factor of H!)

$$H!\binom{\alpha}{\gamma}\binom{M+H-\alpha}{H-\gamma} = H!\,\frac{\alpha\,!}{\gamma\,!\,(\alpha-\gamma)\,!}\;\frac{M+H-\alpha)\,!}{(H-\gamma)\,!\,(M-\alpha+\gamma)\,!}$$

$$= \frac{(M+H)\,!}{M\,!}\left(\frac{\alpha\,!\,(M+H-\alpha)\,!}{(M+H)\,!}\right)\left(\frac{M\,!}{(\alpha-\gamma)\,!\,(M-\alpha+\gamma)\,!}\right)\left(\frac{H\,!}{\gamma\,!\,(H-\gamma)\,!}\right)$$

$$= \frac{(M+H)\,!}{M\,!}\binom{M+H}{\alpha}^{-1}\binom{M}{\alpha-\gamma}\binom{H}{\gamma}\;.$$

Thus, the contravariant Y^H operators defined in theorem 9 and by Kawaguchi differ by a factor of ***, which, because of the linearity property of extensors (theorem 2), are both absolute excontravariant extensors.

Literature Cited

Craig, H. V. 1937. On tensors relative to the extended point transformation. Amer. J. Math., 59:764-774.

———. 1943. Vector and tensor analysis. McGraw-Hill Book Co., New York.

———. 1964, 1965. Teoria ed applicazioni dell'analisi estensoriale. La Scuola in Azione, 13:60-95 and 21:77-132.

Kawaguchi, A. 1940. Die Differentialgeometrie höherer Ordnung I. Erweiterte Koordinatentransformationen und Extensoren. J. Fac. Sci., Hokkaido Imp. Univ., 9(1):1-152.

Morey, P. S., Jr. 1967. Some generalizations of the Kawaguchi $\mathfrak{Y}^H$ operator. Tensor, N. S., 18:113-118.

———. 1981. An excovariant analogue to the Kawaguchi $\mathfrak{Y}^H$ operator. Tensor, N. S., 35: 249-254.

———. 1982. Some Kawaguchi type operators. Tensor, N. S., 37:71-78.

———. 1987. Kawaguchi operators and Jacobian extensors. Tensor, N. S., 45:161-169.

Morey, P. S., Jr., and J. Hardy. 1974. An operator based on quantities due to Zermelo. Tensor, N. S., 28:275-279.

RIPARIAN FORESTS OF THE LEONA AND SABINAL RIVERS

Carl E. Wood and Judith K. Wood

Department of Biology, Texas A&I University, Kingsville, Texas 78363, and H. M. King High School, Kingsville, Texas 78363

Abstract.—Major woody plant communities of the riparian forests of the Leona and Sabinal rivers, which are located on the Rio Grande Plains and lower Edwards Plateau of Texas, were studied in the summer of 1988. Four locations on the Leona River and five on the Sabinal River were sampled using the quadrat method to determine major community relationships. A total of 37 species was encountered with an average of 18 species per location on the Leona, whereas 56 species were encountered with an average of 27 species per location on the Sabinal River. The most important species on the Leona River, based on importance value, was *Quercus virginiana* Mill., followed by *Ulmus crassifolia* Nutt., *Diospyros texana* Scheele, *Celtis reticulata* Torr., *Carya illinoiensis* (Wang.) K. Koch, and *Sophora secundiflora* (Ort.) DC. On the Sabinal River, the most important species was *Taxodium distichum* (L.) Rich., followed by *Diospyros texana, Quercus virginiana, Carya illinoiensis, Celtis reticulata*, and *Platanus occidentalis* L.

The riparian forest of the Leona River is dominated by *Quercus virginiana, Celtis reticulata*, and *Ulmus crassifolia* in the overstory with *Diospyros texana, Sophora secundiflora*, and *Bumelia lanuginosa* (Michx.) Pers. forming the understory. The riparian woody vegetation of the Sabinal River can be divided into four geographical communities based on species composition. The lower Sabinal River plant community is characterized by *Taxodium distichum, Quercus virginiana, Celtis reticulata, Carya illinoiensis, Diospyros texana*, and *Sapindus saponaria* L. The second community is associated with the dry portion of the Sabinal River, which lies over the Balcones fault zone of the Edwards aquifer and is characterized by *Ulmus crassifolia, Taxodium distichum, Platanus occidentalis, Quercus virginiana, Diospyros texana*, and *Sophora secundiflora*. The third Sabinal River community, located from above the Balcones fault zone in northwestern Uvalde County to Vanderpool, Texas, is characterized by *Taxodium distichum, Platanus occidentalis, Carya illinoiensis, Celtis reticulata, Quercus virginiana, Juglans microcarpa* Berl., *Diospyros texana*, and *Melia azedarach* L. The fourth plant community is characterized by *Platanus occidentalis, Juglans microcarpa, Cephalanthus occidentalis* L., *Juniperus ashei* Buchh., *Quercus buckleyi* Dorr & Nixon, *Acer grandidentatum* Nutt., *Quercus sinuata* Walt., and *Diospyros texana*.

Distributional data show that certain species are limited to specific parts of the floodplain, suggesting that moisture is a major parameter responsible for woody plant distribution in the Leona and Sabinal riparian forests. *Key words*: riparian forest; southern Texas; Rio Grande Plains; Leona River; Sabinal River.

Native floodplain forests have received less attention from both qualitative and quantitative standpoints than any other vegetation type in Texas. This lack of information is especially significant in view of the rapid rate at which river bottom and creek area vegetation are being inundated by reservoirs, indiscriminately logged, or cleared for agriculture or flood control purposes.

Information on riparian forests in the Rio Grande Plains region of Texas is especially limited. Most vegetation studies in southern Texas have dealt with the range-brush vegetation that exists adjacent to the floodplains of creeks and rivers (Tharp, 1939; Blair, 1950; Boqusch, 1952;

Box, 1961; Davis and Winkler, 1968; Drawe and Higginbotham, 1980). Literature on riparian forests in southern Texas often is general in nature (Blair, 1950), or contains historical descriptions in travel logs of the early explorers and settlers of the region (Inglis, 1964). Studies that quantify in detail the riparian forests of the Rio Grande Plains include those of Taylor (1982) on the Nueces River, Bush and Van Auken (1984) on the upper San Antonio River, and Wood and Wood (1988) on the Frio River. Other studies on the riparian forests of the Rio Grande Plains include those associated with the lower Aransas River in San Patricio County (Drawe et al., 1978). The forest along the Rio Grande in the Falcon Dam area in Starr County was described by Butterwick and Strong (1976). Forests along the Rio Grande and the upper Nueces River were briefly described by Bray (1901) as a cottonwood-willow association. Lonard and Judd (1985) listed the common floodplain trees of the Rio Grande near Mission, Texas. A brief description of the vegetation and habitat factors of the carrizo sands which cross the Nueces-Frio River watershed was given by McBryde (1933). Upland and riparian forests of the Edwards Plateau and the upper Guadalupe River have been described by Van Auken et al. (1979, 1980, 1981) and Ford and Van Auken (1982). Bray (1904) and Palmer (1920) described the upland and canyon forests of the Edwards Plateau region.

The purpose of this study was to provide a phytosociological study of the Leona and Sabinal rivers on the Edwards Plateau and Rio Grande Plains of Texas. This study also will provide baseline ecological data on several regions of the Leona and Sabinal rivers that have been considered for reservoir construction.

Study Sites

This study was conducted along the Leona and Sabinal rivers in the southern part of the Edwards Plateau and the northwestern portion of the Rio Grande Plains (Gould, 1975). Four sites were studied on the Leona River from the lower reaches of the river in Frio County to the headwaters in Uvalde County (Fig. 1). The Leona is normally dry in its headwater region, which is located over the Balcones fault zone and surfaces in the city of Uvalde. Five sites were studied on the Sabinal River from the lower reaches of the river in southeastern Uvalde County to the headwater region in Bandera County (Fig. 1). Under average rainfall conditions, the Sabinal River is flowing in the upper reaches until it reaches the Balcones fault zone approximately 15 kilometers north of Sabinal, Texas. The river returns to the surface approximately one kilometer south of Highway 90 in Sabinal. In both rivers, the dry portion flows when heavy rainfall occurs in the upper watershed, usually three to five times a year. All sites chosen were considered representative of

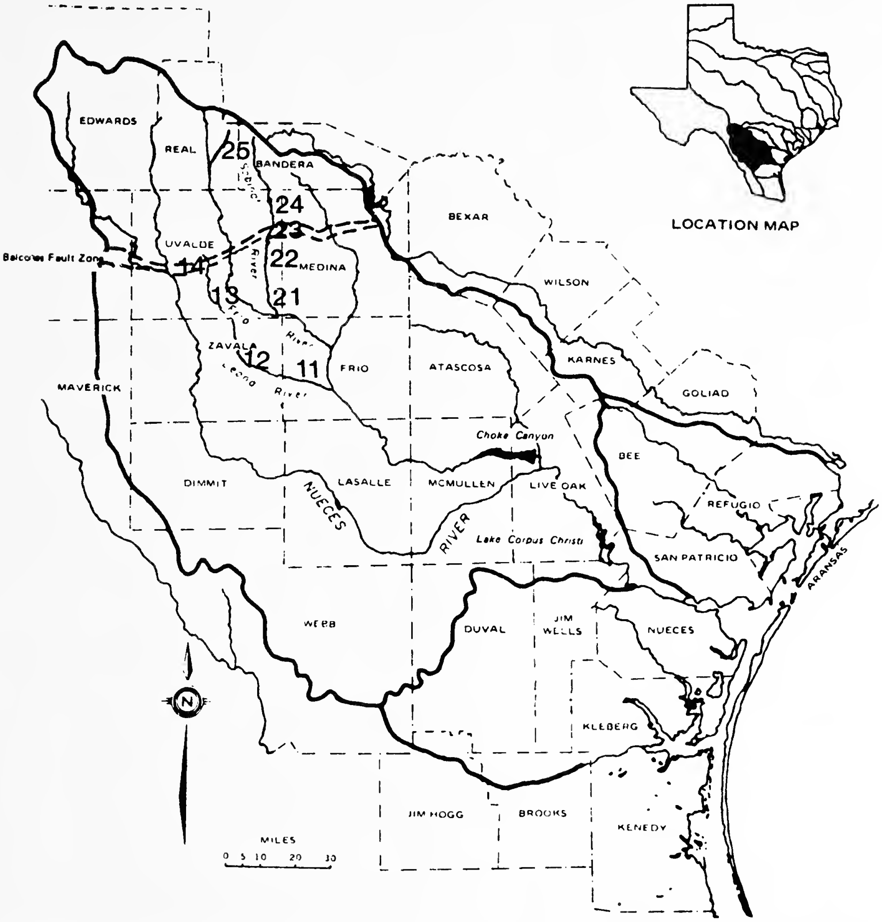

FIGURE 1. Location of study sites on the Leona River (Stations 11-14) and Sabinal River (Stations 21-25).

mature riparian forests after aerial surveilance and the only disturbance in any of the sites was minor grazing by livestock and wildlife.

The Edwards Plateau was classified by Thornthwaite (1948) as dry-subhumid, the Rio Grande Plains as semiarid. Mean annual rainfall is approximately 61 to 71 centimeters in the two river watersheds with maxima occurring in May and September over both of the watersheds (Larkin and Bomar, 1983). Mean annual temperature varies little over the two watersheds, averaging 20°C. Peak temperatures occur in July-August, whereas lowest temperatures occur in December-January (Larkin and Bomar, 1983). Both floodplains are made up of alluvial soils that are light gray to dark gray, calcareous, friable and loamy, and of the Frio series (Carter, 1931). The soils of the two floodplains increase in depths from their headwaters, which overlays limestone bedrock, to the lower reaches of the river.

The physiography of the Leona River can be divided into two regions: the upper region located over the Balcones fault zone and the middle and lower region located in Zavala and Frio counties. In the upper portion of the river, which is characterized by limestone outcrops, the floodplain has only a sight slope (four to eight degrees). The middle and lower reaches of the river lack limestone outcroppings and a steep interbank (more than 25 degrees) is found. The terrace in the remaining portion of this region has a slope of three to eight degrees and is 45 to 55 meters wide. The physiography of the Sabinal River can be divided into three regions: the upper Edwards Plateau region located in Bandera and upper Uvalde counties, the middle or dry river region associated with the Balcones fault zone in Uvalde County, and the lower or Rio Grande Plains region located in lower Uvalde County. The inner bank and floodplain terrace in the upper and dry regions is narrow (less than 50 meters) and characterized by either limestone walls or outcroppings; there is a slight slope in these regions (four to 12 degrees). In lower regions of the river a steep slope (more than 40 degrees) is common, giving a narrow canyon appearance, and limestone outcroppings are absent.

METHODS

Sampling was limited to woody species, including shrubs and vines, on the primary floodplain. No data were collected on the terrace deposits because of extreme disturbances such as farming or brush control. Only stems greater than one centimeter in diameter at breast height were measured. Rectangular quadrats three by 100 meters in size, with the longest dimension parallel to the river bank, were used (Ford and Van Auken, 1982). Depending on the width of the primary floodplain, up to five quadrats were sampled, beginning at the river's edge (1.5 meters) and at distances of five, 15, 25 and 40 meters from the river. Three replicate sampling areas, located within a two-kilometer distance along the river, were sampled at each location.

Woody plants occurring in the quadrats were identified using Correll and Johnston (1970), Johnston (1988), Lynch (1981), and Stanford (1976). Their circumferences, at 1.4 meters above ground, were recorded. Density, basal area, and frequency, as well as their corresponding relative values, also were calculated (Smeins and Slack, 1982). Importance values (IV) were determined by taking the sum of the relative density plus the relative basal area and dividing by two (Ford and Van Auken, 1982). Importance values were used to determine which species dominated a community. The data for the three replicated samples were pooled for each location and correlations were used to compare forest parameters among quadrats and between locations (Steel and Torrie, 1980).

RESULTS

There were few significant differences between major community parameters such as the mean number of species, mean density, or mean total basal area when these parameters were compared across the floodplain or between replicate sampling sites at each sampling location. Consequently, all measurements from all quadrats and replications from all sampling locations for each river system were pooled to determine the overall community composition. Differences in species composition and species dominance did occur from the upper regions of the river to the lower regions and also from the river edge to the outer flood plain terrace.

Leona River

A total of 37 species was encountered in the Leona basin as a whole (Table 1) with an average of 21 species per location. Total density was 2472 plants per hectare. The most important species was live oak (*Quercus virginiana*) with a mean importance value (IV) of 38.6 percent (Table 1). Other species with high IV's were cedar elm (*Ulmus crassifolia*), Texas persimmon (*Diospyros texana*), net leaf hackberry (*Celtis reticulata*), pecan (*Carya illinoiensis*) and Texas mountain laurel (*Sophora secundiflora*). Seven species had mean importance values between 0.5 and 1.0 percent, whereas 17 species occurred infrequently with importance values less than 0.5 percent (Table 1).

High density species in the Leona basin were Texas persimmon, live oak, cedar elm, net leaf hackberry, pecan, coma (*Bumelia lanuginosa*) and soap-berry (*Sapindus saponaria*) (Table 1).

Live oak had the greatest average basal area (24.4 square meters per hectare), and 59 percent of the total basal area (Table 1). Other dominant species, in descending order, were cedar elm, net leaf hackberry, pecan, and Mexican ash (*Fraxinus berlandieriana* A. DC.) (Table 1). Total dominance was 41.3 square meters per hectare.

The riparian forest of the Leona River is a forest dominated by live oak, net leak hackberry, and cedar elm trees in the overstory, with Texas persimmon, Texas mountain laurel, and coma forming the dominant understory (Table 1). Live oak trees are more dominant in the upper part as compared to the lower portions of the river. In the lower and middle parts of the river basin, pecan trees are present along with Mexican ash.

The highest mean number of species (15 and 13) occurred in quadrats located at five and 15 meters, with the lowest number (eight) located in the quadrat farthest from the river (Fig. 2A). Mean density along the river was significantly lower than those found for other quadrats. Total mean density was highest at 25 meters from the river, with significantly lower values at the river edge (1.5 meter) (Fig. 2B). Mean basal area showed highest basal area at 15 meters from the river with lowest basal areas occurring at 1.5 and 40 meters (Fig. 2C).

The spatial distribution of the forest trees as described as a function of distance from the river was dominated by live oak which increased in density with distance from the river (Fig. 3A). Almost all of the dominant species showed declining population statistics at 40 meters from the river (Fig. 3, A-F). The only exception to this decline is the density of live oaks which peaked at 40 meters and cedar elm which increased

TABLE 2. Density, basal area, and importance value (IV) for the major woody species found in the Sabinal River riparian forest. Values presented are the means for each species for the five locations sampled. The importance value is the sum of the mean relative density and relative basal area for each species divided by two.

Species	Density (plants/ha)	Dominance (m^2/ha)	IV (%)
Bald cypress (*Taxodium distichum*)	90.93	36.96	25.52
Texas persimmon (*Diospyros texana*)	356.43	1.47	10.98
Live oak (*Quercus virginiana*)	69.69	14.50	10.97
Pecan (*Carya illinoiensis*)	98.90	9.66	8.79
Net leaf hackberry (*Celtis reticulata*)	213.73	4.42	8.78
Sycamore (*Platanus occidentalis*)	126.78	2.02	4.84
Ashe juniper (*Juniperus ashei*)	82.31	1.06	2.98
Texas mountain laurel (*Sophora secundiflora*)	85.62	.23	2.56
Texas oak (*Quercus buckleyi*)	29.21	2.72	2.52
Soap-berry (*Sapindus saponaria*)	69.69	.19	2.09
Cedar elm (*Ulmus crassifolia*)	36.51	1.31	1.85
Big-tooth maple (*Acer grandidentatum*)	36.51	.96	1.63
Little black walnut (*Juglans microcarpa*)	31.20	.92	1.45
Honey mesquite (*Prosopis glandulosa* Torr.)	39.16	.54	1.44
Common button bush (*Cephalanthus occidentalis*)	43.14	.19	1.34
Coma (*Bumelia lanuginosa*)	37.17	.26	1.21
Red mulberry (*Morus rubra*)	21.24	.89	1.16
Chinaberry (*Melia azedarach*)	26.50	.49	1.06
Others (38 species)*	275.49	2.04	8.83
Total mean:	1770.21	80.53	100.00

*Five species had mean IV's of 0.5 to 1.0 percent: Common hop tree (*Ptelea trifoliata*), mustang grape (*Vitis mustangensis*), brasil (*Condalia hookerii*), Mexican buckeye (*Ungnadia speciosa*), and white shin oak (*Quercus sinuata*). Thirty-three species had IV's of 0.5 percent or less: whitebrush (*Aloysia gratissima*), catclaw acacia (*Acacia roemeriana*), hog plum (*Colubrina texensis*), agarito (*Berberis trifoliolata*), kidneywood (*Eysenhardtia texana* Scheele), red buckeye (*Aesculus pavia* L.), blackwillow (*Salix nigra*), poison ivy (*Rhus toxicodendron*), huisache (*Acacia farnesiana*), Roosevelt weed (*Baccharia neglecta*), escarpment black cherry (*Prunus serotina* Ehrh.), chinkapin oak (*Quercus muehlenbergii*), Texas ash (*Fraxinus texensis*), Texas barberry (*Berberis swaseyi* Buckl.), common spice-bush (*Lindera benzoin* (L.) Bl.), Shumard red oak (*Quercus shumardii* Buckl.), spiny hackberry (*Celtis pallida*), Arizona walnut (*Juglans major* (Torr.) Heller.), rattan vine (*Berchemia scandens*), pink mimosa (*Mimosa borealis*), common elderberry (*Sambucus canadensis* L.), guajillo (*Acacia berlandieri* Benth.), sycamore-leaf snowbell (*Styrax plantanifolia* Englm.), Eve's necklace (*Sophora affinis*), lantana (*Lantana horrida* H.B.K.), lotebush (*Ziziphus obtusifolia*), cat-brier (*Smilax bona-nox*), sugar hackberry (*Celtis laevigata*), Spanish dagger (*Yucca treculeana*), redbud (*Cercis canadensis* L.), Osage orange (*Maclura pomifera* (Raf.) Schneid.), blackbrush acacia (*Acacia rigidula* Benth.), and Virginia creeper (*Parthenocissis quinquefolia*).

slightly at 40 meters. Several species formed a river edge stand while others contributed to the terrace stand. The river edge (1.5 and five-meter quadrats) stand along with live oak was formed by cedar elm, net leaf hackberry and pecan (Fig. 3D). Pecan was found only at two stations (Station 11 and 13) but was a major river edge dominant only in the

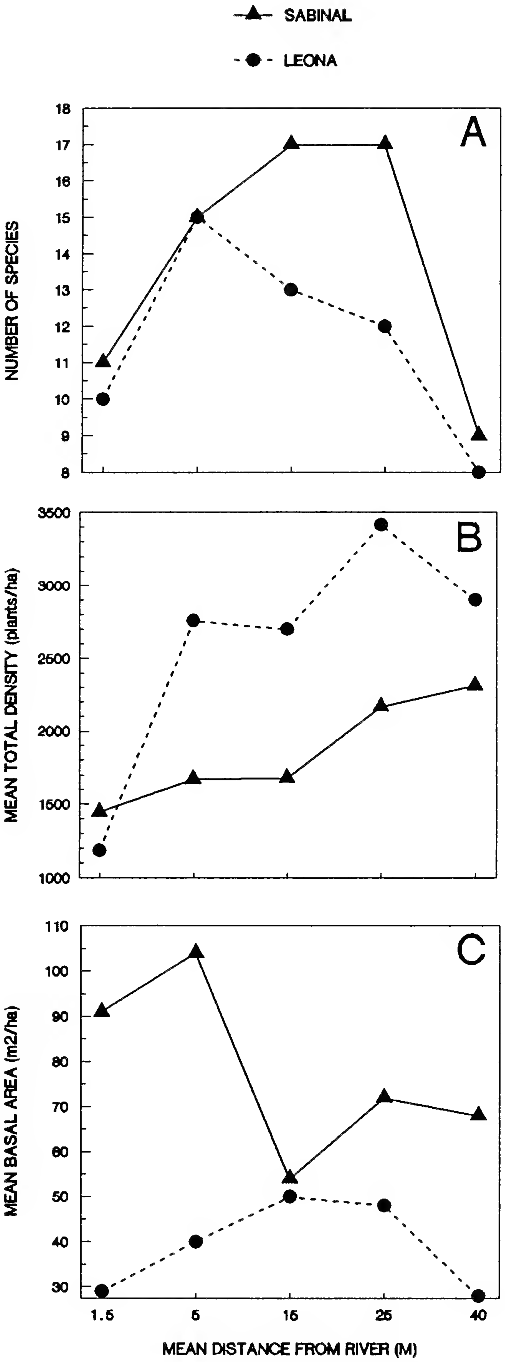

FIGURE 2. Mean number of species (A), mean total density (B), and mean total basal area (C) as a function of distance from the river for the riparian forests of the Leona and Sabinal rivers.

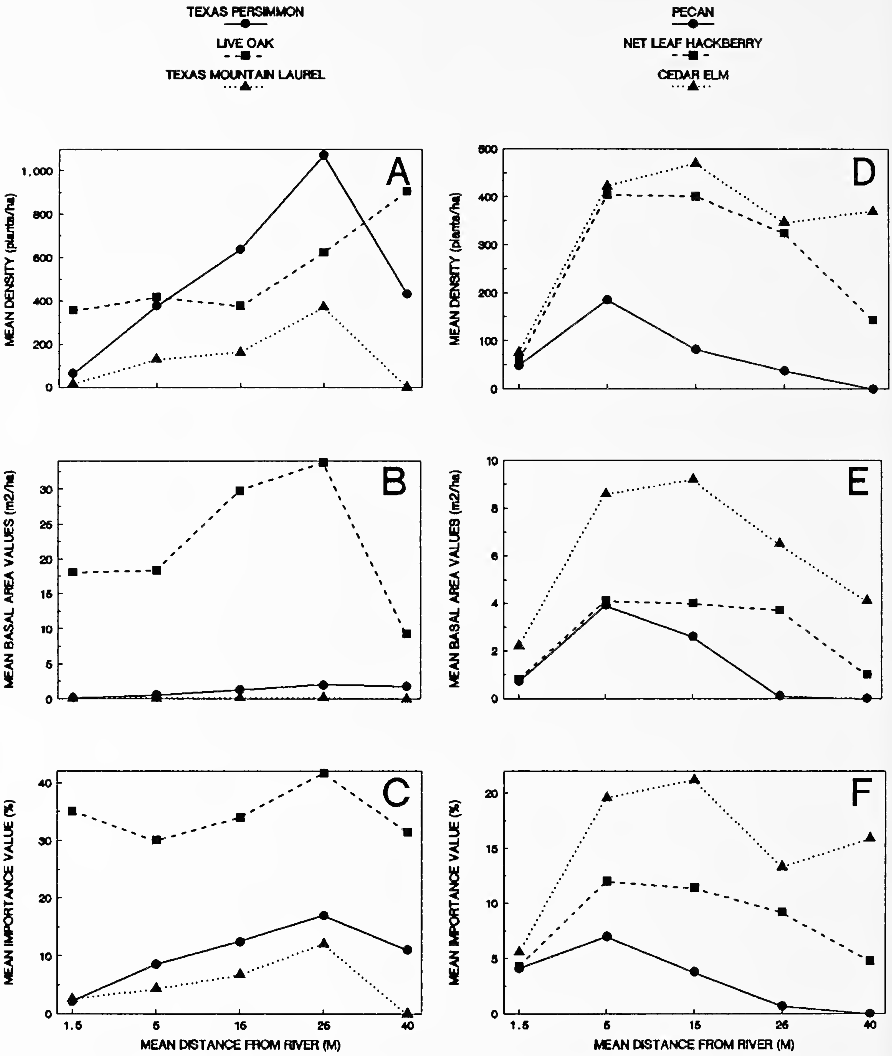

FIGURE 3. Mean total density (A and D), mean total basal area (B and E), and mean importance (C and F) as a function of distance from the Leona River for Texas persimmon, live oak, Texas mountain laurel, pecan, net leaf hackberry, and cedar elm.

lower Leona basin. Pecan declined sharply at 15 meters and was not found beyond 25 meters from the river. The three remaining dominant edge species declined sharply in density at 15 or 25 meters from the river's edge. The same was true for the basal area and IV's of these three edge species (Fig. 3, E and F).

In the terrace stand the dominant species was live oak in the overstory and Texas persimmon and Texas mountain laurel in the understory (Fig. 3A). The density of live oaks was highest at 40 meters but these trees were much smaller then those found in the lower terrace and river edge. All three terrace species were found in highest dominance and IV at 25 meters (Fig. 3, B and C).

Sabinal River

A total of 56 species was encountered in the Sabinal basin as a whole (Table 2) with an average of 27 species per location. Total density was 1770 plants per hectare. The most important species was bald cypress (*Taxodium distichum*) with a mean importance value (IV) of 25.52 percent (Table 2). Other species with high IV's were cedar elm, Texas persimmon, live oak, pecan, net leaf hackberry, and sycamore (*Platanus occidentalis*). Five species had mean importance values between 0.5 and 1.0 percent, whereas 33 species occurred infrequently with importance values less than 0.5 percent (Table 2).

High density species in the Sabinal basin were Texas persimmon, live oak, net leaf hackberry, sycamore, pecan, bald cypress, Texas mountain laurel, Ashe juniper (*Juniperus ashei*), live oak, and soap-berry (Table 2).

Bald cypress had the greatest average basal area (36.96 square meters per hectare), and 46 percent of the total basal area (Table 2). Other dominant species, in descending order, were live oak, pecan, and net leaf hackberry (Table 2). Total dominance was 80.53 square meters per hectare.

Vegetation of the Sabinal River can be divided into four communities. The lower Sabinal River plant community, located below U.S. Highway 90 in Uvalde County (Stations 21 and 22, Fig. 1), is characterized by bald cypress along the edge of the river. The woody vegetation on the terrace consisted of an overstory of live oak, net leaf hackberry, and pecan, and an understory of Texas persimmon and soap-berry. The second community is associated with the dry portion of the Sabinal River, which lies over the Balcones fault zone of the Edwards aquifer (Station 23, Fig. 1). The riparian forest in this region is narrow or absent with cultivated and range land occurring almost to the edge of the river. The river edge stand is composed primarily of cedar elm, bald cypress, sycamore, and live oak, whereas the dominant plants of the terrace are live oak and cedar elm in the overstory. Texas persimmon and Texas mountain laurel were common understory species. The third Sabinal River community was located from above the Balcones fault zone in northwestern Uvalde County to Vanderpool in Bandera County (Station 24, Fig. 1). Flowing water is common on this part of the river except during drought years. The inner bank stand is dominated by bald cypress and sycamore, whereas the terrace overstory is composed of pecan, net leaf hackberry, live oak, and little black walnut (*Juglans microcarpa*). The understory in the terrace region is predominantly Texas persimmon and chinaberry (*Melia azedarach*). The fourth plant community is that associated with the upper portions of the Sabinal River (Station 25, Fig. 1). Surface

TABLE 1. Density, basal area, and importance value (IV) for the major woody species found in the Leona River riparian forest. Values presented are the means for each species for the four locations sampled. The importance value is the sum of the mean relative density and relative basal area for each species divided by two.

Species	Density (plants/ha)	Dominance (m^2/ha)	IV (%)
Live oak (*Quercus virginiana*)	445.82	24.40	38.59
Cedar elm (*Ulmus crassifolia*)	324.07	6.57	14.52
Texas persimmon (*Diospyros texana*)	491.26	.97	11.11
Net leaf hackberry (*Celtis reticulata*)	295.78	3.07	9.70
Pecan (*Carya illinoiensis*)	88.31	1.82	4.00
Texas mountain laurel (*Sophora secundiflora*)	158.61	.14	3.37
Mexican ash (*Fraxinus berlandieriana*)	53.16	1.35	2.71
Coma (*Bumelia lanuginosa*)	90.02	.24	2.11
Honey mesquite (*Prosopis glandulosa* Torr.)	60.01	.70	2.06
Soap-berry (*Sapindus saponaria*)	88.31	.12	1.94
Sugar hackberry (*Celtis laeviqata* Willd.)	38.58	.56	1.46
Common button bush (*Cephalanthus occidentalis*)	42.01	.30	1.22
Mexican buckeye (*Ungnadia speciosa* Endl.)	44.58	.13	1.06
Others (24 species)*	251.19	.88	6.15
Total mean:	2471.71	41.25	100.00

*Seven species had mean IV's of 0.5 to 1.0 percent: Mustang grape (*Vitis mustangensis* Buckl.), red mulberry (*Morus rubra* L.), brasil (*Condalia hookerii* M. C. Johnst.), poison ivy (*Rhus toxicodendron* (L.) O.Ktze.), hog plum (*Colubrina texensis* (T. & G.) Gray), catclaw acacia (*Acacia roemeriana* Scheele), and whitebrush (*Aloysia gratissima* (Gill. & Hook.) Troncoso). Seventeen species had IV's of 0.5 percent or less: Spanish grape (*Vitis berlandieri* Planch.), rattan vine (*Berchemia scandens* (Hill) K. Koch), spiny hackberry (*Celtis pallida* Torr.), lotebush (*Ziziphus obtusifolia* (T. & G.) Gray), common hop tree (*Ptelea trifoliata* L.), Eve's necklace (*Sophora affinis* T. & G.), cat-brier (*Smilax bona-nox* L.), pink mimosa (*Mimosa borealis* Gray), Virginia creeper (*Parthenocissis quinquefolia* (L.) Planch.), huisache (*Acacia farnesiana* (L.) Willd.), agarito (*Berberis trifoliolata* Moric.), Roosevelt weed (*Baccharia neglecta* Britt.), black willow (*Salix nigra* Marsh.), Spanish dagger (*Yucca treculeana* Carr.), chinkapin oak (*Quercus muehlenbergii* Engelm.), desert willow (*Chilopsis linearis* (Cav.) Sweet), and cenizo (*Leucophyllum frutescens* (Berl.) I. M. Johnst.).

water flow is minimal; small pools with permanent flow are restricted to the wet periods of the year. The riparian forest associated with the upper Sabinal is narrow and is often flanked by high limestone canyon walls. The river edge stand consists chiefly of sycamore followed by little black walnut and common button bush (*Cephalanthus occidentalis*). Bald cypress does not occur anywhere along the Sabinal above Vanderpool, Texas. The terrace portion of the floodplain is characterized by Ashe juniper, Texas oak (*Quercus buckleyi*), bigtooth maple (*Acer grandidentatum*), and white shin oak (*Quercus sinuata*) in the overstory, and Texas persimmon in the understory.

The highest mean number of species (15 and 17) occurred in quadrats associated with the terrace berm next to the inner river edge (five meters) and middle terrace (15 and 25 meters), with the lowest number (nine) located in the quadrat farthest from the river (Fig. 2A). Mean density along the river was significantly lower than that found for other quadrats. Total mean density was highest at 40 meters from the river, with lowest values at the river's edge (1.5 meters) (Fig. 2B). Mean basal area showed highest basal area at 5 meters from the river; lowest basal areas occurred at 15 and 40 meters (Fig. 2C).

Spatial distribution of the most important forest trees, as described as a function of distance from the river, indicated that several formed a river edge stand, whereas others contributed to the terrace stand. The river edge (1.5- and five-meter quadrats) stand was formed by bald cypress in the lower and middle parts of the Sabinal, and sycamore in the upper region (Fig. 4, A-C). Neither bald cypress nor sycamore occurred beyond 15 meters from the river edge. Both species achieved their greatest densities, basal areas, and IV's adjacent to the river. In the terrace stand, the dominant species were pecan, net leaf hackberry, and live oak in the overstory, and Texas persimmon in the understory (Fig. 4, A-F). Pecan dominated the terrace berm (five meters) and middle terrace; net leaf hackberry and live oak were dominant in the outer terrace areas (Fig. 4A). The understory of the terrace was mainly Texas persimmon. Net leaf hackberry was the most abundant species in the overstory on the terrace, but live oak had the highest basal area (Fig. 4D and E).

Discussion

Most compositional studies of riparian forests have been conducted in eastern Texas (Chambless, 1971; Pullen et al., 1971; Allen, 1974; Nixon and Willett, 1974; Nixon and Raines, 1976; Nixon et al., 1977; Marks and Harcombe, 1981), whereas only a few have been undertaken in central and southern Texas (Van Auken et al., 1979; Ford and Van Auken, 1982; Taylor, 1982; Bush and Van Auken, 1984; Wood and Wood, 1988).

The species richness associated with the woody communities in this study exceeds, or is similar to, that found in other studies of riparian forests (Campbell, 1925; Chambless, 1971; Allen, 1974; Marks and Harcombe, 1981; Van Auken et al. 1979; Ford and Van Auken, 1982; and Bush and Van Auken, 1984). The species richness on the Leona and Sabinal rivers is approximately one-half and three-fourths, respectively, of the richness reported by Taylor (1982) on the Nueces River and Wood and Wood (1988) on the Frio River. One-third more species were found on the Sabinal then on the Leona. A probable cause for greater diversity on the Sabinal is that there were more physiographic regions on the Sabinal then on the Leona. The cypress-hardwood forest cover type in the Sabinal basin is typical of the final stage of succession found in many southern forests (Society of American Foresters, 1980). A notable

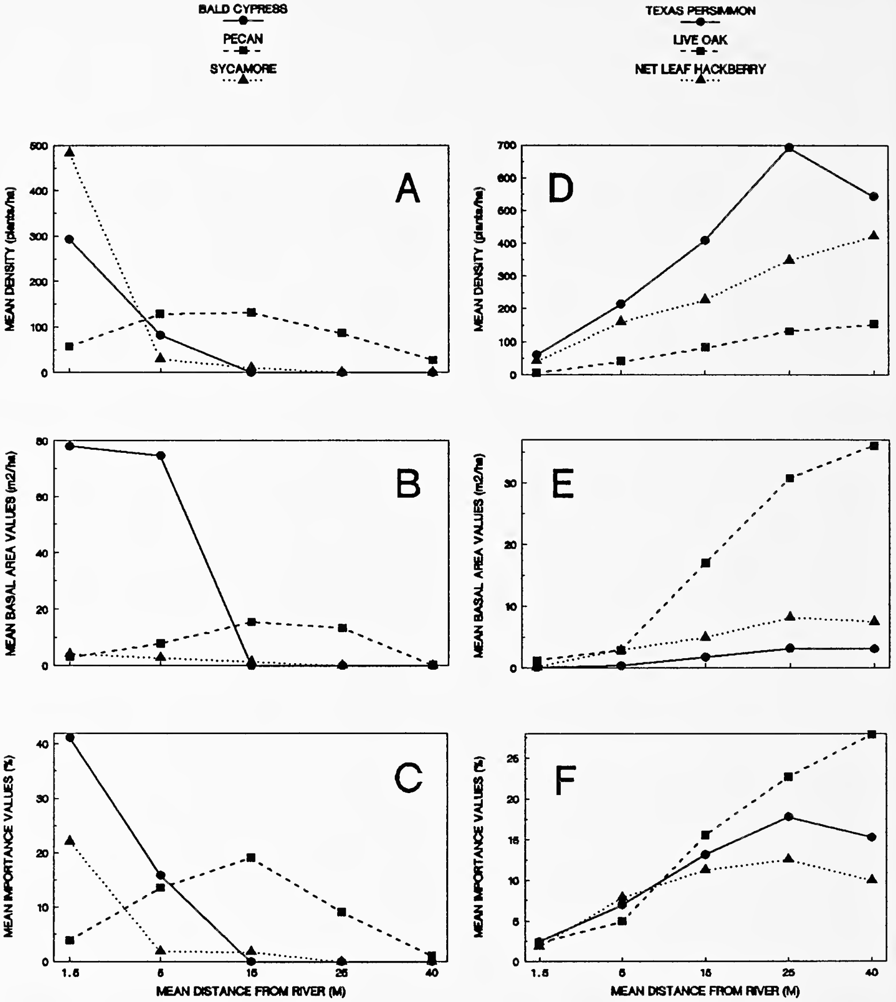

FIGURE 4. Mean total density (A and D), mean total basal area (B and E), and mean importance (C and F) as a function of distance from the Sabinal River for bald cypress, pecan, sycamore, Texas persimmon, live oak, and net leaf hackberry.

difference between the floodplain forests of the Frio and the Sabinal rivers is the presence and dominance of bald cypress trees along most (85 percent) of the Sabinal River. Both the density and size of the bald cypress were greater on the Sabinal than on the Guadalupe and Frio rivers as reported by Ford and Van Auken (1982) and Wood and Wood (1988). The Sabinal differs from the Leona and Nueces rivers because of the lack of bald cypress as found in this study and by Taylor (1982). Bald cypress is a dominant in some southern riparian forests and reaches a level of importance similar to this study only in the most southern areas investigated (Thieret, 1971; Conner and Day, 1976; Marks and Harcombe, 1981; Ford and Van Auken, 1982).

The riparian forests of the middle Frio and the lower Sabinal are similar, but the lack of many cedar elm trees on the lower Sabinal differs sharply from the forest on the middle Frio. The sharp reduction in density and IV of cedar elm in the Edwards Plateau region supports the distribution pattern reported by Correll and Johnston (1970).

The middle and lower Sabinal River have many similar elements with southern forests, but nowhere is the combination (qualitatively or quantitatively) of dominants the same as in this study. Oak trees, pecan, and both net leaf and sugar hackberry are dominant or subdominant species in other riparian forests in central, eastern, and southern Texas (Pullen et al., 1971; Allen, 1974; Nixon and Willett, 1974; Taylor, 1982; Bush and Van Auken, 1984). Live oak is dominant in the lower and middle Sabinal and is replaced by Texas oak in the upper Sabinal basin. Oaks (*Quercus* sp.) are commonly found as dominants in southern floodplains (Shelford, 1954; Chambless, 1971; McLeod, 1971; Pullen et al., 1971; Allen, 1974; Nixon, 1975; Van Auken et al., 1979; Marks and Harcombe, 1981). The lack of live oak in the upper Frio is similar to what Ford and Van Auken (1982) found in the upper Guadalupe floodplain. They, in observing the data of Muzny (1975), suggested that live oak and other species would be of more significant importance on river terraces had man not caused frequent disturbances, such as clearing or overgrazing by livestock, in these areas. This idea is supported by data from the upper Sabinal River (Station 25) where four species of oak were found and the activities of man in this region were minimal. The dominance of live oak differs from what Wood and Wood (1988) found on the Frio River and what Bush and Van Auken (1984) found on the upper San Antonio River.

Pecan is a dominant species in the lower and middle Sabinal and only a minor species in the upper region of the Sabinal. However, the lower and middle Sabinal dominance of pecan is similar to what Ford and Van Auken (1982) found on the upper Guadalupe River, Wood and Wood (1988) found on the middle Frio River, and Nixon and Willett (1974) found on the Trinity River. Rarity of pecan in the upper Sabinal region is similar to what Taylor (1982) found on the Nueces River and what Wood and Wood (1988) found on the Frio River, but notably different from what Ford and Van Auken (1982) found on the upper Guadalupe River. The minor species status of pecan on the upper Sabinal also is similar to that in other southern floodplain forests (Shelford, 1954; Pullen et al., 1971; Allen, 1974; and Nixon, 1975).

The dominant hackberry in the Sabinal basin is the net leaf hackberry. Only a few sugar hackberry trees were in the Sabinal riparian forest and these were located in the upper regions of the river. This differs significantly from what Wood and Wood (1988) found on the Frio River, Ford and Van Auken (1982) reported for the Guadalupe River on the Edwards Plateau, and Bush and Van Auken (1984) found on the upper San Antonio River. Sugar hackberry also has been reported as a dominant in some riparian forests in Tennessee and Louisiana (Shelford, 1954; Conner and Day, 1976).

The riparian forest of the Leona River is a live oak-cedar elm-net leaf hackberry-Texas persimmon community. The oak-cedar elm-hackberry community is similar to those reported by Allen (1974) for the lower Navasota River, Petranka and Holland (1980) for bottomland communities in south-central Oklahoma, and Taylor (1982) for the Nueces River. A noticeable difference between the Leona River and both the Frio and Sabinal rivers is the absence of bald cypress. This is similar to what Taylor (1982) found on the Nueces River and suggests that the northwestern part of the Rio Grande Plains is the southwestward distributional limit of this species.

The ashes (*Fraxinus* sp.) are important plants in some riparian forests (Rice and Penfound, 1956; Pullen et al., 1971; Nixon and Willett, 1974). The Mexican ash is present in the lower Leona region but is absent from the middle and upper reaches of the river floodplain. Mexican ash was not found on the Sabinal; however, Texas ash (*Fraxinus texensis* (Gray) Sarg.) is found on the lower and middle reaches of that river. Lack of any ashes from the upper Leona and Sabinal rivers is similar to what Ford and Van Auken (1982) found on the upper Guadalupe River and what Wood and Wood (1988) found on the Frio River. The absence of Mexican ash in the upper Leona floodplain and its complete absence from the Sabinal basin suggests that the lower Frio and Leona floodplains are close to the northern distributional limits of this species in southern Texas.

Pecan is a subdominant in the lower Leona basin; it becomes less dense and important in the middle basin and disappears completely in the upper Leona basin. This distribution is similar to what Taylor (1982) found on the Nueces River and what Wood and Wood (1988) reported on the Frio. It differs with what Ford and Van Auken (1982) found on the upper Guadalupe River.

The distribution data of this study show clearly that certain species are limited to certain parts of the floodplain (Figs. 3 and 4). This is especially true on the Sabinal River for the bald cypress and sycamore, which are primarily restricted to the moist regions adjacent to the river. The distribution of bald cypress supports the findings of Van Auken and Bush (1988) as to the importance of light gaps in the establishment, growth, and development of this species. The distribution of terrace species (Figs. 3 and 4) also indicates habitat or niche selection by different species. This is particularly true for pecan, net leaf hackberry, and live oak. The distribution of the dominant species supports the idea of Van Auken et al. (1979) of a soil moisture gradient as a major parameter responsible for plant distribution in the riparian forest. These data also support the idea that spatial distribution is controlled by the flood tolerance of the species (Bell, 1974).

Mean number of species was highest at the floodplain terrace berm and middle terrace regions (five to 25 meters) and lowest in the outer terrace region (Fig. 2A). This differs from the reports of Bell (1974) and Ford and Van Auken (1982), who found the highest number of species at the outer ecotone region of the riparian forest. On both the rivers, the density of trees immediately adjacent to the river was significantly lower than the tree densities on the rest of the floodplain (Fig. 2B), and this differs from Ford and Van Auken (1982) and Bush and Van Auken (1984), who found highest densities nearest the river and at both the river edge and upper forest ecotone. Greater basal area in the 15 meters adjacent to the river edge (Fig. 2C) was due to bald cypress and sycamore, which grow only in places of increased moisture availability. Increases in basal area in the outer terrace region on the Sabinal River was caused by the many large live oak trees found in this area (Figs. 2C and 4E). Decreases in total density and mean basal area in the outer terrace region on the Leona River is directly related to decreases in the pecans and cedar elms, suggesting that soil moisture is a major controlling factor. Other factors such as light availability, flood frequency, and soil depth and aeration, as Ford and Van Auken (1982) and Wales (1972) have suggested, may have contributed to the spatial distribution of plants in a riparian forest.

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LITERATURE CITED

Allen, H. G. 1974. Woody vegetation of the lower Navasota River watershed. M.S. thesis, Texas A&M Univ., College Station, Texas, 80 pp.

Bell, D. T. 1974. Tree stratum composition and distribution in the streamside forest. Amer. Midland Nat., 92:36-46.

Blair, W. F. 1950. The biotic provinces of Texas. Texas J. Sci., 2:93-117.

Bogusch, E. R. 1952. Brush invasion in the Rio Grande Plains of Texas. Texas J. Sci., 4:85-91.

Box, T. W. 1961. Relationships between plants and soils of four range plant communities in South Texas. Ecology, 42:794-810.

Bray, W. L. 1901. The ecological relations of the vegetation of western Texas. Bot. Gaz., 32:262-290.

———. 1904. The timber of the Edwards Plateau of Texas; its relation to climate, water supply, and soil. Bull. USDA Bur. Forestry, 49:1-30.

Bush, J. K., and O. W. Van Auken. 1984. Woody-species composition of the upper San Antonio River gallery forest. Texas J. Sci., 34:139-149.

Butterwich, M., and S. Strong. 1976. Rio Grande-Falcon thorn woodland. Nat. Area Surv., LBJ School Public Affairs, Univ. Texas, 13:1-92.

Campbell, E. G. 1925. Plant relations in Brazos County, Texas, with special reference to eastern and western types. Ecology, 6:163-170.

Carter, W. T. 1931. The soils of Texas. Bull. Texas Agric. Exp. Sta., 431:1-184.

Chambless, L. 1971. The woody vegetation of the Angelina River bottom in Nacogdoches County, Texas. Unpublished M.S. thesis, Stephen F. Austin State Univ., Nacogdoches, Texas, 110 pp.

Conner, W. H., and J. W. Day, Jr. 1976. Productivity and composition of a bald cypress-water tupelo site and a bottomland hardwood site in a Louisiana swamp. Amer. J. Bot., 63:1354-1364.

Correll, D. S., and M. C. Johnston. 1970. Manual of vascular plants of Texas. Texas Res. Found., Renner, Texas, 1881 pp.

Davis, R. B., and C. K. Winkler. 1968. Brush versus cleared range as deer habitat in southern Texas. J. Wildlife Manag., 32:321-329.

Drawe, D. L., A. D. Chamrad, and T. W. Box. 1978. Plant communities of the Welder Wildlife Refuge. Contrib. no. 5, ser. B., revised, Welder Wildlife Found., Sinton, Texas, 37 pp.

Drawe, D. L., and I. Higginbotham, Jr. 1980. Plant communities of the Zachry Ranch in the South Texas plains. Texas J. Sci., 32:319-332.

Ford, A. L., and O. W. Van Auken. 1982. The distribution of woody species in the Guadalupe River floodplain forest in the Edwards Plateau of Texas. Southwestern Nat., 27:383-392.

Gould, F. W. 1975. Texas plants—a checklist and ecological summary. Bull. Texas Agric. Exp. Sta., MP-585:1-121.

Inglis, J. M. 1964. A history of vegetation on the Rio Grande Plains. Bull. Texas Parks and Wildlife Dept., 45:1-122.

Johnston, M. C. 1988. Vascular plants of Texas. A list, updating the manual of the vascular plants of Texas. Published by author, Austin, Texas, 120 pp.

Larkin, T. J., and G. W. Bomar. 1983. Climatic atlas of Texas. Bull. Texas Dept. Water Res., LP-192:1-151.

Lonard, R. I., and F. W. Judd. 1985. Effects of a severe freeze on native woody plants in the lower Rio Grande Valley, Texas. Southwestern Nat., 30:397-403.

Lynch, D. 1981. Native and naturalized woody plants of Austin and the Hill Country. Saint Edwards Univ., Austin, Texas, 180 pp.

Marks, P. L., and P. A. Harcombe. 1981. Forest vegetation of the Big Thicket, southeast Texas. Ecol. Monogr., 51:287-305.

McBryde, J. B. 1933. The vegetation and habitat factors of the Carrizo sands. Ecol. Monogr., 3:247-297.

Muzny, R. T., Jr. 1975. Application of selected morphological, stratigraphic, and botanical criteria to distinguish floodplain and terrace deposits in the Guadalupe River valley, eastern Comal County, Texas. Unpublished M.S. thesis, Univ. Texas, Austin, Texas, 97 pp.

Nixon, E. S. 1975. Successional stages in a hardwood bottomland forest near Dallas, Texas. Southwestern Nat., 20:323-336.

Nixon, E. S., and J. A. Raines. 1976. Woody creekside vegetation of Nacogdoches County, Texas. Texas J. Sci., 27:443-452.

Nixon, E. S., and R. L. Willett. 1974. Vegetative analysis of the floodplain of the Trinity River, Texas. Rept. U.S. Army Corp. Engs. Contract no. DACW63-74-C-0030, Stephen F. Austin State Univ., Nacogdoches, Texas, 267 pp.

Nixon, E. S., R. L. Willett, and P. W. Cox. 1977. Woody vegetation of a virgin forest in an eastern Texas river bottom. Castanea, 42:227-236.

Palmer, E. J. 1920. The canyon flora of the Edwards Plateau of Texas. J. Arnold Arbor., 1:233-239.

Pullen, A. M., J. R. Humphries, A. D. Neal, M. M. Morris, H. A. Peterson, R. N. Singh, and J. H. Speer. 1971. An environmental inventory and survey of the Sulphur River Basin. Contract no. DACW 29-71-C-0230, Dept. Army, Corps Engin., New Orleans Dist., 350 pp.

Rice, E. L., and W. T. Penfound. 1956. Composition of a green ash forest near Norman, Oklahoma. Southwestern Nat., 1:145-147.

Shelford, V. E. 1954. Some lower Mississippi Valley flood plain biotic communities; their age and elevation. Ecology, 35:126-142.

Smeins, F. E., and R. D. Slack. 1982. Fundamentals of ecology laboratory manual. Kendall/Hunt Publ. Co., Dubuque, Iowa, 140 pp.

Society of American Foresters. 1980. Forest cover types of the eastern United States. Report of the committee on forest types. J. Forestry, 30:451-498.

Steel, R. G. and J. H. Torrie. 1980. Principles and procedures of statistics, a biometric approach. McGraw-Hill, New York, New York, 481 pp.

Stanford, J. W. 1976. Keys to the vascular plants of the Texas Edwards Plateau and adjacent areas. Howard Payne Univ., Brownwood, Texas, 365 pp.

Taylor, R. J. 1982. Vegetation resources of the Nueces River floodplain, Texas. U.S. Bur. Reclamation Contract no. 2-07-50-VO637, ECS Technical Services, Fort Worth, Texas, 65 pp.

Tharp, B. C. 1939. The vegetation of Texas. Texas Academy of Science. The Anson Jones Press, Houston, Texas, 74 pp.

Thieret, J. W. 1971. Quadrat study of a bottomland forest in St. Martin Parish, Louisiana. Castanea, 36:174-181.

Thornthwaite, C. W. 1948. An approach toward a rational classification of climate. Geogr. Rev., 38:55-94.

Van Auken, O. W., and J. K. Bush. 1988. Dynamics of establishment, growth, and development of black willow and cottonwood in the San Antonio River forest. Texas J. Sci., 40:269-277.

Van Auken, O. W., A. L. Ford, and J. L. Allen. 1981. An ecological comparison of upland deciduous and evergreen forests of central Texas. Amer. J. Bot., 68:1249-1256.

Van Auken, O. W., A. L. Ford, and H. Stein. 1979. A comparison of some woody upland and riparian plant communities of the southern Edwards Plateau. Southwestern Nat., 24:165-180.

Van Auken, O. W., A. L. Ford., A. Stein, and A. G. Stein. 1980. Woody vegetation of upland plant communities of the southern Edwards Plateau. Texas J. Sci., 32:23-35.

Wales, B. A. 1972. Vegetation analysis of north and south edges in a mature oak-hickory forest. Ecol. Monogr., 42:451-471.

Wood, C. E., and J. K. Wood. 1988. Woody vegetation of the Frio River riparian forest, Texas. Texas J. Sci., 40:309-321.

THE OCCURRENCE OF GRASS CARP IN TEXAS WATERS

David L. Trimm, George Guillen, Charles T. Menn,
and Gary C. Matlock

Coastal Fisheries Branch, Texas Parks and Wildlife Department, P. O. Box 8, Seabrook, Texas 77586, Resource Protection Division, Texas Parks and Wildlife Department, P. O. Box 8, Seabrook, Texas 77586, Inland Fisheries Branch, Texas Parks and Wildlife Department, 1004 E 26th, Bryan, Texas 77803, and Fisheries Division, Texas Parks and Wildlife Department, 4200 Smith School Road, Austin, Texas 78744

Abstract.—Verified reports of grass carp were collected from 1983 through 1987 from Texas coastal regions. One hundred and sixty-one fish were collected from 14 locations in and around the Galveston Bay system. Age was estimated from length data and ranged from seven to nine years. Water salinities at catch locations ranged from zero to nine parts per thousand. Origin of the grass carp collected could not be determined. *Key words*: grass carp; Galveston Bay, Texas.

Grass carp, *Ctenopharyngodon idella*, has been used for aquatic vegetation control (Hickling, 1966). This ability led to a rapid spread of grass carp stockings in several states. Provine (1975) reported on the advantages and disadvantages of stocking this species. Although previous stocking experiments (Bailey, 1978; Avault et al., 1966) resulted in positive effects, Provine pointed out that the effects grass carp may have in open-water environments are unknown. Because of his recommendations, the Texas Parks and Wildlife Commission prohibited the introduction of grass carp in Texas waters in 1980.

In 1981, after more than a year of litigation between pro- and anti-grass carp stocking factions, the Texas Legislature passed House Bill 556, which allowed for the release of grass carp into Lake Conroe for research purposes. In 1981-82, 270,000 fish were released into the reservoir (Martyn et al., 1986).

The controversial nature of the stocking in Lake Conroe resulted in widespread publicity. In 1981-82, Texas Parks and Wildlife Department (TPWD) offices received reports of grass carp caught by commercial fishermen in the Trinity River and Galveston Bay. In addition, during this period department biologists learned of illegal introductions of grass carp for the purpose of vegetation control in private ponds. The objective of this paper is to document all verified occurrences of grass carp in Texas waters.

Methods

In December 1987, five data sources were reviewed for information on grass carp occurrence. They were: 1) TPWD Coastal Fisheries routine monitoring data files, 2) TPWD Inland Fisheries reports, 3) TPWD Resource Protection fish kill reports, 4) verified reports from sport and

TABLE 1. Grass carp occurrences from the Galveston Bay System and surrounding region.

Date	Location	Site numbers	Number	Mean total length (mm)	Total length range (mm)	Salinity (ppt)
Jul 1983	Trinity River	1	29	700		
Dec 1983	Trinity Bay	2	1	827		0
Mar 1984	San Jacinto River	3	2	622	559-686	0
Mar 1984	San Jacinto River	4	1	737		0
Apr 1984	San Jacinto River	5	1	660		0
Apr 1984	Trinity River	6	1	805		
May 1984	Cedar Bayou	7	10	869		
May 1984	Trinity River	8	1	813		
Jul 1984	Baytown	9	3	80	79-82	0
Sep 1984	Cedar Bayou	7	4	600	450-755	1
Jun 1986	Galveston Bay	10	2	731	721-743	2
Aug 1986	Spring Bayou	11	94	737	711-762	
Apr 1987	Spring Bayou	11	5	838	762-914	9
Apr 1987	Cedar Bayou	12	1	873		
Jun 1987	San Jacinto River	13	4	600		
Oct 1987	Lake Houston	14	2	760	750-770	0

[a]See Figure 1 for specific geographic locations.

commercial fishermen, and 5) data collected by TPWD personnel while accompanying commercial fishermen.

For each occurrence, auxiliary data including date, location, and salinity were tabulated as well as number of fish, length and range. The study area consisted of all inland and coastal waters of Texas.

RESULTS AND DISCUSSION

From July 1983 to October 1987, 161 grass carp were collected or observed on 16 occasions from 14 different locations in Texas (Table 1). Seventy-one percent of the fish were collected during fish kill investigations in Cedar and Spring bayous, which feed into northern portions of the Galveston Bay System (Fig. 1). Two fish were caught in gill nets near the Houston Ship Channel and another 30 were caught in commercial hoop nets in the Trinity River and Trinity Bay. The remaining information came from reports by local fishermen and from surveys by TPWD biologists.

The origin of grass carp found during this study could not positively be determined. Grass carp catches from upper portions of the San Jacinto River (Fig. 1) suggests that some escaped from Lake Conroe and migrated downstream into coastal areas. Noble et al. (1986) stated, in reference to the stocking of Lake Conroe, that "grass carp are notorious for escaping whenever possible" and noted that the river (San Jacinto), another reservoir (Lake Houston), and the estuary (Galveston Bay

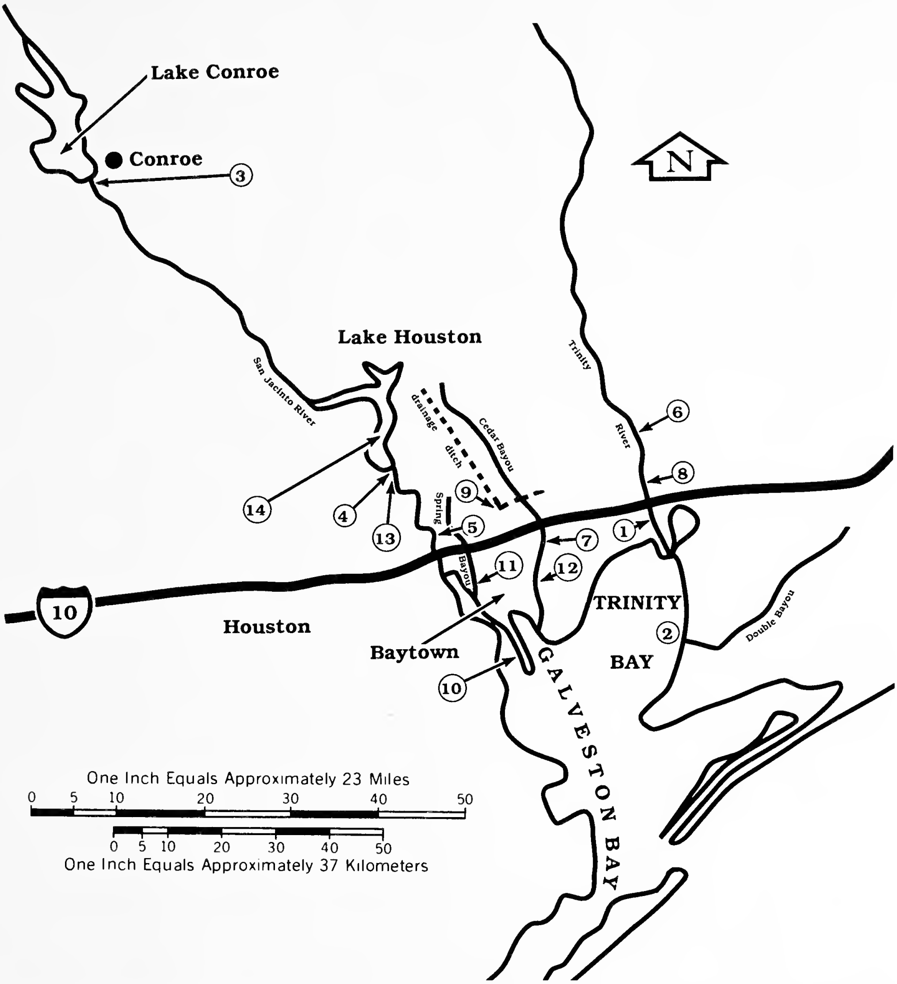

FIGURE 1. Grass carp occurrences from the Galveston Bay System and surrounding region (reference numbers from Table 1).

System) downstream of Lake Conroe were of concern. In their study, a single grass carp was collected from the San Jacinto River. They theorized this fish came from the Lake Conroe stocking. Klussmann et al. (1988) reported two more grass carp from the San Jacinto River in 1986 (they actually reported three but one of these had been previously reported by Noble et al., 1986).

Grass carp more than two years old have been reported to survive in salinities up to 17.5 parts per thousand (Cross, 1970). During the current study, grass carp were observed or caught at salinities ranging from zero to nine parts per thousand. Salinities in Trinity and Galveston Bay vary seasonally but typically average between five and 10 parts per thousand

(Texas Department Water Resources, 1981). These low salinities possibly have allowed for grass carp dispersal throughout the upper regions of the bay system. A similar occurrence of grass carp migrating across a brackish water body was noted by Pavlov and Nelovkin (1963).

The size range of grass carp collected in this study (Table 1) further suggests they may have come from the Lake Conroe stocking. Mean total lengths of carp stocked into Lake Conroe were 289 and 247 mm for 1981 and 1982, respectively (Martyn et al., 1986). They determined that by May 1983 the mean lengths of grass carp stocked in 1981 and 1982 had increased to 705 and 520 mm, respectively. In our study, 98 percent of the grass carp collected were longer than 600 mm. This size range correlates well enough with the post-stocking length data to hypothesize a relationship.

A good method to verify the origin of stocked fish is mark and recapture. During the Lake Conroe stocking, pelvic fin clips were placed on 12,225 fish (Martyn et al., 1986). By September 1983, after numerous cove rotenone samples, only 19 fin clipped fish had been recaptured. This less than 0.2 percent recapture figure in Martyn's et al. (1986) study suggests that a small sample size, such as in our study, would have a low probability of containing marked fish. No fin clipped fish were collected in this study.

The three small grass carp (< 100 mm) collected near Baytown were, more than likely, a result of an illegal purchase of fingerlings. The supposition that they resulted from natural reproduction in Texas waters is quite unlikely. Noble et al. (1986), in their study dealing with the San Jacinto River, stated that natural reproduction was believed to have occurred in another river in the estuary's (Galveston) watershed. We assume that Noble et al. were referring to the Trinity River, which directly connects with the Galveston Bay Estuary, but Menn and Pitman (1986) found no larval grass carp there in 1984 or 1985. During that period, water temperatures and current velocities were within ranges required for successful spawning. Noble et al. (1986) also suggested that successful spawning in the San Jacinto or its tributaries would be unlikely and post-stocking samples produced no evidence of reproduction in the river system.

The fact that illegal introductions of grass carp into Texas inland waters have occurred cannot be ignored as a possible explanation for occurrences in this study. Unverified reports of grass carp in Choke Canyon Reservoir and in ponds near Eagle Pass, West Columbia, and Olmito, Texas (Personal Communication, Chester Burdett, 4200 Smith School Road, Austin, Texas 78744) are known. To date, no distribution of grass carp in areas adjacent to these locations has been reported. Continued routine monitoring will assist in determining the distribution of grass carp in Texas. In future studies, intensive tagging efforts prior to introduction is recommended so that origin can be determined.

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LITERATURE CITED

Avault, J. W., Jr., R. 0. Smitherman, and B. W. Shell. 1966. Evaluation of eight species of fish for aquatic weed control. Proc. World Symp. Warmwater Pond Fish. Cult., Rome, Italy, 19-25 May, FAO Fisheries Rept. 44(5)VII-E-3. pp. 109-122.

Bailey, W. M. 1978. A comparison of fish populations before and after extensive grass carp stocking. Trans. Amer. Fish. Soc. 107:181-206.

Cross, D. G. 1970. The tolerance of grass carp, *Ctenopharngodon idella* (Valenciennes), to seawater. J. Fish. Biol., 2:231-233.

Hickling, W. F. 1966. On the feeding process of white amur, *Ctenopharyngodon idella*. J. Zool. London, 148:408-419.

Klussmann, W. G., R. L. Noble, R. D. Martyn, W. C. Clark, R. K. Betsill, P. W. Bettoli, M. F. Cichra, and J. M. Campbell. 1988. Control of aquatic macrophytes by grass carp in Lake Conroe, Texas, and the effects on the reservoir ecosystem. Texas Agric. Exp. Sta., Texas A&M Univ., College Station.

Martyn, R. D., R. L. Noble, P. W. Bettoli and R. C. Maggio. 1986. Mapping aquatic weeds with aerial color infrared photography and evaluating their control by grass carp. J. Aquat. Plant Manag., 24:46-56.

Menn, C. T., and V. M. Pitman. 1986. Performance Report. Job A: Existing reservoir and stream management recommendations lower Trinity River, 1984-1985. Texas Parks and Wildlife Dept., Inland Fisheries Branch, Austin, Texas, 42 pp.

Noble, R. L., P. W. Bettoli, and R. K. Betsill. 1986. Considerations for the use of grass carp in large, open systems. Lake Reservoir Manag., 2:46-48.

Pavlov, A. V., and P. D. Nelovkin. 1963. Some information on the results of transferring white amur and tostolobik to the basin of the lower Volga. Pp. 169-170, *in* Problemy rybokhozyaystuennogo ispol'zovaniya rastitel' novadnykh ryb v vodoyemkh SSSR (Problems of the fisheries exploitation of plant-eating fishes in the water bodies of the USSR), Ashkhabad, Akedemiia Nauk Turkmenistan SSR. I. 169-170 (in Russian).

Provine, W. C. 1975. The grass carp. Spec. Rept., Texas Parks and Wildlife Dept., Inland Fisheries Res., Austin, 51 pp.

Texas Department of Water Resources (TDWR). 1981. Trinity-San Jacinto estuary: A study of the influence of freshwater inflows. LP 113, 383 pp.

ECOLOGICAL NOTES ON A BARRIER ISLAND DUNE SNAIL, *SUCCINEA PARALIA* HUBRICHT, ON SOUTHERN PADRE ISLAND, TEXAS

Raymond W. Neck

Texas Parks and Wildlife Department, 4200 Smith School Road, Austin, Texas 78744

Abstract.—The only land snail known to be native to southern Padre Island, Texas, is *Succinea paralia* Hubricht, 1983. Living snails have been observed around the periphery of a temporary pool in an interdune depression. Preference for zones with high soil moisture and leaf litter cover was noted. *Key words*: dune snail; *Succinea paralia*; Padre Island, Texas.

Barrier islands and peninsulae fringe much of the southern Atlantic and Gulf of Mexico coasts of the United States. Consisting of sand and sandy soils accumulated by the action of wind and wave movement, these areas provide a harsh environment for terrestrial gastropods. Dune sand is characterized by low calcium levels (Baden-Powell, 1942). Presence of strand woodlands (Oosting, 1954) can ameliorate the deficit moisture environments typical of these coastal areas and allow survival of several species of land snails (Beetle, 1967; Bequaert and Clench, 1936; Harry, 1950).

Especially harsh conditions for land snails prevail on barrier islands and peninsulae of southern Texas. Compared to other Texas barrier islands, southern Padre Island is narrower, contains fewer freshwater pools, and experiences higher temperatures and evaporation rates. Climatic data (Orton, et al., 1967) for Port Isabel (on the mainland across the Laguna Madre from southern Padre Island) reveal an average annual temperature of 23.4°C (74.1°F). The coolest month is December (16.6°C = 61.8°F.), whereas the warmest month is August (28.8°C = 83.8°F.). Annual precipitation is 65.5 centimeters and is markedly seasonal with peaks in June (6.32 centimeters) and September-October (12.62-7.75 centimeters). The driest month is March (2.92 centimeters). Evaporation is much higher than precipitation. Lake evaporation is rated at 147.3 centimeter with standard pan evaporation at 210.8 centimeters.

Survey of southern Padre Island, Texas, has revealed no native land snails except for extremely localized and low-density populations of a single succineid species in an interdune depression immediately behind the primary dune line. Sufficient collections and observations now have been made to allow taxonomic identification and ecological characterization of the species at this locality.

Identification and Description

Specimens collected on 19 October 1984 by the author were identified by Leslie Hubricht as *Succinea paralia* Hubricht, 1983. The collection locality was an interdune depression immediately north of the southernmost beach access road on South Padre Island, Cameron Co., Texas. This access road is 5.9 kilometers north of the intersection of queen Isabella Causeway and Park Road 100.

S. paralia was described initially by Hubricht (1983:15) from snails collected in a salt marsh near Port Lavaca, Calhoun Co., Texas (approximately 300 kilometers north of the South Padre Island locality). Paratypes were reported from marsh habitats in Alabama and Florida. Hubricht (1983) reported that *S. paralia* is most closely related to *Succinea barberi* (Marshall, 1926), which is known from southernmost Florida—see *Oxyloma sanibelensis* (Rehder, 1933) in Pilsbry (1948:793), but note synonymization by Hubricht (1968). Hubricht (1985:14) reported the species from "brackish marshes, crawling on the mud and herbs in wet weather."

Shells of *S. paralia* from southern Padre Island are of the general shape of medium-sized *Succinea luteola* Gould, 1848, from southern Texas. However, the shell exhibits a translucent amber color in contrast to the chalk white typical of *S. luteola*. Bleached shells of *S. paralia* are whitish, but of less intensity than *S. luteola*. Streaking, which is typical of *S. luteola,* is absent, although shells of *S. paralia* have minor but definite growth ridges on the body whorl. Body whorl and aperture widths are somewhat broader in *S. paralia* than *S. luteola*. Reliable identification of *S. paralia* from shell characters, as is typical for most succineids, is difficult. A typical *S. paralia* from this study site measures 10.7 mm in height and 6.6 mm in width (3.8 whorls).

Habitat—Spatial Structure

Interdune depressions of South Padre Island normally do not contain surface water although the sand may often be moist. Apparent but weakly—defined zonation of dominant plant species was observed (Fig. 1). From the lowermost portion of the depression to the low interdune ridges, the dominant plants are *Eleocharis obtusa* (spike sedge), *Scirpus americanus* (three-square bulrush), *Spartina patens* (marsh hay cordgrass), *Schizachyrium scoparium* var. *littoralis* (sand bluestem), *Panicum amarum* (beach panicum), and *Uniola paniculata* (sea oats). Present on disturbed portions of the dunefield are various herbaceous species, for example, *Machaeranthera phyllocephala* (camphor daisy), *Cassia fasciculata* (partridge pea), *Croton punctatus* (beach tea), and *Heterotheca subaxillaris* (camphor weed). This typical interdune community of southern Padre Island was briefly described by Judd et al. (1977).

Living adult *S. paralia* were found on 19 October 1984 from the lower portion of the *Spartina* zone upslope to about the middle of the *Schizachyrium* zone, where some *Spartina* occurs (see Table 1). Snails were present on wet soil where decaying grass leaf litter was present. *S.*

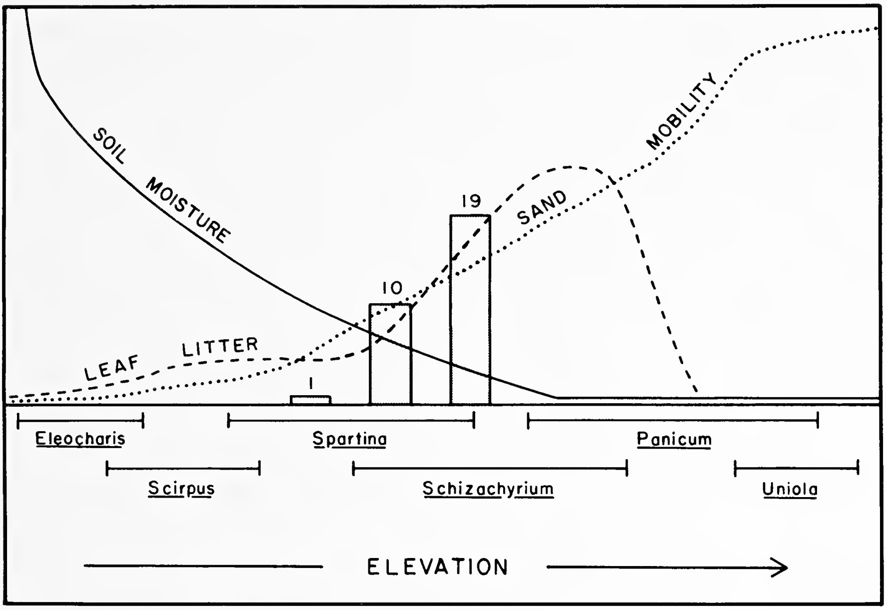

FIGURE 1. Areal relationship of *Succinea paralia* and environmental factors (plant community, soil moisture, leaf litter, and sand mobility). Vertical bars are census counts of *S. paralia* in various plant communities.

paralia was found most commonly in the area with a mixed *Schizachyrium-Spartina* community where soil moisture was high and leaf litter was abundant (Fig. 1). Fewer snails were found in the lower portion of the *Spartina-Schizachyrium* zone, because *Spartina* does not produce an accumulation of leaf litter at bases of plants. At the level where *Panicum* becomes dominant over *Schizachyrium*, snails were absent, apparently as a result of insufficient moisture levels. Snails were also absent from areas dominated by *Uniola* and *Panicum*, because of the near absence of leaf litter, shifting nature of sand substrate, and lack of moisture (except following moderate to heavy rains).

Maximum pool depth in September 1984 was estimated to have been approximately 65 centimeters. Water was clear with a brownish color. Specific gravity was measured as 1.00; no salt was discernible by taste. The only indication of freshwater gastropods was a single, old *Biomphalaria obstructa* shell recovered on 26 September 1984.

HABITAT—TEMPORAL STRUCTURE

Snails of this succineid were first collected on South Padre Island on 22 December 1970. All specimens proved to be immature; identification only could be made to generic level, that is, *Succinea* sp. (Hubricht, personal correspondence). Only dead shells were located until 11 July

TABLE 1. Distribution of *Succinea paralia* in various microhabitats (zones) surrounding interdune pool, South Padre Island, Texas, in 1984. Zones are arranged in same order as natural elevation from top to bottom.

Zone	Date			Total
	26 September	19 October	16 November	
Floating trash	1	0	0	1
Uniola-Panicum	0	0	0	0
Panicum-Schizachyrium	0	0	0	0
Schizachyrium-Spartina	1	18	0	19
Spartina-Schizachyrium	*	7	3	10
Spartina	*	*	1	1
Eleocharis-Scirpus	*	*	*	0
Total	2	25	4	31

*standing water.

1975 when two immature snails were found. Search for this species was initiated again on 21 May 1982. On this date, an area of suitable habitat was located but no snails were discovered. As late as 22 June 1984, only a few empty shells of *Succinea* could be found under wood and trash. The number of empty shells indicated that dense populations probably develop under favorable environmental conditions. Digging in moist sand revealed no snails.

The site was visited on 26 September 1984 when there were unusually great accumulations of water. From 16 to 19 September 1984, torrential rains (14.46 inches at Brownsville, 20.82 inches at Port Isabel) had fallen on the area. On this date two *S. paralia* were observed; one was found on grass detritus above the water level, whereas the other was found on a piece of styrofoam trash floating at the edge of the pool. On 19 October 1984, a subsequent visit revealed a pool elevation approximately 30 centimeters lower than one month previously. However, a total of 25 living *S. paralia* were discovered. Subsequent visits on 16 November 1984 (pool elevation 12 centimeters lower), 6 May 1985 (pool 15 centimeters lower), and 17 October 1985 (pool five centimeters lower—very little surface water) revealed decreasing numbers of snails (Table 1). Distribution of snails in these successive sampling periods indicates that the animals move downslope as the pool decreases in area coverage; similar movements have been observed in *Oxyloma retusa* (Lea, 1834) around freshwater pools in Iowa (Lannoo and Bovbjerg, 1985).

DISCUSSION

S. paralia is believed to be the only terrestrial gastropod native to the southern part of Padre Island. No other species have been found in native habitats in this area, although a few species have been found in residential areas (Neck, unpublished data). Hubricht (1960) reported that *Succinea luteola* was "probably native to Padre Island, although none was found alive." Shells that appear to be *S. luteola* have been found on southern Padre Island only in disturbed habitats with trash piles (no living snails have yet been discovered).

Unlike other Texas barrier islands, no historical or biological evidence of extensive stands of native woody shrubs or trees exists for southern Padre Island (Lonard and Judd, 1981). Grass cover would have been much thicker during the eighteenth and nineteenth centuries prior to grazing activities (Price and Gunter, 1942), but these grasslands are likely to have been too xeric for development of land snail populations due to the periodic but frequent drought periods. Diverse terrestrial gastropod faunas (including three species of *Succinea*) exist in dune valleys in the Netherlands (Mözer Bruijns et al, 1959). Although *Aegopinella nitidula* (Draparnaud, 1805) is able to survive within old tufts of the grass, *Ammophila arenaria*, along the French Atlantic coast (Cloudsley-Thompson, 1960), the climate of southern Texas is much less hospitable to land snails.

Coastal species of *Succinea* in eastern North America tend to occur in salt marsh habitats (Grimm, 1975). Dune habitats possess a different set of environmental conditions to which a land snail must adapt. Except for the presence of salt spray, the habitat of *S. paralia* on southern Padre Island more closely resembles that of freshwater marsh species of *Succinea* and *Oxyloma* (Archer 1936; Lannoo and Bovbjerg, 1985) in the central United States. Most of the time the apparent preferred habitat of *S. paralia* is too desiccated to support snail activity. Snails must spend long periods of time buried in refugia in soil (assumed, not observed) at depths where thermal and moisture conditions are favorable for survival. The only observed period of abundance of *S. paralia* was following extremely heavy rains in September 1984. These rains were the result of the interaction of an early cool front and a tropical system (remnants of the Pacific Tropical Storm Edouard).

Note should be made that these interdune depressions are periodically inundated by sea water when tropical storms produce sufficient storm tidal surges. Complete coverage of this area occurred in August 1980 (Hurricane Allen) and September 1967 (Hurricane Carla). Some coverage may have occurred in August 1983 (Hurricane Alicia).

Continued suitability of the study site for *S. paralia* is in doubt even with eventual return of adequate moisture. Natural processes will reshape the interdune depressions and some filling from aeolian sand transport will occur. Additionally, sand is being deposited along the southern margin of the area as a result of road cleaning activities. Rampant development on southern Padre Island has undoubtedly altered and obliterated many sites suitable for *S. paralia*. Survey of the margins of freshwater ponds on northern Padre Island, Mustang Island, Matagorda Island, and Galveston Island has not revealed any other populations of *S. paralia*. No populations of *S. paralia* have been observed in developed areas of southern Padre Island (Neck, unpublished data). Loss of the only native terrestrial gastropod population on southern Padre Island would be a biological tragedy.

Literature Cited

Archer, A. F. 1936. The land Mollusca of Cheboygan County, Michigan. Occas. Papers Mus. Zool., Univ. Michigan, 340:1-15.

Baden-Powell, D. F. W. 1942. On the marine Mollusca of Studland Bay, Dorset, and the supply of lime to the sand dunes. J. Anim. Ecol., 11:82-95.

Beetle, D. E. 1967. Mollusks of the Outer Banks, N.C. The Nautilus, 81:61-65.

Bequaert, J., and W. J. Clench. 1936. A second contribution to the molluscan fauna of Yucatan. Publ. Carnegie Inst. Washington, 457:61-75.

Cloudsley-Thompson, J. L. 1960. Some aspects of the fauna of the coastal dunes of the Bay of Biscay. Entomol. Monthly Mag., 96:49-53.

Grimm, F. W. 1975. A review of *Succinea wilsoni*, a coastal marsh snail of eastern North America. The Nautilus, 89:39-43.

Harry, H. W. 1950. Studies on the nonmarine Mollusca of Yucatan. Occas. Papers Mus. Zool., Univ. Michigan, 524:1-34.

Hubricht, L. 1960. Beach drift land snails from southern Texas (exclusive of Polygyridae). The Nautilus, 74:82-83.

———. 1968. Four new species of land snails. The Nautilus, 82:63-70.

———. 1983. Five new species of land-snails from the southeastern United States with notes on other species. Gastropodia, 2:13-19.

———. 1985. The distributions of the native land mollusks of the eastern United States. Fieldiana Zool. (n.s.), 24:1-191.

Judd, F. W. R. I. Lonard, and S. L. Sides. 1977. The vegetation of South Padre Island, Texas in relation to topography. Southwestern Nat., 22:31-48.

Lannoo, M. J., and R. V. Bovbjerg. 1985. Distribution, dispersion, and behavioral ecology of the land snail *Oxyloma retusa* (Succineidae). Proc. Iowa Acad. Sci., 92:67-69.

Lonard, R. I., and F. W. Judd. 1981. The terrestrial flora of South Padre Island, Texas. Misc. Paper Texas Mem. Mus. 6:1-74.

Mözer Bruijns, M. F., C. O. Van Regteren Althena, and L. J. M. Butot. 1959. The Netherlands as an environment for land Mollusca. Basteria, 23 (suppl.):132-162.

Oosting, H. J. 1954. Ecological processes and vegetation of the maritime strand in the southeastern United States. Bot. Rev., 20:226-262.

Orton, R., D. J. Haddock, E. G. Bice, and A. C. Webb. 1967. Climatic guide. The Lower Rio Grande Valley of Texas. Texas Agric. Exp. Sta., MP-841:1-108.

Pilsbry, H. A.1948. Land Mollusca of North America (north of Mexico). Monogr. Acad. Nat. Sci. Philadelphia, 3, vol. II (2):521-1113

Price, W. A. and G. Gunter. 1942. Certain recent geological and biological changes in South Texas, with consideration of possible causes. Trans. Texas Acad. Sci., 26:138-156.

GENERAL NOTES

DISTRIBUTION AND HABITAT OF THE PARTHENOGENETIC WHIPTAIL LIZARD, *CNEMIDOPHORUS NEOMEXICANUS* (SAURIA: TEIIDAE), IN TEXAS

James E. Cordes, James M. Walker, James F. Scudday,
and Ramadan M. Abuhteba
Department of Zoology, University of Arkansas Fayetteville, Arkansas 72701,
and Department of Biology, Sul Ross State Univeristy, Alpine, Texas 79832 (JFS)

The all-female whiptail lizard, *Cnemidophorus neomexicanus*, has been intensively studied by numerous workers in New Mexico, but it remains almost unknown in Texas. The only definite records for Texas are in El Paso County, with those for three additional counties in the extreme southwestern part of the state being questionable. The purpose of this paper is to update our knowledge of the habitat and distribution of *C. neomexicanus* in Texas, including a significant range extension into Presidio County.

Assessment of color pattern and scutellation in *C. neomexicanus*, or PER-B (Walker, 1986), and *C. inornatus* follow Wright and Lowe (1967) and Walker (1981). Museum collections referenced include University of Arkansas Department of Zoology (UADZ), University of Kansas Museum of Natural Histoy (KU), University of Texas at El Paso (UTEP), University of Texas at El Paso Osteological Collection (OC), and Sul Ross State University (SRSU).

A specimen of the parthenogenetic *C. neomexicanus* (UADZ 3466), obtained in 1988 in Presidio County has seven cream-beige stripes, wavy vertebral and paravertebral stripes, cream-beige spots in the upper lateral and dorsolateral fields, beige markings on the dorsal surfaces of the hindlimbs, 73 granules around midbody, 188 granules from occiput to rump, 11 granules separating the paravertebral stripes, 15.0 percent of the granules around midbody lying between the paravertebral stripes, 36 femoral pores combined, 31 subdigital lamellae of the longest toe of the left pes, 17 circumorbital scales combined, 28 interlabial scales combined, granular postantebrachial scales, and small mesoptychial scales bordering the gular fold (Fig. 1A). *Cnemidophorus inornatus*, represented by UADZ 3460 from a nearby site in Presidio County, differs from *C. neomexicanus* in having straight paravertebral and vertebral stripes, unspotted upper lateral and dorsolateral fields, 61 granules around midbody, slightly larger postantebrachial scales, and slightly larger mesoptychial scales (Fig. 1B).

The following sites for *C. neomexicanus* in Texas are reported for the first time. El Paso Co.: El Paso, UTEP campus (UTEP 6, 96, 140, 1250 [behind Hudspeth Hall], 2597-2660, 2610-2616, 2850-2851, 3406, 4088 [west side of campus] 4659, 5593 [in an arroyo], 6314, 6656); El Paso, Alicia Park behind 1000 block Kelly Way (UTEP 34-36); El Paso, west side drain on Bend Rd. near St. Matthews Catholic Church (UTEP 151a); El Paso, 4141 W City Ct. near apt. complex (UTEP 181); El Paso, arroyo 0.4 km. SW Mesa and Sunbowl Dr. (UTEP 336, 6318); El Paso, arroyo 0.4 km. NW Mesa and Sunbowl Dr. (UTEP 5594-5595, 6315); El Paso, arroyo behind 504 Ridgemont Dr. (UTEP 751-752, 754-758, 837-857, 869-870); El Paso, near Fountain Plaza Apts. (UTEP 3407, OC 856); El Paso, arroyo behind 200 Wallington Drive (UTEP 2574); West El Paso at N end Castellano Rd. (UTEP 4147); El Paso, 407 Rim Rd. (UTEP 6317); El Paso, near jct. Sunland Park Drive and Mesa Hills Drive near West Town Apts. (UTEP 8936-8938); Franklin Mts., Tom Mays Memorial Park in canyon to Cotton Wood Springs (UTEP 2629); Hueco Tanks State Park (UTEP 609, 10793-10794); Hueco Tanks on S side of first enclave of rocks E entrance (UTEP 1695-

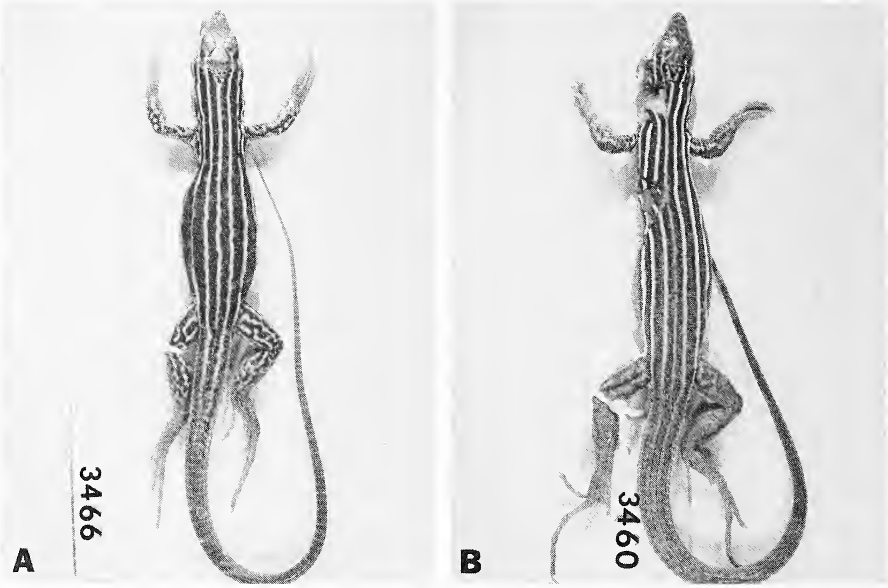

FIGURE 1. Comparison of representative specimens of *Cnemidophorus neomexicanus* (A) from 3.3 km. S Candelaria, Presidio County, Texas (UADZ 3466, snout vent length 47 mm), and *Cnemidophorus inornatus* (B) from 9.1 km. E Ruidosa, Presidio County, Texas (UADZ 3460, female, snout vent length 54 mm).

1696); Horizon Lake on W bank (SRSU 4162, 4195); Hueco Mts., between Horizon Lake and El Paso Natl. Compressor Station (SRSU 4156, 4161). HUDSPETH CO.: Hueco Mts., S side lower slope Padre Peak (SRSU 4169?); Hueco Mts., between El Paso Natl. Compressor Station and Horizon Lake (SRSU 4185-4186). PRESIDIO CO.: 3.3 km. S Candelaria on FM 170 (UADZ 3466).

Previous reports of *C. neomexicanus* in El Paso County by Axtell (1966) and Wright (1971) have been limited to the references "city of El Paso" and "Hueco Tanks." The previously cited UTEP records indicate a number of sites in the city of El Paso that include open habitat with sparse grasses and herbaceous plants, sandy substrate, and some degree of disturbance. *C. neomexicanus* is the most ubiquitous saurian species on the UTEP campus, which exemplifies its adaptablility to disturbed areas heavily utilized by man (C. S. Lieb, personal commnication). Although *C. neomexicanus* is typically the only whiptail present in its preferred microhabitats in El Paso County, which include arroyos and canyon bottoms (some with rocky substrates and scattered mesquite), several other teiids occur in the vicinity of *C. neomexicanus* sites in the Franklin Mts. (*C. marmoratus, C. inornatus, C. tesselatus, C. exsanguis* and *C. uniparens*) and in the Hueco Mts. (*C. mamoratus, C. inornatus, C. tesselatus* and *C. exsanguis*). Hueco Mt. sites are the only *C. neomexicanus* sites in Texas that are not in close proximity to disturbed habitats along the Rio Grande. The "Hueco Tanks" records represent the greatest departure, being separated from the Rio Grande by approximately 70 kilometers of creosote desert flats and sand dunes (J. D. Johnson, personal communication). The population of *C. neomexicanus* in Presidio County was discovered on 15 September 1988 at 3.3 km. S Candelaria (104° 41′ 30″ W—30° 06′ 32″ N). About 25 yearlings were observed at the site between 1530 and 1600 (CDT). The location is about 0.4 kilometers east of the Rio Grande and the strip of floodplain inhabited by *C. neomexicanus* is only about 0.1 hectare in size. Here the floodplain is composed

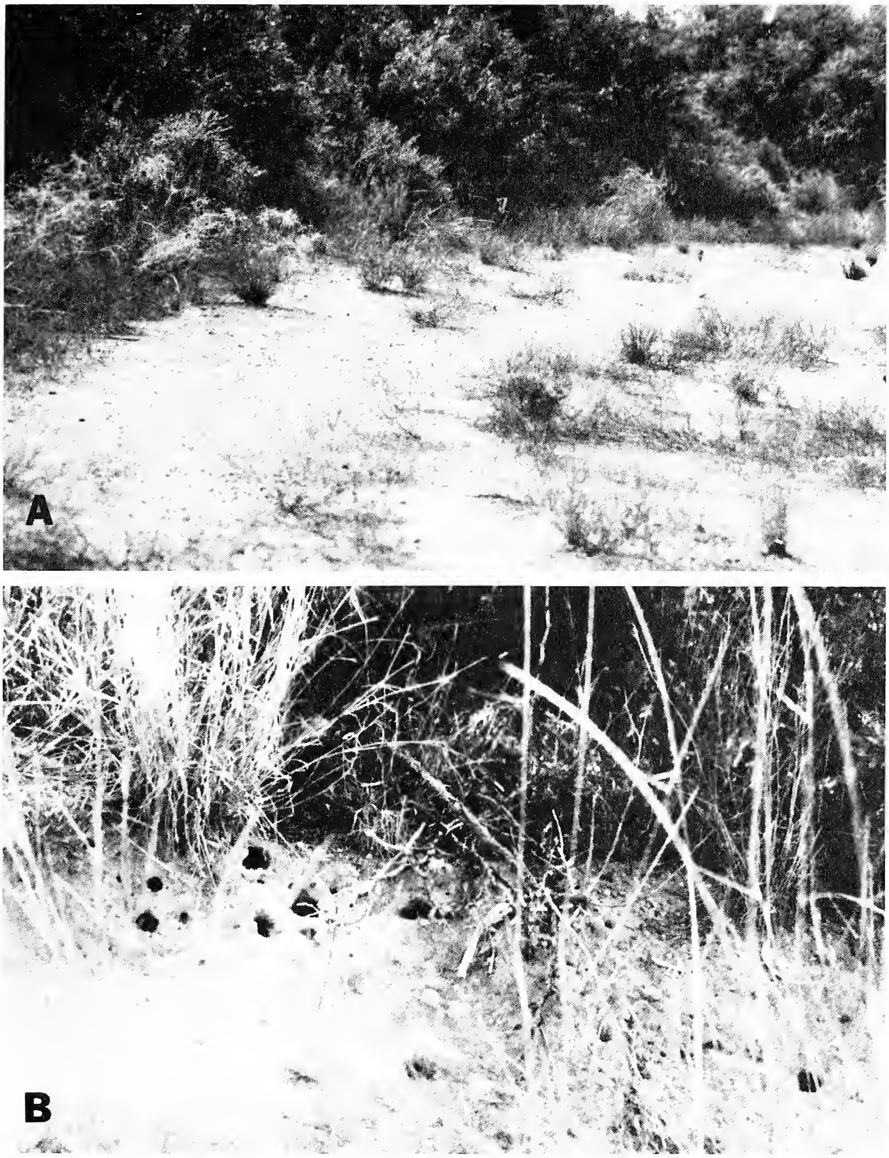

FIGURE 2. Example of habitat utilized by *Cnemidophorus neomexicanus* at 3.3 km. S Candelaria, Presidio County, Texas (A), entrances to burrows used by *Cnemidophorus neomexicanus* (B).

primarily of alluvial sediments imbricated by low terrace deposits from mountain streams (Geologic Atlas of Texas, Marfa Sheet, 1979). The vegetation consists of an open-structured growth of grasses and forbes between a roadside and border of trees and shurbs (Fig. 2A). When flushed from the sparse vegetation near the roadside lizards retreated to the edge of the border. Here the soil was perforated with burrows that some of the lizards used for escape (Fig. 2B). *Cnemidophorus marmoratus* was observed along the periphery of the

Candelaria site and both *C. inornatus* and *C. tesselatus* E were collected within three kilometers of the site.

The discovery of *C. neomexicanus* near Candelaria is significant for the following reasons. It establishes the presence of *C. neomexicanus* in Presidio County and marks its lower elevational limit of 866 meters and southern distributional limit. The patchy availability of sites suitable for *C. neomexicanus* in Presidio County is consistent with expectations based upon its patchy distribution in El Paso County.

Axtell (1966) listed one specimen (KU 40264) from 23 mi. N and 52 mi. W Marfa, Presidio County, but Wright (1971) stated that this record "... requires verification," an opinion shared by Dixon (1987). Our discovery of *C. neomexicanus* in Presidio County restores confidence in Axtell's (1966) record, which is about 60 kilometers to the north. Dixon (1987) also listed Hudspeth and Culberson counties within the Texas range of *C. neomexicanus*. The Hudspeth County record first was listed by Raun and Gehlbach (1972), who cited Axtell (1966) as their source; however, Axtell actually listed no records for Hudspeth County. Records reported herein (none greater than 1.7 kilometers from the El Paso County boundary), therefore, represent the only known records of *C. neomexicanus* from Hudspeth County. The Culberson County record only has been listed by Dixon (1987), but to our knowledge no museum specimens exist. Therefore, the only verified Texas records for *C. neomexicanus* are from El Paso, Hudspeth, and Presidio counties.

Field research in Texas was conducted under authority of Texas Parks and Wildlife permit no. 61 provided through the assistance of Mr. David Riskind, Texas Parks Division, and Mr. George C. Adams, Texas Resources Protection Branch. Dr. Carl S. Lieb, University of Texas at El Paso (UTEP), provided museum collection data and helpful advice. Dr. Jerry D. Johnson, El Paso Community College, read a draft of the manuscript and provided habitat descriptions. The Graduate Studies Committee, University of Arkansas, provided a Graduate Grant-in-Aid of Research Award in support of field work associated with this study.

LITERATURE CITED

Axtell, R. W. 1966. Geographic distribution of the unisexual whiptail *Cnemidophorus neomexicanus* (Sauria: Teiidae)—present and past. Herpetologica, 22:241-253.

Dixon, J. R. 1987. Amphibians and reptiles of Texas. Texas A&M Univ. Press, College Station, xii + 434 pp.

Raun, G. G., and F. R. Gehlbach. 1972. Amphibians and reptiles in Texas. Bull. Dallas Mus. Nat. Hist., 2:1-61.

Walker, J. M. 1981. Systematics of *Cnemidophorus gularis*. I. Reallocation of populations currently allocated to *Cnemidophorus gularis* and *Cnemidophorus scalaris* in Coahuila, Mexico. Copeia, 1981:826-849.

———. 1986. The taxonomy of parthenogenetic species of hybrid origin: cloned hybrid populations of *Cnemidophorus* (Sauria: Teiidae). Syst. Zool., 35:427-440.

Wright, J. W. 1971. *Cnemidophorus neomexicanus*. Cat. Amer. Amphib. Rept., 109.1-109.3.

Wright, J. W., and C. H. Lowe. 1967. Hybridization in nature between parthenogenetic and bisexual species of whiptail lizards (genus *Cnemidophorus*). Amer. Mus. Novit., 2286:1-36.

PYRMNESIUM PARVUM CARTER (CHRYSOPHYCEAE) AS A SUSPECT OF MASS MORTALITIES OF FISH AND SHELLFISH COMMUNITIES IN WESTERN TEXAS

Terry L. James and Augustine De La Cruz

Texas Water Commission, 2626 Parkway Boulevard, Building B, Suite 129, Odessa, Texas 79761, and Texas Water Commission, 140 Heimer Road, Suite 360, San Antonio, Texas 78232

There have been several major fish kills in the Pecos River in recent history. In October and November 1985, some 110,000 fish died in the reach of river from Iraan, Pecos Co., Texas, to the backwaters of Lake Amistad in Val Verde County. In November and December of 1986, more than 500,000 fish were killed in the same area. More recently, in November and December of 1988, more than a million and a half fish were killed in the Pecos River from southeastern New Mexico to below the town of Imperial, Pecos Co., Texas. Also in November of 1988, 48,000 fish were killed in Paint Creek, a tributary of the Brazos River, in Haskell and Throckmorton counties near Abilene, Texas.

The suspected causative agent of these fish kills has been identified as *Pyrmnesium parvum* (Chrysophyceae). This halophilic alga has been implicated in numerous fish kills in Europe and the Middle East (Shilo, 1967, 1971, 1972). Past studies have demonstrated that toxin secreted from the *Pyrmnesium parvum* cell is toxic to teleost fish (Ulitzer and Shilo, 1966; Shilo, 1967, 1971, 1972), aquatic invertebrates such as bivalves, and tadpole stages of amphibians (Ulitzer and Shilo, 1966; Shilo, 1967, 1971). Data suggest that all gill-breathing animals are sensitive to the toxin, and it is believed that the toxin directly affects the gill epithelium (Ulitzer and Shilo, 1966; Shilo, 1971). Aquatic gill-breathing animals, when subjected to the toxin, experience a loss of gill selective permeability and are 10 to 40 times more sensitized, nonspecifically, to various fish toxicants (Ulitzer and Shilo, 1966).

Pyrmnesium parvum was present in bloom conditions during the 1985, 1986, and 1988 fish kills on the Pecos River and Paint Creek. Cell densities of 150 million cells per liter were observed in samples collected during the Pecos River fish kill in 1986. All species of fish inhabiting the fish kill areas were affected. These included, but were not limited to, *Lepisosteus osseus, Cyprinus carpio, Micropterus salmoides, Pylodictus olivaris, Etheostoma grahami*, and *Gambusia affinnis.* Also killed were bivalves of the family Unionidae and the Asiatic clam, *Corbicula fluminea.* The *Corbicula* appeared to be particularly sensitive to the *Pyrmnesium* toxin. Prior to the 1985 Pecos River fish kill, densities as high as 100 *Corbicula* per square foot were common. Since the 1985 fish kill, no live *Corbicula* have been observed in the Pecos River, suggesting a recent introduction of *Pyrmnesium parvum* to the Pecos River in Texas. A massive *Corbicula* kill also was observed during the 1988 fish kill on Paint Creek. All other species of the benthic macroinvertebrate community were apparently unharmed during blooms of *Pyrmnesium parvum.*

Since 1985, more than two million fish have died in the Pecos River during blooms of the biotoxic alga, *Pyrmnesium parvum.* Recent data suggest that *P. parvum* is expanding its range from the lower Pecos River in Pecos, Terrell, and Val Verde counties in Texas to the Pecos in southeastern New Mexico and Reeves County, Texas. It also appears to have become established recently in the Brazos River system of Texas. Should the frequency of dense blooms of *Pyrmnesium parvum* persist as they have in recent years, it is reasonable to expect a continued impact on the fish and shellfish fauna inhabiting the Pecos River. It is also possible that *Pyrmnesium parvum* will be implicated in future fish kills in the United States and Mexico.

We are indebted to Jack Ralph of the Texas Parks and Wildlife Department in San Marcos for his personal efforts and creative contributions during the fish-kill events and to

David Buzan of the Texas Water Commission headquarters in Austin for identifying the *Pyrmnesium parvum* organism and for his guidance during the past years.

LITERATURE CITED

Shilo, M. 1967. Formation and mode of action of algal toxins. Bacteriol. Rev., 31:180-193.

———. 1971. Toxins of Chrysophyceae. Pp. 67-103, *in* Microbial toxins: a comprehensible treatise, vol. 7, Algal and fungal toxins, Academic Press, New York.

———. 1972. Toxigenic algae. Pp. 233-265, *in* Progress in industrial microbiology, vol. 11, Churchill, Livingstone Press, Edinburgh.

Ulitzur, S., and M. Shilo. 1966. Mode of action of *Pyrmnesium parvum* ichthyotoxin. J. Protozool., 13:332-336.

SPRING MOLT IN THE MEXICAN GROUND SQUIRREL, *SPERMOPHILUS MEXICANUS* (RODENTIA: SCIURIDAE)

JIM R. GOETZE AND FREDERICK B. STANGL, JR.
Department of Biology, Midwestern State University, Wichita Falls, Texas 76308

Little information is available on the molting patterns of ground squirrels in general, and nothing specific is known of the molt in *Spermophilus mexicanus* (Young and Jones, 1982). This study was undertaken as an extension of an earlier work characterizing seasonal pelage extremes of this species (Stangl et al., 1986).

Hansen (1954) described three major molt patterns within the genus *Spermophilus.* Citing Howell (1938) and his own observations, Hansen (1954) considered members of the subgenera *Ictidomys, Xerospermophilus*, and *Ammospermophilus* (the latter taxon now considered generically distinct) as exhibiting a similar molt pattern. This scheme entails molt in both spring and autumn, each marked by indistinct molt lines.

A total of 112 museum study skins of adult *Spermophilus* (*Ictidomys*) *mexicanus* from Texas was examined from the collections of Midwestern State University, Texas Tech University, and Texas A&M University. Due to inherent seasonal biases in mammal collections (Stangl and Jones, 1987), there were insufficient data to describe the autumnal molt. However, eight specimens taken in the months of March through May permit characterization of the replacement of a dense winter pelage with a relatively sparse summer coat.

Transition from winter to summer pelage in Mexican ground squirrels is best described as two distinct molts. Each is initiated cranially, and proceeds dorsally and caudally (Fig. 1), and is summarized briefly below.

Guard hair molt.—Molt line of the stout guard hairs is relatively indistinct, due to its breadth and transitional nature. This zone is characterized by persistent winter guard hairs and emerging summer guard hairs.

Wool hair molt.—Molt line of wool hairs lags somewhat behind that of the guard hairs, but proceeds in a similar fashion. Seasonal dimorphism of wool hairs is particularly striking (Stangl et al., 1986), but their fine morphology results in an indistinct molt line.

The pattern and direction of molt in *Spermophilus mexicanus* best fit the diffuse model of Hansen (1954) for squirrels that molt but once each year. However, *S. mexicanus* molts twice a year. Hansen's (1954) subdivision of ground squirrel subgenera on the basis of molt and the resulting phylogenetic implications merit reevaluation.

We thank the collection managers and curators of The Museum at Texas Tech University and the Texas Cooperative Wildlife Collection at Texas A&M University for the loan of critical specimens in this study.

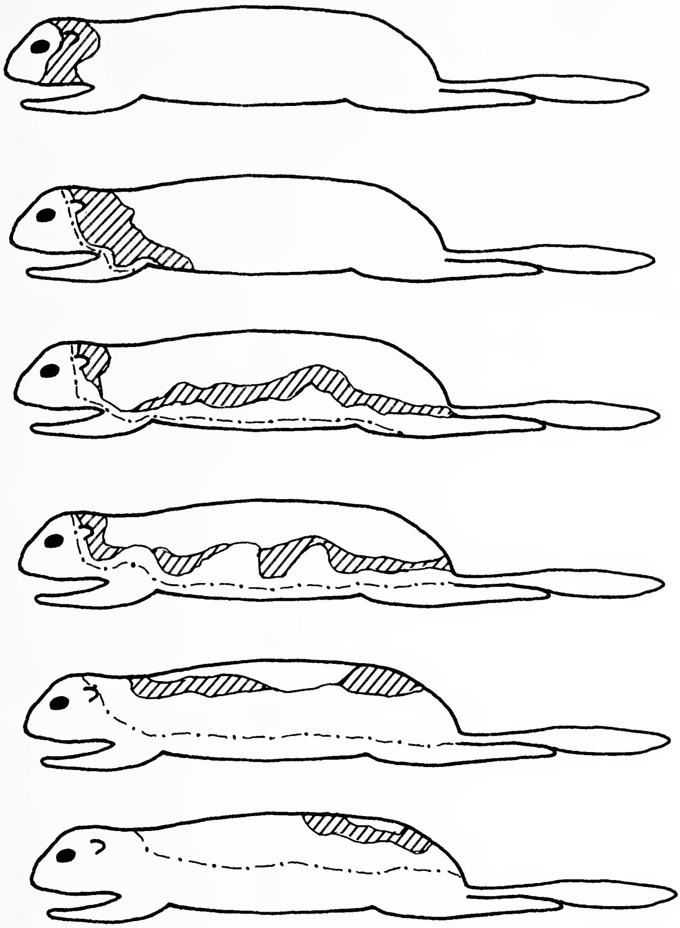

FIGURE 1. Representative stages (sequential, from top to bottom) of spring molt as observed in six specimens of *Spermophilus mexicanus* from Texas. Hatched regions are areas of both winter guard hairs and emerging summer guard hairs. Broken line separates winter wool hair from summer wool hair. Caudal and dorsal to each border is old winter pelage; cranial and ventral to each is new summer pelage.

LITERATURE CITED

Hansen, R. M. 1954. Molt patterns in ground squirrels. Proc. Utah Acad. Sci., Arts & Lett., 31:57-60.

Howell, A. H. 1938. Revision of the North American ground squirrels with a classification of the North American Sciuridae. N. Amer. Fauna, 56:1-256.

Stangl, F. B., Jr., J. V. Grimes, and J. R. Goetze. 1986. Characterization of seasonal pelage extremes in *Spermophilus mexicanus* (Rodentia: Sciuridae). Texas J. Sci., 38:147-152.

Stangl, F. B., Jr., and E. M. Jones. 1987. An assessment of geographic and seasonal biases in systematic mammal collections from two Texas universities. Texas J. Sci., 39:129-137.

Young, C. J., and J. K. Jones, Jr. 1982. Spermophilus mexicanus. Mamm. Species, 164:1-4.

NOTES ON REPRODUCTION IN THE HISPID POCKET MOUSE, *CHAETODIPUS HISPIDUS*, IN TEXAS

Larry L. Choate and J. Knox Jones, Jr.
The Museum and Department of Biological Sciences, Texas Tech University, Lubbock, Texas 79409

Little has been published (Paulson, 1988) about reproduction in the hispid pocket mouse, *Chaetodipus hispidus*. In an attempt to add to the meager available knowledge, we surveyed specimens of *C. hispidus* housed in the collections of Recent mammals of The Museum, Texas Tech University, and of Midwestern State University. All material examined was from northern and western counties of Texas.

Most of the mice in the two collections were prepared as museum study skins accompanied by skulls, but, unfortunately, many had no reproductive data affixed to their labels. We recorded such information on reproduction as was available, and also took note of all specimens that were not completely in adult pelage.

Reproductive data were recorded for 367 specimens (including those in juvenile pelage) of *C. hispidus*; not surprisingly, we examined more than that number that lacked reproductive information. Among those specimens for which data on reproduction were recorded, the number of individuals per month of capture varied from two in January to 97 in October indicating seasonal collecting bias as described by Stangl and Jones (1987).

Testicular measurements were recorded from 119 males. Sixty-two of these in adult pelage and with a total length of 190 mm or more were considered as adults. The mean annual testicular length for those individuals was 7.4 mm, with larger means in February (8.5), March (9.0), April (11.5), May (10.1), June (10.3), July (8.0), and August (9.8), and smaller mean measurements in September (5.0), October (5.3), and November (5.3). One adult male each from January and December had testes four and seven in length, respectively. These data imply more reproductive activity from early spring to autumn than in the colder months. Females that were pregnant, lactating, or had placental scars were recorded from March (one lactating), April (one pregnant), May (one pregnant), June (two pregnant), July (two pregnant, one placental scars), August (three pregnant), September (one placental scars, one lactating), October (one pregnant), and November (one pregnant).

Davis (1974) indicated that one or two litters are produced annually in the northern part of the range, but that in southern Texas reproduction is year round due to milder climatic conditions. Schmidly (1983) concurred with Davis, but noted that in the northern part of eastern Texas the breeding season for *C. hispidus* was from June to August. Jones et al. (1985) placed the reproductive season on the northern Great Plains as from spring through late summer.

In our study, specimens of *C. hispidus* in less than fully adult pelage were recorded for every month of the year, indicating to us that some reproduction does occur year round in Texas, at least when conditions are favorable. Litter size, according to Davis (1974) and Schmidly (1983), ranges from two to nine with a mean of six. Our small sample of pregnant females, 11, had fetal counts of four to 10, with a mode of five and a mean of 6.3. All three pregnant females taken in August still were partially in juvenile pelage. In view of the paucity of reproductive data available for *C. hispidus*, mammalogists are urged to record such useful information on specimen labels when preparing museum specimens of this and all other species of mammals.

Literature Cited

Davis, W. B. 1974. The mammals of Texas. Bull. Texas Parks and Wildlife Dept., 41:1-294.

Jones. J. K., Jr., D. M. Armstrong, and J. R. Choate. 1985. Guide to the mammals of the Plains States. Univ. Nebraska Press, Lincoln, xvii + 371 pp.

Paulson, D. D. 1988. Chaetodipus hispidus. Mamm. Species, 320:1-4.
Schmidly, D. J. 1983. Texas mammals east of the Balcones Fault Zone. Texas A&M Univ. Press, College Station, xviii + 400 pp.
Stangl, F. B., Jr., and E. M. Jones. 1987. An assessment of geographic and seasonal biases in systematic mammal collections from two Texas universities. Texas J. Sci., 39:129-137.

SMALL MAMMALS CAPTURED BY BARN OWLS IN LAMB COUNTY, TEXAS

RUSSELL J. PESATURO, RICHARD W. MANNING, AND J. KNOX JONES, JR.
The Museum and Department of Biological Sciences, Texas Tech University, Lubbock, Texas 79409

In the course of field work relating to the mammalian fauna of the Muleshoe Sandhills of Bailey, Lamb, and Hale counties, Texas, we collected cast pellets of barn owls (*Tyto alba*) from a grove of trees in Lamb County. The collection site was located 1 mi. N and 5 mi. E Fieldton, at the southern margin of the sandhills. The small woodlot, from which a barn owl was flushed in October 1988 when most of the pellets (66 whole and 27 partial) were found, no doubt was the remnant of an old homestead. Twenty-nine additional pellets were obtained at this site in January 1989, but no owls were present at that time, apparently having abandoned the area. The sandy soil immediately surrounding the grove is cultivated; grassland with some sage, yucca, and mesquite lies directly to the north about 200 yards distant.

Skeletal parts of vertebrates were removed from pellets after they had been soaked in water for a brief period to loosen the matrix. Crania, rami, and some postcranial skeletal elements of mammals initially were retained for identification, but, in order to avoid potential double-counting, only crania were used to obtain numbers of individual prey species.

TABLE 1. Number of individual mammals and birds (percent of total in parentheses) found in barn owl pellets from Lamb County, Texas.

Species	October 1988	January 1989
Cryptotis parva		2 (4.3)
Geomys bursarius	4 (2.6)	1 (2.2)
Perognathus sp.[1]	26 (16.9)	15 (32.6)
Chaetodipus hispidus	27 (17.6)	4 (8.7)
Dipodomys ordii	24 (15.6)	9 (19.6)
Reithrodontomys sp.[2]	29 (18.8)	6 (13.1)
Peromyscus maniculatus	10 (6.5)	3 (6.5)
Onychomys leucogaster	15 (9.8)	3 (6.5)
Sigmodon hispidus	5 (3.3)	
Mus musculus	3 (1.9)	
Rattus norvegicus	1 (0.6)	
Passerine bird	9 (5.8)	3 (6.5)
Quail	1 (0.6)	

[1] Most apparently *Perognathus flavescens*, but *P. flavus* possibly occurs in area and could have been represented.

[2] Most apparently *Reithrodontomys megalotis*, but *R. montanus* possibly occurs in area and could have been represented.

Contents and percentage of the total for pellets obtained in October 1988 and January 1989 are given in Table 1. Minimally, remains of 11 kinds of small mammals were found, along with a few passerine birds and one quail. Perhaps the most interesting among the prey species is the least shrew, *Cryptotis parva*, which is otherwise unknown from the Muleshoe Sandhills. These shrews have been reported previously from several localities on the Llano Estacado (Owen and Hamilton, 1986), the nearest being in Lubbock County to the southeast and at Muleshoe National Wildlife Refuge, which is south of the sandhills in Bailey County. The only other species unrepresented in our collections from the sandhill region is *Rattus norvegicus*, which likely occurs sparingly in the vicinity of human habitations and feedlots.

Otherwise, we have collected specimens of all other taxa taken by the owls, in roughly the same proportion except for the relatively high totals of *Chaetodipus hispidus*, the hispid pocket mouse, *Perognathus* sp., and *Reithrodontomys* sp. Trapping results indicated fewer hispid pocket mice than represented in pellets. This species may forage to some degree in relatively open areas, along with *Perognathus, Dipodomys ordii*, and *Onychomys leucogaster*, and thus be more easily taken by owls than otherwise might be the case, but our collecting efforts suggested that it is most often associated with the cover of weedy fencerows, as is *Reithrodontomys megalotis*. Of the pocket gophers (*Geomys bursarius*) taken by owls, one was a young adult, probably a female, and the other four were juveniles.

LITERATURE CITED

Owen, R. D., and M. J. Hamilton. 1986. Second record of *Cryptotis parva* (Soricidae: Insectivora) in New Mexico, with review of its status on the Llano Estacado. Southwestern Nat., 31:403-405.

A PLETHODONTID VERTEBRA FROM THE MID-HEMPHILLIAN OF TEXAS

DENNIS PARMLEY
Department of Biological and Environmental Sciences, Georgia College, Milledgeville, Georgia 31061

Records of plethodontid salamanders from rocks of Miocene age are rare (Tihen and Wake, 1981). Thus, a well-preserved plethodontid vertebra collected by the author from the mid-Hemphillian (late Miocene) Coffee Ranch local fauna of Hemphill County, Texas, is noteworthy. The fossil is deposited in the Georgia College Collection of Vertebrate Fossils as GCVP 2301. Previously reported Coffee Ranch amphibians and reptiles include an ambystomatid salamander, land tortoise remains, a few aquatic turtle bones, and an erycinine boid, and four colubrid snakes (Parmley, 1984, 1986).

Edwards (1976) reported major groups of salamanders have characteristic placements of spinal nerve foramina. GCVP 2301 has nerve foramina directly posterior to the rib bearers as in the Sirenidae, Salamandridae, Ambystomatidae, and Plethodontidae. Vertebrae of Sirenidae and Salamandridae are larger and have markedly more complicated neural spines and neural arches than the fossil. Vertebrae of plethodontids and the fossil differ from those of ambystomatids in being smaller and more gracile, and with longer, narrower centra, more centrally positioned neural spines, and lower, thinner neural arches.

Important vertebral differences between the two subfamilies of Plethodontidae (Desmognathinae and Plethodontinae) are: vertebrae opisthocoelous in Desmognathinae, amphicelous in Plethodontinae; and basapophyses well developed in Desmognathinae, but usually absent or weakly developed in Plethodontinae (Tihen and Wake, 1981; Wake, 1966).

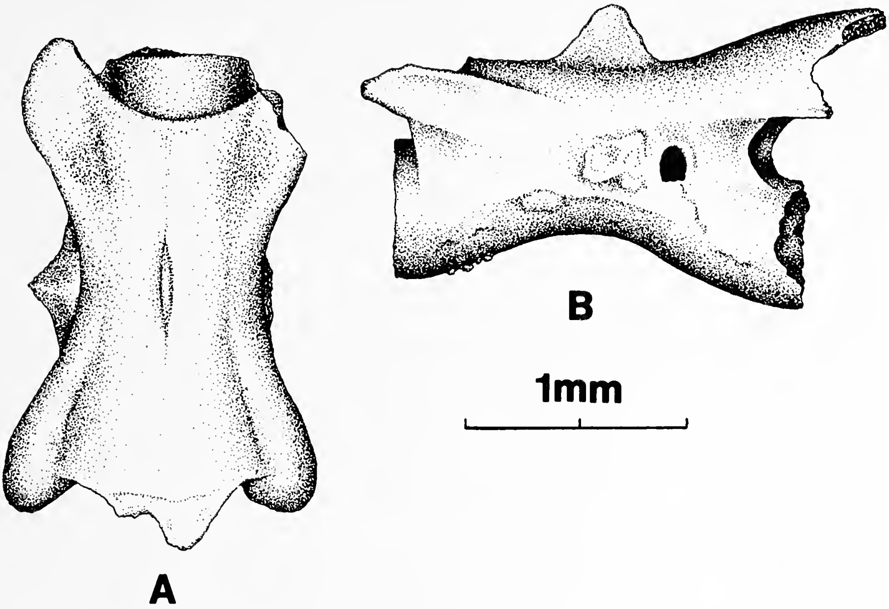

FIGURE 1. Plethodontine vertebra (GCVP 2301) in dorsal (A) and lateral (B) views.

The fossil shows no evidence of opisthocoely and lacks basapophyses (Fig. 1) and thus is referred to Plethodontinae. Vertebral characters of Recent plethodontines overlap between genera as well as varying ontogenetically and geographically (Wake, 1966; personal observation). Nonetheless, the fossil differs from *Eurycea* in having a shorter neural spine, and is similar in size and structural details to Recent *Plethodon*, but I cannot be certain it belongs to that genus.

Measurements in millimeters of GCVP 2301 are: centrum length 1.9; neural arch width 1.2; length through pre- and postzygapophyses 2.5; prezygapophyseal width 1.8; postzygapophyseal width 1.9.

The Coffee Ranch plethodontid is noteworthy because it represents the first record of this family from the Miocene of Texas, and only the second Miocene record of a plethodontid salamander from the Great Plains region. Previously, Tihen and Wake (1981) identified *Plethodon* and *Aneides* from the lower Arikareean mammal age (lower Miocene) of Montana.

LITERATURE CITED

Edwards, J. L. 1976. Spinal nerves and their bearing on salamander phylogeny. J. Morphol., 148:305-328.

Parmley, D. 1984. Herpetofauna of the Coffee Ranch local fauna (Hemphillian land mammal age) of Texas. Pp. 97-106, *in* (N. V. Horner, ed.), Festschrift for Walter W. Dalquest. Midwestern State Univ., Wichita Falls, Texas, xx + 163 pp.

———. 1986. *Lampropeltis similis* from the Coffee Ranch local fauna of Texas. Texas J. Sci., 39:123-128.

Tihen, J. A., and D. B. Wake. 1981. Vertebrae of plethodontid salamanders from the lower Miocene of Montana. J. Herpetol., 15:35-40.

Wake, D. B. 1966. Comparative osteology and evolution of the lungless salamanders, family Plenthodontidae. Mem. So. California Acad. Sci., 4:1-111.

NOTEWORTHY RANGE EXTENSIONS AND MARGINAL DISTRIBUTIONAL RECORDS FOR FIVE SPECIES OF TEXAS MAMMALS

Frederick B. Stangl, Jr., Stephen Kasper, and Tracy S. Schafer
Department of Biology, Midwestern State University, Wichita Falls, Texas 76308

Voucher specimens of five species of Texas mammals recently added to the Collection of Recent Mammals at Midwestern State University (MWSU) represent noteworthy records that extend the known distributions of these taxa in the state, or more clearly define the extent of their ranges.

Tadarida brasiliensis.—The Brazilian free-tailed bat certainly must range across the Texas Panhandle, although records from that region are few. Jones et al. (1988), for example, reported no specimens from the Trans-Canadian part of the Panhandle. Two males and three females of this species (MWSU 16080-16084) were netted on 12 September 1988 over a small stream 7 mi. N Clarendon, Donley County. These bats represent the northernmost records in Texas for the taxon.

Reithrodontomys fulvescens.—The fulvous harvest mouse apparently is absent from northwestern Texas, that part of the state comprised of the High Plains and Edwards Plateau (Davis, 1974; Hall, 1981). We obtained a single male (MWSU 16556) on 19 February 1989 at a location 1.6 mi. N Winters, Runnels County. Habitat was a grassy railroad right-of-way, on the fringe of the Edwards Plateau, where *Peromyscus leucopus* and *Mus musculus* also were taken. Records for this species along the western margin of its range are scarce; it was not listed, for example, in a recent mammal survey from Coke County, immediately to the west (Simpson and Maxwell, 1989).

Peromyscus maniculatus.—No specimens of the deer mouse are on record from a large area of south-central Texas (Hall, 1981), where two distinctive subspecies (*P. m. blandus* and *P. m. pallescens*) might be expected to meet. A single adult male (MWSU 16655) was trapped 9.8 mi. NE Stephenville, Erath County, in a grassy woodland margin on 20 March 1989. Several *P. leucopus* and one *P. attwateri* were taken nearby. This specimen slightly extends the range of *P. m. pallescens* westward into a distributional gap for this species as mapped by Hall (1981).

Ondatra zibethicus.—A mandible and assorted limb bones of a muskrat (MWSU 16115) were recovered from the regurgitated pellets of a great-horned owl near a stream 7 mi. N Clarendon, Donley County, on 10 September 1988. A muskrat, not collected, had been sighted in the creek on the previous evening. Muskrats are known from only three other northern counties in the Texas Panhandle (Jones et al., 1988), and some of these records are quite old (see Bailey, 1905). This specimen helps to fill a considerable gap between these northern records and those immediately to the southeast, where the species is more common.

Erethizon dorsatum.—Dalquest and Horner (1984) recorded the easternmost record of the porcupine in Texas as from Wichita County. Specimens from north-central Texas are scarce in collections, although occasional pelts of coyotes and bobcats from there may contain porcupine quills. On 10 June 1988, dogs cornered an adult female (MWSU 15857) near Lake Arrowhead, Clay County. Owners of the dogs captured the animal and presented it to us. This represents a modest eastward extension of the known range of the porcupine in Texas.

Literature Cited

Bailey, V. 1905. Biological survey of Texas. N. Amer. Fauna, 25:1-222.

Davis, W. B. 1974. The Mammals of Texas. Bull. Texas Parks Wildlife Dept., Austin, 41:1-294.

Dalquest, W. W., and N. V. Horner. 1984. Mammals of north-central Texas. Midwestern State Univ. Press, Wichita Falls, 261 pp. + 72 pls.

Hall, E. R. 1981. The mammals of North America. John Wiley and Sons, New York, 2nd ed., 2:vi + 601-1181 + *90*.

Jones, J. K., Jr., R. W. Manning, C. Jones, and R. R. Hollander. 1988. Mammals of the northern Texas Panhandle. Occas. Papers Mus., Texas Tech Univ., 126:1-54.

Simpson, L. A., and T. C. Maxwell. 1989. The mammal fauna of Coke County, Texas. Texas J. Sci., 41:177-192.

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RICHARD W. MANNING AND JIM R. GOETZE
The Museum and Department of Biological Sciences,
Texas Tech University, Lubbock, Texas, 79409

This index has separate subject and author sections. Key (or other important) words or phrases are followed by an abbreviated title and initial page number of each article in which they appeared. Scientific names of organisms were indexed only to genus, followed by the initial page number of each article in which that generic name was mentioned. Generic names selected by authors as key words or used in titles, however, were treated as all other key words indexed. Specific geographic areas or localities used by authors in titles or as key words were entered as index headings with the exception of Texas, because the majority of articles in the *Journal* dealt with that state. All states (or countries) other than Texas appear as separate headings in the index. Vernacular names of biological species, ordinal and familial names, and chemical compounds were indexed only if used in the titles or as key words.

The index does not include two supplements published with volume 41, as follows:

Ward-McLemore, E., and J. E. McLaughlin. 1989. Bibliography of the publications of the Texas Academy of Science, 1929-1987. Texas J. Sci., 41 (Suppl.): 1-128.

Ward-McLemore, E. 1989. The academies of science of Texas (1880-1987). Texas J. Sci., 41 (Suppl.): 1-130.

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