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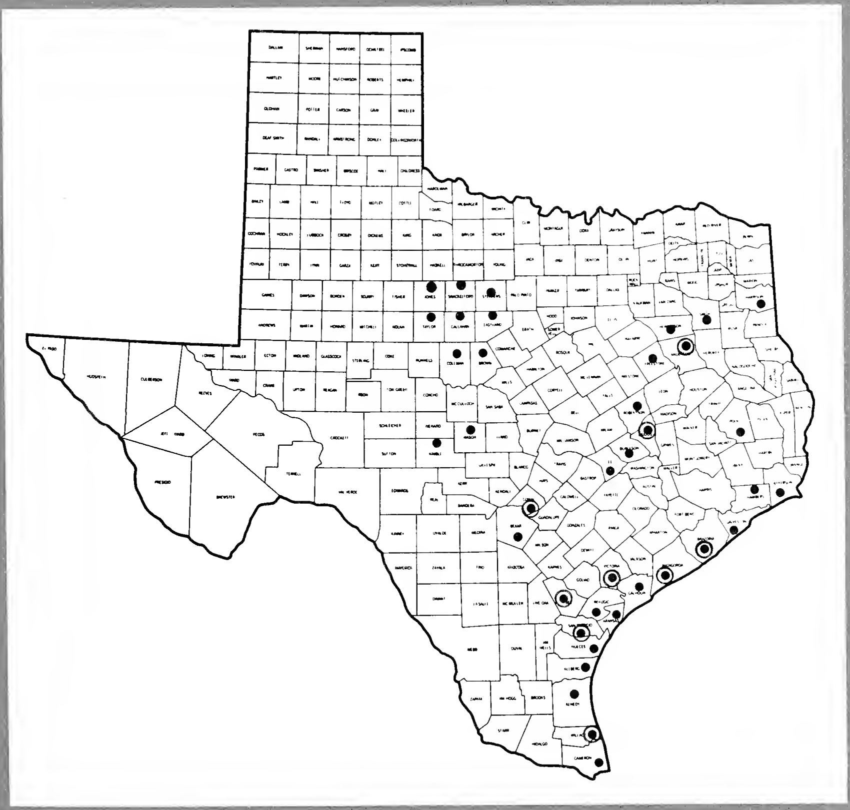

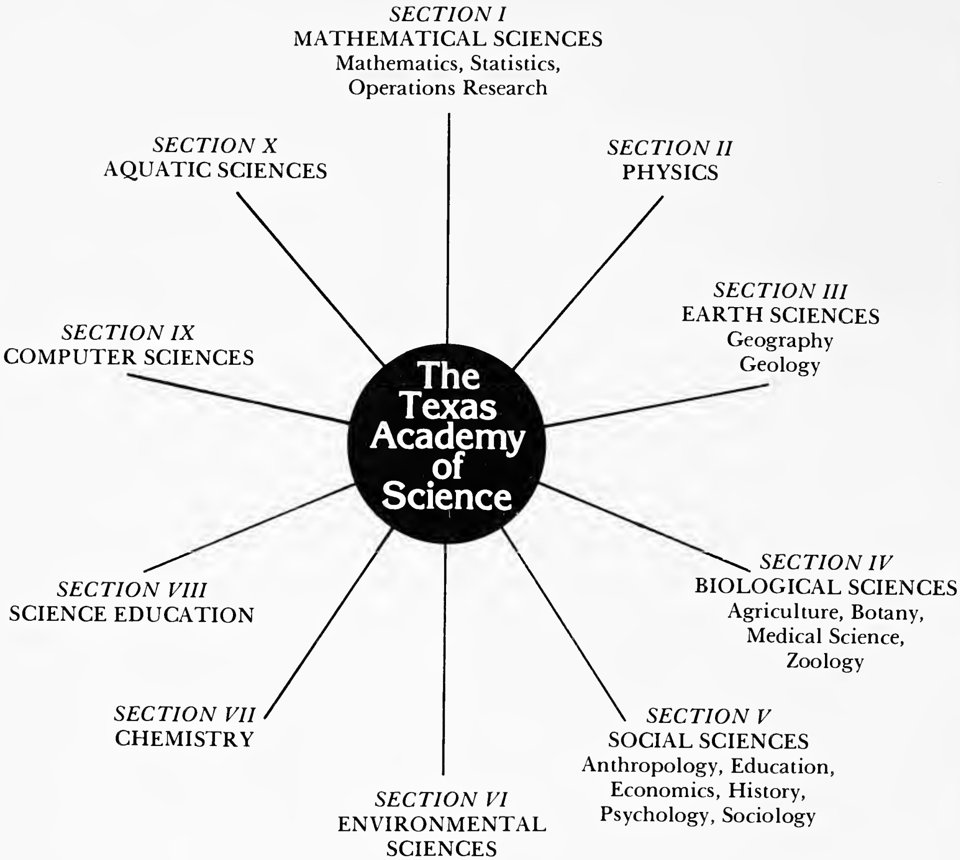

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STELLAR PERTURBATIONS OF COMETARY ORBITS AND THE PRODUCTION OF LONG-PERIOD COMETS

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ABSTRACT

A model of the Oort Comet Cloud containing 10^5 members and with a space density varying roughly as the inverse square of its radius was constructed. The effects on the comet orbits due to each of 100 passing stars were computed. The passing stars were chosen to be representative of those which do pass by the sun.

Results indicate that observable comets are produced by small perturbations of large and highly eccentric cometary orbits. It was also found that diffusion from the outer regions limits the cloud radius to 5×10^4 AU.

INTRODUCTION

Every year some hitherto unobserved comets are discovered. Many of these are classified as long-period ($>$ 200 years) comets. While some may be "new" short-period comets, Everhart (1973) has shown that repeated encounters with Jupiter can perturb long-period comets into short-period ($<$ 200 years) orbits. He found the converse was not true: A short-period comet was more likely to be ejected from the solar system than injected into a long-period orbit. Hence, short-period comets were shown to initially have been long-period comets.

Distribution of orbital parameters for 523 long-period comets are given by Marsden (1975). Orientation of the orbits was shown to be nearly random with only a small deficiency in those with an argument of perihelion near 270°, which Weissman (1978) attributes to observational selection.

Marsden (1976), in a new calculation of original semi-major axes (a) for comets with well determined orbits, found a "pile-up" of comets with values of $1/a$ less than 10^{-4} AU^{-1} sufficient to suggest that these comets came from a swarm or cloud of comets such as that suggested by Oort (1950).

Oort's original work (Oort 1950) showed that a cloud of comets surrounded the sun, indicated that the cloud radius should be no more than 10^5 AU and that the cloud must contain about 10^{11} members.

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Oort found that cloud members would be perturbed into orbits rendering them visible by the gravitational influence of passing stars. Oort computed the impulse transmitted from an average passing star to a comet at a given distance from the sun. He calculated cumulative effects on the comet orbit caused by successive passing stars on the assumption that the impulses are oriented randomly.

Recent studies have taken up the question of stellar perturbations on individual comet orbits. Rickman (1976) studied the perturbations for perihelion distances less than 5 AU. He found that if planetary perturbations did not reduce the aphelion distance to within 2×10^4 AU, stellar perturbations are likely to increase perihelion distance. Similar results were found by Yabushita (1972) and Weissman (1978).

Sekanina (1968) computed the effect of stellar encounters on interstellar comets, which are not observed. More recently, Weissman (1981) reported on the effects of stellar perturbations on comets having a wide range of perihelion and aphelion distances. He allowed random perturbations to be applied only at aphelion, and determined whether a comet would be ejected outright, perturbed to aphelia comparable to interstellar distances or to perihelia within the planetary system. His results showed that an inward diffusion of perihelia, capable of producing observable comets, would occur if aphelion distances were greater than 2×10^4 AU. While planetary perturbations were found easily capable of ejecting comets with small perihelion distances, stellar perturbations were found to result in an outward diffusion of aphelia with only a small percentage of outright ejections.

Except for Weissman's recent study (Weissman 1981), only Oort dealt with random perturbations of orbits of typical Oort cloud comets. Both of these studies assumed a Maxwellian distribution of perturbations and only Weissman applied a random selection of these perturbations to individual orbits. Also, Weissman limited his study to perturbations applied at aphelion.

This paper presents a modeling study of orbital changes due to a random selection of passing stars, where the original orbits and position of the comets in their orbits are also selected randomly.

BASIC MODEL

The quantities needed to define the cometary orbits and the nature and paths of the passing stars were obtained using the random generator of a CDC Cyber 74 computer. The orbital parameters for the comets were chosen randomly within the limits given in Table 1. Values were chosen to assure that the full range of perihelion and aphelion distances (D1 and D2) of interest would be studied. The smaller of the two distances was taken as the perihelion distance. The

TABLE 1. Orbital parameters used in the model.

	$10 \leq D1 \leq 10^5$ AU
	$3 \times 10^3 \leq D2 \leq 10^5$ AU
Perihelion distance:	$q = \min(D1, D2)$
Aphelion distance:	$Q = \max(D1, D2)$
Semi-major axis:	$a = (q + Q)/2$ AU)
Eccentricity:	$e = (Q - q)/(Q + q)$
Inclination:	$0 \leq i \leq \pi$
Longitude of the ascending node:	$0 \leq \Omega < 2\pi$
Argument of perihlion:	$0 \leq \omega < 2\pi$
	T = portion of period in years

inner bound of D1 was set at 10 AU. The inner bound of 3×10^3 AU for D2 was selected because comets with aphelion distances less than this would suffer negligible perturbations from passing stars. The outer bound of 10^5 AU for both distances was selected to allow large circular orbits, and with the realization that long-period comets are not observed to come from greater distances. The resulting density distribution is that given in Figure 1.

Some 100 passing stars were chosen to be representative of those in the solar neighborhood. The data of Table 2 are based on those of Allen (1964). The heliocentric longitude ℓ of the point of closest approach of the star to the sun was chosen randomly over the interval $0 \leq \ell < 360°$. The latitude b of that point was chosen over the interval

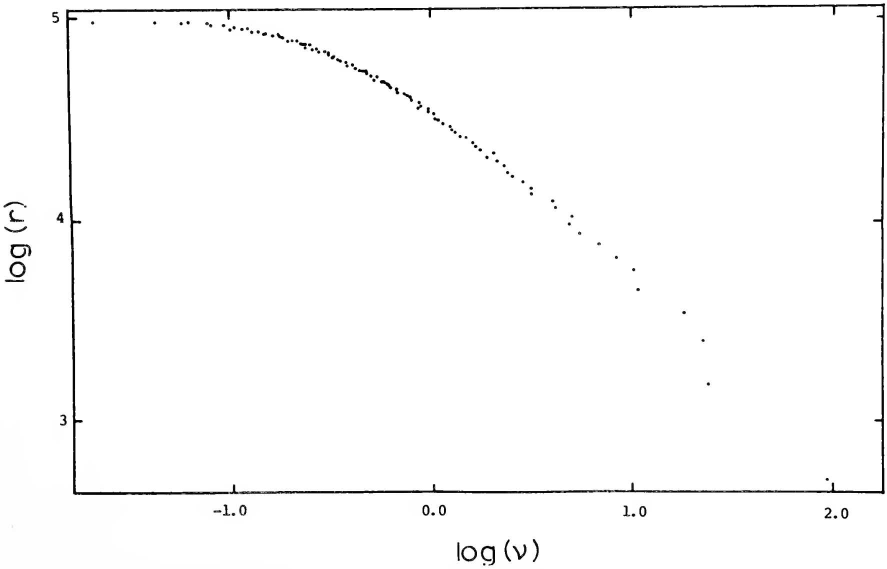

FIGURE 1. Space density ν (the number of comets per $4\pi \times 10^3$ AU^3) of the model cloud at a distance r AU from the sun. The positions of comets are computed at a randomly selected time.

TABLE 2. Characteristics of passing stars.

Type	% of total	Mass relative to sun	Velocity in AU/Yr	M/V
dA + Giants	1.6	3.5	5.8	0.60
dF	3.3	1.8	7.2	0.25
dG + wd	15.1	1.1	11.0	0.10
dK	13.3	0.8	11.4	0.07
dM	66.7	0.5	12.5	0.04

$-90° \leq b \leq 90°$, with choice of latitudes being weighted by the factor cos b. The position angle γ of the star's motion at the point of closest approach was chosen randomly between $0 \leq \gamma < 360°$. The choice of distance of closest approach r was weighted linearly with distance from the sun, with the constraint that the star pass within 10^5AU of the sun.

For each comet the position and the velocity in the orbit at the randomly chosen time T were computed. Then the total change was

$$\Delta\bar{v} = \Delta\bar{v}_c - \Delta\bar{v}_s$$

$$= \frac{2GM_*}{V_*}\left(\frac{\hat{d}}{d} - \frac{\hat{D}}{D}\right)$$

where $\Delta\bar{v}_c$ = component of the change of the velocity of the comet due to the action of the passing star,
$\Delta\bar{v}_s$ = component of the change of the velocity of the sun due to the action of the passing star,
G = universal gravitational constant,
M_* = mass of passing star in units of the sun's mass,
V_* = velocity of the passing star in AU per year,
d = distance of closest approach of passing star to comet,
$\hat{d}$ = unit vector from comet to star,
D = distance of closest approach of star to sun, and
$\hat{D}$ = unit vector from sun to star.

This represents the difference in the impulse the star applies to the comet and the sun, and it is thus the impulse of the comet with respect to the sun which is caused by the passing star. This impulse was added to the velocity of the comet to find the perturbed velocity of the comet, from which the perturbed orbital elements were found.

The accuracy of the impulse method was checked by performing numerical integrations on the orbits of several selected comets. Results indicate that the perturbations were determined to within 1% accuracy except when the comet was undergoing perihelion passage and suffered an extremely small perturbation.

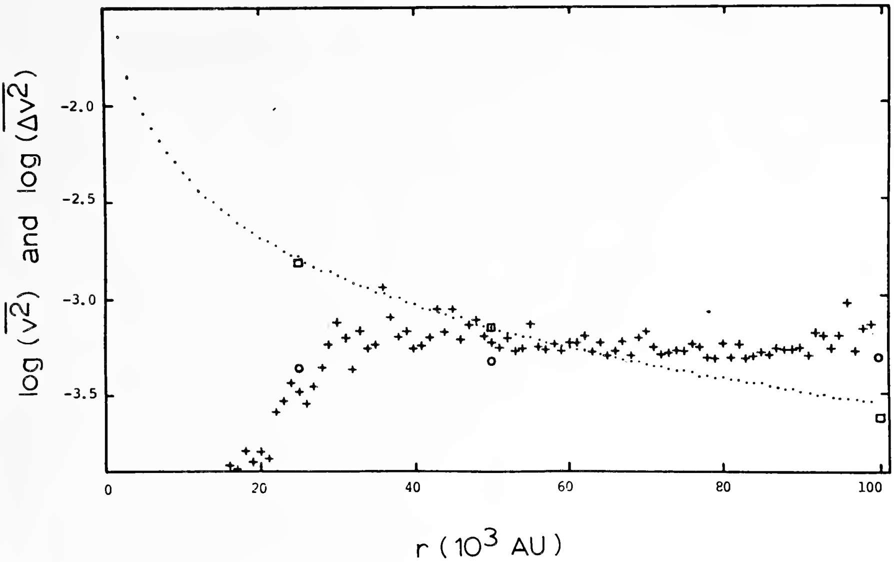

FIGURE 2. Lifetime changes in mean squared orbital velocity. The crosses represent the expected changes in $\overline{v^2}$ over the lifetime of the solar system. The dots represent the $\overline{v^2}$ at a distance r from the sun. Similar data obtained by Oort are plotted with squares representing $\overline{v^2}$ and circles representing $\overline{\Delta v^2}$.

RESULTS AND DISCUSSION

With 10^7 perturbations in the model it was not practical to examine each perturbation individually; rather, mean and root-mean-square (rms) values of the perturbations were computed. These data were broken down into shells of r, each with a thickness of 10^3 AU, where r is the distance of the comet from the sun at the time of perturbation.

Chebotarev (1972) found that one close stellar pass (7×10^4 AU) might occur every 10^6 years, so that over the lifetime of the sun, 10^4 stars may be expected to have passed within 10^5 AU. It may be expected that the total perturbation on a comet orbit during the lifetime of the sun is 100 times greater than the rms perturbations. These expected perturbations are shown as a function of distance from the sun in Figures 2 and 3.

In interpreting these results it must be remembered that the rms changes were produced with each comet suffering repeated and then averaged perturbations, each perturbation imposed at the same point of that comet's original orbit. On the other hand, the positions of comets in their orbits were selected at random; thus, the average figures do represent the average effects on comets for perturbations which occur when they pass through a given shell.

The stability of the comet cloud is best indicated by $\overline{\Delta v^2}$. Figure 2 gives this information as a function of the distance of the comets from

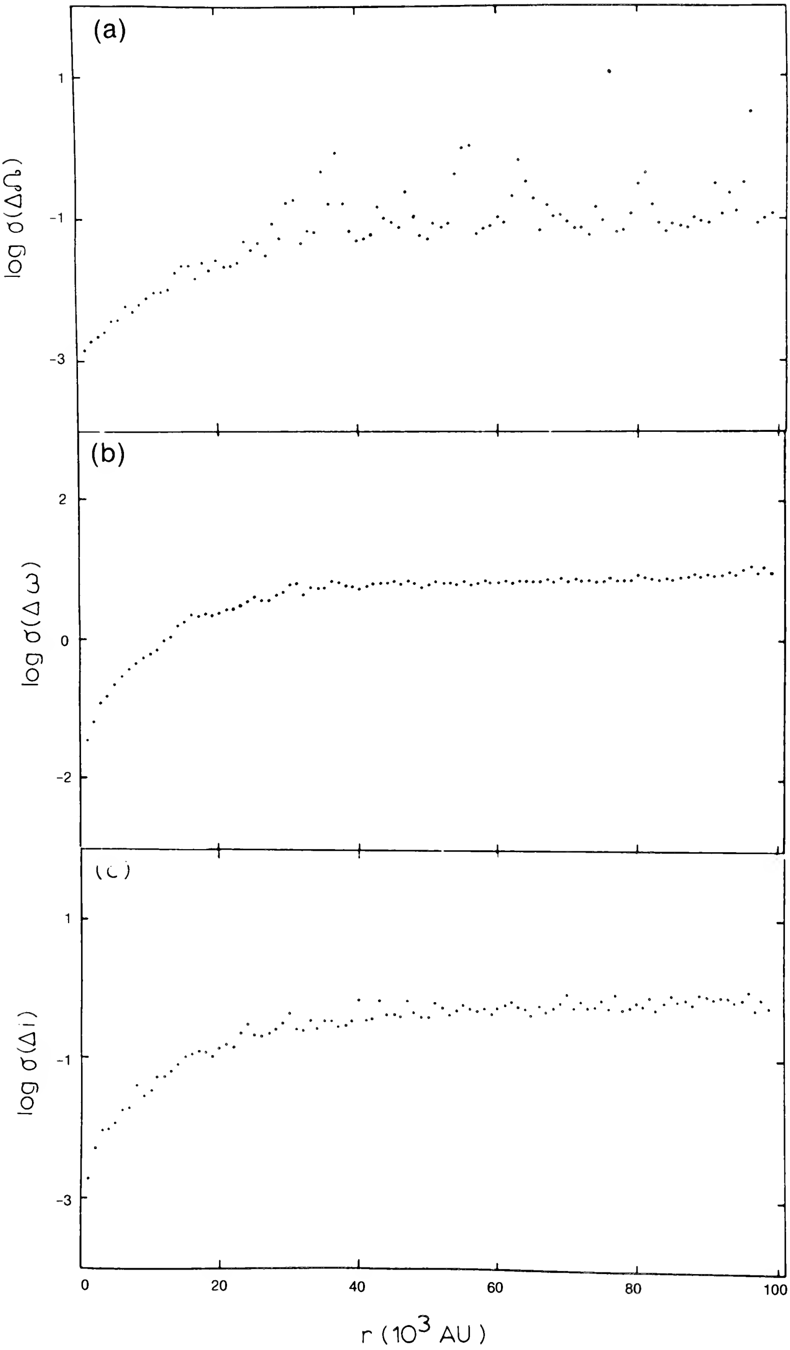

FIGURE 3. RMS changes in orbital parameters. The perturbations shown are the total expected over the lifetime of the solar system as a function of distance from the sun. (a) Longitude of the ascending node; (b) argument of perihelion; (c) inclination.

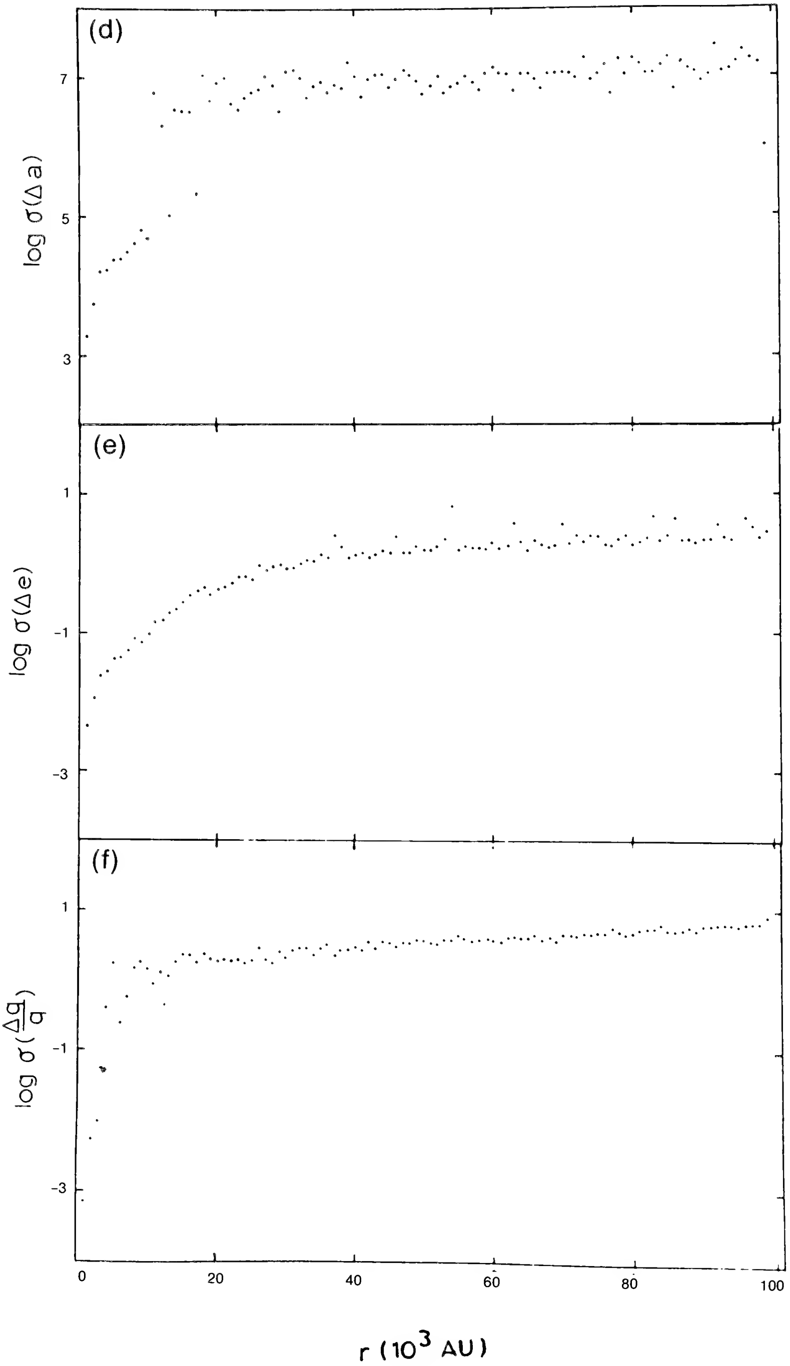

FIGURE 3 (continued). RMS changes in orbital parameters. (d) Semi-major axis; (e) eccentricity; and (f) fractional changes in perihelion distance.

the sun. Also plotted is the average v^2 for these comets. The distance 5.5×10^4 AU where the $\overline{\Delta v^2}$ curve crosses the $\overline{v^2}$ curve is the distance at which the kinetic energy of the comet in its orbit could be doubled, resulting in the ejection of the comet from the solar system. Few comets beyond this distance would be expected to be retained.

With respect to changes in the other orbital characteristics, the longitude of the ascending node Ω and the argument of perihelion ω for comets beyond 10^4 AU show no indication of their original distribution (Fig. 3a, 3b). Changes in inclination i are smaller, however (Fig. 3c). The value of σ (Δi) reaches 0.8 radians at about 4×10^4 AU and this limit should not be sufficient to randomize the inclination of the orbits if at one time they were coplanar.

Figures 3 d, e, and f deal with changes in the shape rather than the orientation of the orbits. Orbits having semi-major axes suffering changes (Δa) greater than 10^5 AU or suffering changes in eccentricity (Δe) approaching 1 would be loosely bound or indeed lost from the solar system. The distances where this would happen are beyond 3×10^4 AU for $\sigma(\Delta a)$ and 5×10^4 AU for $\sigma(\Delta e)$, in general agreement with the outer bound as determined by $\sigma(\Delta V^2)$.

The value of $(\Delta q/q)$ does not reach 1 until a distance of 3×10^4 AU is attained. In general, comets with aphelia less than this will not have suffered sufficient perturbations to render them visible. The implication of this is that the preponderance of visible comets should have semi-major axes greater than 1.5×10^4 AU. Also, it is clear that comets beyond 5×10^4 AU should have suffered $\Delta q/q \geq 1$ and if such comets did exist, we should see some at present. Since the observations show a distinct lack of such comets, the inescapable conclusion is that few if any exist.

The conclusions regarding $(\Delta q/q)$ are supported by an examination of the 7 "visible" comets which were produced by the 10^7 perturbations. All originally had small perihelion distances. Two of the comets, in fact, had aphelia near the outer limit of the distribution, again suggesting that if such comets exist some must be observable (Table 3).

In addition to analysis of rms changes in the orbital parameters, the individual changes in perihelion and aphelion distances were examined. Both the perihelion and aphelion distances were broken into shells with thicknesses $\log D = 0.5$. Table 4 gives the number of comets with perihelion distances crossing 0, 1, 2, or more shell boundaries. These data show a rough equivalence in the number of perihelion distances crossing a boundary in the inward or outward directions. Thus the distribution of perihelion distances should remain essentially unchanged except that the comets evaporated by solar heat would be replenished by those with perihelia already within 100 AU.

Table 3. Comets perturbed into visible orbits. First row gives the original orbital elements, perihelion and aphelion distance for the comet. Second row gives the same quantities for the perturbed comet.

Star	Comet	a(AU)	e	i (rad)	Ω (rad)	ω (rad)	q (AU)	Q (AU)
57	44304	33218	0.99821	2.179	1.796	5.342	59.3	66377
		32671	0.99992	2.112	1.912	5.361	2.5	65340
48	57210	31595	0.99963	1.898	0.163	0.804	11.7	63178
		81885	0.99991	2.032	0.326	0.872	2.9	63768
61	61339	50006	0.99970	2.562	1.145	2.315	15.1	99997
		49580	0.99996	2.302	1.484	2.566	2.2	99158
57	63092	36770	0.99946	1.351	4.996	2.635	19.9	73520
		36776	0.99997	1.090	5.159	2.581	1.0	73552
30	68543	23909	0.99756	0.942	1.831	4.072	58.2	47760
		24811	0.99998	2.448	3.865	4.580	0.4	49622
36	81705	35596	0.99904	1.226	3.194	5.828	34.2	71158
		35642	0.99993	1.598	3.015	5.852	2.7	71280
49	90909	47674	0.99914	1.388	1.341	5.008	40.9	95306
		47667	0.99994	1.915	5.664	4.761	2.7	95332

A similar diffusion is seen with the aphelion distances (Table 5), again, with a rough equivalence in the inward and outward crossings of the shell boundaries. A significant number of comets have aphelion distances that cross the boundary at 10^5 AU. This outward diffusion

Table 4. Perturbations of perihelion distance. The left-hand column gives the boundaries of shells in which the original perihelion distances are located. The top row gives the boundaries of shells in which the perturbed perihelion distances are located. The bottom row indicates how many shells outward the perihelion distance is perturbed.

log q' / log q	> 5.0	4.5 to 5.0	4.0 to 4.5	3.5 to 4.0	3.0 to 3.5	2.5 to 3.0	2.0 to 2.5	1.5 to 2.0	1.0 to 1.5	0.5 to 1.0	<0.5			
1.0 to 1.5							3	163	2008	23	2	1		
1.5 to 2.0							2	134	6921	134	5	3	1	
2.0 to 2.5					1		1	212	18773	111	2			
2.5 to 3.0							1	628	67951	220				
3.0 to 3.5					1		3	1839	236395	561	4			
3.5 to 4.0				11			5	7373	1298297	1908	3	3		
4.0 to 4.5				34				9549	3532367	4042	4		2	1
4.5 to 5.0				71					4804870	8947	9	2	1	
log q / n				∞	+3		+2	+1	0	-1	-2	-3	-4	-5

TABLE 5. Perturbations of aphelion distance. The left-hand column gives the boundaries of shells in which the original aphelion distances are located. The top row gives the boundaries of shells in which the perturbed aphelion distances are located. The bottom row indicates how many shells outward the aphelion distance is perturbed.

log Q'				>5.5	5.0 to 5.5	4.5 to 5.0	4.0 to 4.5	3.5 to 4.0	3.0 to 3.5
3.0 to 3.5								900	
3.5 to 4.0							26	75774	
4.0 to 4.5	1			2		4	1132	869357	4
4.5 to 5.0	115	1	1	4	13	65	41382	9010293	936
log Q / n	∞	+6	+5	+4	+3	+2	+1	0	-1

will deplete substantially the population in the shell from log Q = 4.5 to 5.0 over the lifetime of the solar system.

A small number of comets is ejected outright from the outermost shell of aphelion distance. (These comets are listed in the n = ∞ column of Tables 4 and 5.) However, direct ejections can cause little depletion of the comet cloud.

CONCLUSIONS

The principal mechanism producing observable comets is an inward diffusion of perihelion distances for those comets already having highly eccentric orbits. The perihelion distances for those comets are already near or within the planetary system before a stellar passage perturbs them into orbits rendering them visible.

The principal mechanism for loss of comets from the solar system is an outward diffusion to orbits extending beyond 10^5 AU, where single perturbations may more easily eject them. Few comets are lost by single perturbations when their aphelion distances are less than 10^5 AU.

The cloud considered had a distribution of space densities roughly proportional to r^{-2}. Since the number of comets with periphelia and aphelia diffusing inward and outward across shell boundaries was aproximately equal, a distribution of this nature should be stable.

Characteristics of the comet orbits should appear randomly distributed except that any original concentration in a plane should still be observable, especially for comets with aphelia less than 10^4 AU.

An outer bound to the present distribution should be near 5 × 10^4 AU. This is supported by the lack of observed comets with aphelia at greater distances, whereas this study shows that if they exist some should be observed.

ACKNOWLEDGMENTS

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MAJOR AROMATIC CONSTITUENTS IN MEXICAN VANILLA EXTRACTS

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ABSTRACT

Formulations of currently produced Mexican vanilla extracts are similar to those of U.S. imitation vanilla extracts produced prior to 1954 when additives such as coumarin were outlawed. Fifty brands of Mexican vanilla extract were examined for their major aromatic constituents; vanillin, coumarin, umbelliferone, ethyl vanillin and piperonal were identified. The majority of brands (32) contained vanillin, coumarin and umbelliferone as their principal aromatic compounds. The 50 brands averaged only 0.57% vanillin. The 41 brands that contained coumarin had vanillin:coumarin ratios ranging from 66:1 to 1:14. The purportedly superior aromaticity of Mexican vanilla extracts over American brands marketed today is probably due to the presence of coumarin and/or tonka bean extract.

INTRODUCTION

Mexican vanilla extracts are extremely popular among residents of the southwestern United States. This popularity derives from the purportedly superior flavor and/or aroma and relatively low cost of the typical Mexican product in comparison to American-produced vanilla extracts.

Unlike American manufacturers of true vanilla extracts and imitation vanilla flavors, Mexican producers are not restricted by rigid food regulations. Thus, Mexican vanilla extracts may contain additives which in the United States are considered unfit for human consumption. One such additive is coumarin. According to the *Federal Register* of March 5, 1954 (19 CFR 1239), "any food containing added coumarin as such or as a constituent of tonka beans or tonka extract is deemed to be adulterated." The U.S. government decision, to declare coumarin a poisonous and deleterious substance, was based on pharmacological investigations which demonstrated that coumarin is a toxic substance causing damage to various organs, particularly the liver. The possible

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toxic implications of coumarin in Mexican vanilla extracts have been previously reported (Sullivan 1981 a, b, c).

The objective of the present study was to determine the major aromatic constituents of Mexican vanilla extracts sold under various trade names.

MATERIALS AND METHODS

Materials

Approximately 1500 samples of Mexican vanilla extract, sold under 50 brand names, were received from residents of Texas and twenty other States. For brands represented by more than 9 samples, 9 samples were selected randomly for examination.

Preliminary Chromatographic Analysis

The thin-layer chromatographic (TLC) procedure employed in the preliminary examination of Mexican vanilla extracts for their major aromatic constituents was essentially that of Kahan and Fitelson (1964). Individual 200 × 200 × 0.25 mm silica gel G plates (gypsum-free) that had been precoated with fluorescent indicator UV_{254} (Polygram Sil G/UV_{254}) were spotted with 1 μl of extract and developed for a distance of 10 cm in a solvent system composed of hexane:ethyl acetate (4:1). The developed TLC plate was air-dried, sprayed with 5% KOH in methanol, allowed to dry and examined under UV light.

Isolation and Identification of Fluorescent Compounds

The brands La Vencedora and Zambrano, between them, contained all 5 aromatic compounds evident from the preliminary analysis. Therefore, these two brands were selected as sources of material for diagnostic tests. Five hundred ml of each of the two extracts was partitioned with three 500 ml aliquots of methylene chloride in a separatory funnel. The three aliquots were combined and dried on a rotary evaporator. Approximately one-half of the resulting solids was solubilized in a minimal amount of methylene chloride and placed on a 3 × 25 cm silicic acid column (Bio-Sil A, 100-200 mesh) which had previously been conditioned with hexane:ethyl acetate (4:1). The column was eluted with this solvent mixture and 25 ml fractions collected. These fractions were examined by the TLC procedure described above and identical fractions combined.

The combined fractions were individually dried and the resulting residue placed in a thermal gradient sublimer (Scientific Instruments Accessories) and sublimed under reduced pressure. Each sublimed compound was characterized by melting point, visible and ultra violet spectrum and mass spectroscopy. Identification of each isolated and purified compound was accomplished by matching these parameters with those of a reference compound (Sigma Chemical Co.) and verified by mixed melting-point determination and two-dimensional TLC with the reference compound. A solvent system composed to benzene: methanol (97:3) was employed in the second dimensional development.

Quantitative Determination

One μl of each Mexican vanilla extract was placed on a TLC plate, developed, air-dried and the quantity of coumarin and vanillin determined by spectrodensitometry. The developed and dried plate was placed in a spectrodensitometer (Schoeffel Instrument Corp., Model SD 3000) and scanned with the UV light source set at 254 nm. The signal from the spectrodensitometer was input to a density computer (Schoeffel, Model SDC 300). The resulting output was input to a data processor (Shimadzu Corp., Altex, Model CR1A) which computed and recorded the area under the curve. Calibration was achieved via standard solutions containing 0.05, 0.1 and 0.15% reference coumarin and vanillin in methanol prepared and processed in the same manner.

Verification of Qualitative Determination

One μl of each Mexican vanilla extract was spotted on a TLC plate along with reference compounds, developed, air-dried, sprayed with methanolic KOH and examined under UV light.

TABLE 1. Diagnostic parameters and inferred identity for five aromatic compounds isolated by column chromatography from Mexican vanilla extracts.

Compound from Extract	TLC R_f	Sublimation Temperature (C)	Melting Temperature (C)	MS m/z	UVλ_{max} (nm) MeOH	Equivalent Reference Material
A	0.55	24	37	150	312 272 230	piperonal
B	0.45	50	68-70	146	306 272	coumarin
C	0.27	70	80-81	152	304 274 226	vanillin
D	0.15	60	77-78	166	307 277 231	ethyl vanillin
E	0.10	200	225-228	162	324 254 216	umbelliferone

TABLE 2. Major aromatic constituents in Mexican vanilla extracts. Umbelliferone, ethyl vanillin and piperonal were scored only as present (+) or absent (–).

Brand	Number of Samples	% Vanillin	% Coumarin[a]	V/C Ratio[b]	Umbelliferone	Ethyl Vanillin	Piperonal
Alferco's Premier	9	.09	.08	1:1	+	+	–
Alther	1	1.17	.61	2:1	+	–	–
American Food de Mexico	1	.01	.14	1:14	+	–	–
Botica Central	1	.32	.46	2:3	+	–	–
Bremer	1	1.73	.11	16:1	+	–	–
Ciervo	4	.32	.02	16:1	+	–	–
Cristal	1	1.92	.03	64:1	+	–	+
Danncy	2	1.16	.14	9:1	+	–	–
Deiman	1	.10	~0		–	+	+
Delicia	1	.21	~0		–	–	–
Demesa	2	1.52	~0		–	–	–
Dey Ley	1	.14	.02	7:1	+	–	–
Diana	1	1.29	.15	9:1	+	–	–
El Gallito	9	.45	.08	5:1	+	–	–
El Jarocho	6	.05	.10	1:2	+	–	–
Empacador Artificial	1	.06	.07	1:1	+	–	–
En Rama Ofrenda	2	.05	~0		–	–	–
E. W. (Ernesto Weinstein)	6	1.45	.14	10:1	–	–	–
Famus	1	.15	~0		–	+	+
Gallo	1	1.94	.08	24:1	+	–	+
La Anita	6	.89	.03	29:1	+	–	–
La Bandera	5	.16	.003	53:1	+	–	–
La Corona de Oro	1	.70	.11	7:1	+	–	–
La Favorita	1	.08	.015	5:1	+	–	–
La Jarocha	1	.65	.08	8:1	+	–	–
La Puresta	1	.52	.16	3:1	+	–	–

La Pureza	9	.29	.14	2:1	+	–	–
La Vencedora	9	2.00	.03	66:1	+	–	+
Leudol	1	.05	.06	1:1	+	–	–
Lubek	1	.22	.06	4:1	+	–	–
Lubor	1	.12	.02	6:1	+	–	–
Lucio R. Beltran	2	.14	.05	3:1	+	–	–
Molina	9	1.33	.08	16:1	+	–	–
Old San Antonio	1	.45	.11	4:1	+	–	–
Paisa	9	.25	.09	3:1	+	–	–
Paisa (Colorless)	1	.31	.13	3:1	–	–	–
Pardo	4	.18	.09	2:1	+	–	–
Product of Riko Mitla	1	.17	.15	11:1	–	+	–
Pura de Ejotes	8	.19	.01	19:1	+	+	–
Pura Premier (R. M. Leal)	9	.10	.07	1:1	+	+	–
Triunfo	9	.48	.05	10:1	+	–	–
Tropical	9	.19	~0		–	+	–
Tropical World	3	.27	.10	3:1	+	–	–
Unica	2	.22	.07	3:1	+	–	–
Vai Mex	6	.11	~0		–	–	–
Vainilla de Cordoba	1	.05	.06	1:1	+	–	–
Vainillera	1	.08	.05	1:1	+	–	–
Vreez	3	.18	~0		–	–	–
Zambrano	9	.83	~0		–	+	–
Zappor	1	.20	.03	7:1	+	–	–

[a] These values for coumarin were previously reported in Sullivan (1981c).

[b] Approximate ratio of vanillin/coumarin.

RESULTS

The preliminary TLC examination of Mexican vanilla extracts revealed the presence of five fluorescent compounds residing at R_f 0.55 (Compound A), R_f 0.45(B), R_f 0.27 (C), R_f 0.15 (D) and R_f 0.10 (E). For diagnostic tests, Mexican vanilla extract La Vencedora provided compounds A, B, C and E; Zambrano provided compounds C and D.

Results of the diagnostic tests indicated that compounds A, B, C, D and E were identical with piperonal, coumarin, vanillin, ethyl vanillin and umbelliferone, respectively (Table 1). In each case, the melting point of an admixture with the reference material was not depressed, and the extract and pure compounds were inseparable by two-dimensional TLC.

Table 2 indicates which of the five aromatic constituents were present in each brand of Mexican vanilla extract. Eight different combinations were found: (1) 5 brands contained only vanillin; (2) 2 brands contained vanillin and coumarin; (3) 2 brands contained vanillin and ethyl vanillin; (4) 1 brand contained vanillin, coumarin and ethyl vanillin; (5) 2 brands contained vanillin, ethyl vanillin and piperonal; (6) 32 brands contained vanillin, coumarin and umbelliferone; (7) 3 brands contained vanillin, coumarin, umbelliferone and piperonal; (8) and 3 brands contained vanillin, coumarin, umbelliferone and ethyl vanillin.

Quantitative determinations of vanillin and coumarin also are listed in Table 2. A high of 2.0%, a low of 0.01% and an average of 0.57% vanillin was found for the 50 brands of Mexican vanilla extract. A high of 0.61%, a low of 0.003% and an average of 0.1% coumarin was determined in the 41 brands of Mexican vanilla extract that contained detectable amounts of coumarin. Vanillin/coumarin ratios ranged from 66:1 to 1:14.

DISCUSSION

Prior to 1954, U.S. manufacturers were permitted to use coumarin or an extract from tonka bean, *Dipteryx odorata* (Aubl.) Willd., as a constituent of imitation vanilla extracts. Heliotropin (piperonal) and bourbonal (ethyl vanillin) also were used. In the 1940's, U.S. vanilla extracts had vanillin/coumarin ratios ranging from 75:1 to 1:1, with the typical ratio being 5:1 (Jacobs 1946). These ratios are similar to those of present-day Mexican vanilla extracts (Table 2). American extracts produced before 1954 contained approximately 0.7% vanillin; whereas, the Mexican types examined had a slightly lower average content of 0.57%. Nine brands of Mexican vanilla extract contained a relatively higher vanillin content, 1.16-2.0%, which is similar to that of the double-strength type of imitation vanilla flavoring agents currently produced in the U.S. The average coumarin content of pre-1954 American brands was 0.18% (Jacobs 1946) versus 0.10% in the Mexican brands examined in this study.

The presence of coumarin and umbelliferone in the majority of Mexican vanilla extracts strongly suggests that the manufacturers of these products have incorporated tonka bean extract; umbelliferone co-occurs with coumarin in tonka beans (Sullivan 1982). The most prevalent combination, occurring in 32 brands, was a blend of vanillin, coumarin and umbelliferone. This combination of aromatic constituents implies that these brands were prepared by incorporating both vanilla bean and tonka bean extracts.

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VEGETATION OF AN OPEN, PRAIRIE-LIKE COMMUNITY IN EASTERN TEXAS[1]

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ABSTRACT

The plot method was used to analyze the herbaceous vegetation of a prairie-like community in eastern Texas during the growing season of 1978. The northwestern portion of the community had been disturbed in 1965, whereas the southeastern portion was relatively undisturbed. Based on frequency and density, *Iva angustifolia, Anemone caroliniana, Crotonopsis linearis,* and *Krigia occidentalis* dominated the disturbed site while *Bigelowia virgata, Aristida longespica, Schizachyrium scoparium,* and *Crotonopsis linearis* dominated the more natural site.

INTRODUCTION

Although the natural vegetational cover of east Texas is primarily forest, patches of prairie exist. Bray (1906) mentioned that a "piney woods" grassland occurred within longleaf pine forests where the growth of shrubs and trees was prevented by constantly recurring fires. Duvall and Linnartz (1967) later referred to these areas as longleaf pine/bluestem range. There also exist in east Texas other, relatively undisturbed communities that are generally devoid of woody vegetation and thus prairie-like in character. The present study was undertaken to quantitatively describe adjacent disturbed and undisturbed portions of one such herbaceous community.

Soils

Natural, prairie-like openings in the forests of east Texas appear to be a result of edaphic factors associated with the Catahoula Formation, and typically are associated with a very shallow and very slowly permeable upland soil of the Browndell Series (personal communication, Raymond Dolezel, Soil Conservation Service, Nacogdoches, TX). Taxonomically, the Browndell series is a clayey, montmorillonitic, thermic, shallow Albaquic Hapludalf. The soil is saturated for periods up to a month during the cool season of the year; however, it may

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become extremely dry and develop cracks during the late spring and summer.

Climate

The rather mild mesohumid climate of east Texas is characterized by about 122 cm of precipitation that is fairly evenly distributed throughout the year and by an average free air temperature of 18 C with highs that rarely exceed 40 C or lows that seldom fall below -10 C. The growing season averages about 245 days (Carr 1967). Precipitation, during the year of this study (1978), was approximately 30 cm below normal with driest months being March, April, and May.

METHODS AND PROCEDURES

The study was conducted about 27 km southeast of Zavalla, Texas, in northern Jasper County. Braun (1950) places this part of east Texas in the Southern Evergreen Forest region. Tharp (1939), who earlier classified Texas vegetation, designated it as the Longleaf Pine region.

The generally flat study site was approximately 50 × 140 m (0.6 ha) in size and was surrounded by scattered clumps of woody vegetation. These clumps were composed mainly of *Quercus stellata, Forestiera ligustrina, Ilex decidua, Vaccinium arboreum, Crataegus spathulata,* and *C. marshallii.* Mosses and lichens were sometimes abundant on the soil, but small areas of bare ground were also common.

The study area was divided into northwestern and southeastern portions. The southeastern portion (0.4 ha) showed no signs of disturbance. In 1965 the northwestern portion (0.2 ha) had been disturbed by the highway department. The upper 2 to 5 cm of soil was scraped off and used in road construction.

Four transects, each with 15 one-m^2 plots located at regular intervals, were used to sample the herbaceous vegetation. Two transects with plots occurring every other meter were located in the northwestern portion and two transects with plots every four meters were in the southeastern portion to insure adequate coverage of the community. Plots were sampled every two weeks during the growing season of February through October, 1978. Plants were identified and counted as they flowered. Each shoot of rhizomatous plants was treated as an individual plant. Voucher specimens were placed in the Stephen F. Austin State University herbarium. Nomenclature followed that of Correll and Johnston (1970) and Gould (1975).

The plot data were used to determine the frequency, density, and importance value of each herbaceous species. Importance value was defined as the sum of relative frequency and relative density. Impor-

TABLE 1. Physical and chemical properties of the A and B horizons of the soil at the study site.

	Exchangeable cations (ppm)					Distribution (%) of particle size			
Community	pH	Ca	P	K	Mg	sand	silt	clay	Texture
Northwest portion									
A horizon	5.7	650	t[a]	49.8	185	51.6	27.6	20.8	Sandy clay loam
B horizon	5.8	1950	t	58.1	300	28.4	24.8	46.8	Clay
Southeast portion									
A horizon	5.7	650	t	58.1	225	55.6	27.6	16.8	Sandy clay loam
B horizon	5.8	1700	t	62.3	300	31.6	25.6	42.8	Clay

[a] t = trace amounts.

tance value data were used to determine a coefficient of similarity between the northwestern and southeastern portions of the community. The formula used was $C = 2W/A + B$, where W equals the sum of the smaller importance values for species shared by the two portions of the community, A equals the sum of all importance values for the first portion and B equals the sum of all importance values for the second portion (Cox 1980). The Shannon-Weiner diversity index was computed for each portion of the community and for the community as a whole (Shannon and Weaver 1949).

Soil samples collected from the A and B horizons of each portion were analyzed for acidity (pH), Ca, P, K, and Mg by the Stephen F. Austin State University soil testing lab. Particle size and textural classes were determined by the hydrometer method (Bouyoucos 1962).

RESULTS AND DISCUSSION

The thickness of the A horizon ranged from 2 to 5 cm in the southeast and from 10 to 15 cm in the northwest. Texturally, the A horizon was a sandy clay loam with gravel-size pyroclastic particles and incorporated quartz grains (Table 1). Cobbles or stones were occasionally present on the surface. Below the A horizon was the B2t horizon, consisting of an accumulation of translocated silicate clays. This very slowly permeable layer was about 25 cm thick and texturally a clay. Thus, the total depth of the soil was from 35 to 50 cm, which is an extremely shallow soil profile. The pH ranged from 5.7 to 5.8. Amounts of exchangeable calcium and magnesium cations present in the B horizon greatly exceeded those in the A horizon, probably because of leaching. The amount of phosphorous was very low, a condition often encountered in east Texas soils (Nixon et al. 1980; Marietta and Nixon 1983).

TABLE 2. Frequency, density, and importance value data for the herbaceous species in the northwest portion of the study site.

Species	Frequency (%)	Relative frequency (%)	Density (no./plot)	Relative density (%)	Importance value[a]
Iva angustifolia	100.0	5.5	126.53	27.6	33.1
Anemone caroliniana	100.0	5.5	114.00	24.9	30.4
Crotonopsis linearis	100.0	5.5	39.90	8.7	14.2
Krigia occidentalis	70.0	3.8	37.37	8.1	11.9
Evolvulus sericeus	60.0	3.3	30.77	6.7	10.0
Aristida longespica	93.3	5.1	13.73	3.0	8.1
Plantago virginica	73.3	4.0	10.47	2.3	6.3
Callirhoe papaver	90.0	4.9	4.63	1.0	5.9
Lechea tenuifolia	86.7	4.8	4.37	1.0	5.8
Dichanthelium dichotomum	70.0	3.8	2.70	.6	4.4
Others[b]		53.8	73.76	16.1	69.9
Total		100.0	458.23	100.0	200.0

[a] Sum of relative frequency and relative density.

[b] Other species present, listed in order of decreasing importance value, were *Papalum plicatulum, Linum medium, Dichanthelium angustifolium, Hypericum drummondii, Habranthus texana, Rhynchospora globularis, Scleria pauciflora, Saxifraga texana, Nothoscordum bivalve, Phacelia glabra, Schoenolirion texanum, Aristida oligantha, Marshallia caespitosa, Dichanthelium oligosanthes, Krameria lanceolata, Oenothera linifolia, Gratiola flava, Hedeoma hispidum, Tradescantia hirsutiflora, Aster patens, Neptunia lutea, Coreopsis tinctoria, Diodia teres, Sisyrinchium* sp., *Astragalus distortus, Tradescantia ohioensis, Hypoxis hirsuta, Erigeron tenuis, Andropogon virginicus, Aira elegans, Valerianella radiata, Andropogon ternarius, Carex complanata, Gnaphalium purpureum, Vulpia octoflora, Ruellia humilis, Linaria canadensis, Oxalis dillenii, Rumex hastatulus, Eragrostis spectabilis, Polygala mariana, Sabatia campestris, Hedyotis crassifolia, Cyperus globulosus, Carex flaccosperma, Liatris mucronata, Eragrostis hirsuta, Juncus dichotomus, Allium canadense.*

Vegetation of the Northwest Portion

The more recently disturbed northwest portion of the community was dominated by *Iva angustifolia, Anemone caroliniana, Crotonopsis linearis, Krigia occidentalis* and *Evolvulus sericeus* (Table 2). These five species accounted for 76% of the total density and 50% of the importance value; they averaged 349 plants per one-m^2 plot. With the exception of *Evolvulus sericeus,* all were small plants that covered little area and generally did not exceed 25 cm in height.

A total of 59 species was present in this northwestern portion of the community; 37 (63%) of these were perennials. Thirty-nine species flowered in the spring, nine in the summer and 11 in the fall. The Shannon-Weiner diversity index was 3.46, with 59 species and 13,747 plants represented.

TABLE 3. Frequency, density, and importance value data for the herbaceous species in the southeast portion of the study site.

Species	Frequency (%)	Relative frequency (%)	Density (no./plot)	Relative density (%)	Importance value[a]
Bigelowia virgata	60.0	4.6	52.23	38.2	42.8
Aristida longespica	83.3	6.4	12.27	9.0	15.4
Schizachyrium scoparium	86.7	6.7	10.73	7.8	14.5
Crotonopsis linearis	90.0	6.9	9.13	6.7	13.6
Sporobolus silveanus	93.3	7.2	8.17	6.0	13.2
Dichanthelium angustifolium	80.0	6.1	3.20	2.3	8.4
Hypoxis hirsuta	50.0	3.8	4.63	3.4	7.2
Lechea tenuifolia	56.7	4.3	2.50	1.8	6.1
Rhynchospora globularis	56.7	4.3	1.73	1.3	5.6
Anemone caroliniana	26.7	2.1	4.83	3.5	5.6
Others[b]		47.6	27.38	20.0	67.6
Total		100.0	136.80	100.0	200.0

[a] Sum of relative frequency and relative density.

[b] Other species present, listed in order of decreasing importance value, were *Marshallia caespitosa, Krameria lanceolata, Andropogon ternarius, Carex flaccosperma, Aster patens, Scleria pauciflora, Dichanthelium dichotomum, Aristida oligantha, Ruellia humilis, Fimbristylis puberula, Evolvulus sericeus, Nothoscordum bivalve, Iva angustifolia, Krigia occidentalis, Plantago virginica, Paspalum setaceum, Hypericum drummondii, Stylosanthes biflora, Euphorbia corollata, Linum medium, Diodia teres, Sisyrinchium* sp., *Hedyotis crassifolia, Astragalus distortus, Hedyotis nigricans, Neptunia lutea, Allium canadense, Paspalum plicatulum, Helianthemum rosmarinifolium, Juncus dichotomus, Talinum parviflorum, Lechea mucronata, Aristida purpurascens, Tradescantia ohioensis, Polygala mariana, Gnaphalium purpureum, Boltonia diffusa, Oenothera linifolia, Paspalum floridanum, Carex complanata, Saxifraga texana, Asclepias verticillata, Baptisia leucophaea, Luzula bulbosa, Coreopsis tinctoria, Gratiola flava.*

Vegetation of the Southeast Portion

The southeast portion of the community was quite different from the northwest portion, as indicated by a coefficient of similarity of 0.39; however, 38 of the 76 species present were common to both portions. This difference was due in part to the dominance of *Bigelowia virgata* and *Sporobolus silveanus*, neither of which occurred in the northwest portion, and to a greater abundance of perennial bunch grasses (Table 3). Other dominants in the southeast portion were *Aristida longespica, Schizachyrium scoparium* and *Crotonopsis linearis.* Of these five dominant species, the perennial bunch grasses *Schizachyrium scoparium* and *Sporobolus silveanus* were large plants that covered much area for most of the year. *Bigelowia virgata,* a rhizomatous taxon, was present almost the entire growing season. The remaining dominants, *Aristida longespica* and *Crotonopsis linearis,* are small annual species.

A total of 56 species was present in the southeast portion of the community, with 42 species (75%) being perennials. This was a larger percentage of perennials than occurred in the northwest. Of the species present, 32 flowered in the spring, 10 in the summer, and 14 in the fall, a flowering distribution very similar to that of the northwest portion of the community.

There were more bare ground, lichens, and mosses in the southeast portion. This may have been a result of the shallowness of the A horizon in the southeast. Plant density also was less in the southeast portion, with an average of 137 plants per plot as compared to 458 for the northwest. The five dominant species mentioned above had a combined density of 94 plants per plot, or 68% of the total, and made up 48% of the importance value. The diversity index for the southeast portion of the study area was 3.68, with 56 species and 4,104 plants represented. Both portions had about the same number of species, but the northwest area had over three times as many individuals and a slightly smaller diversity index. This is an indication of an earlier successional stage.

Vegetation of the Community as a Whole

A total of 76 herbaceous species, representing 32 families, was recorded in plots of the combined portions of the community during the growing season. An additional 42 herbaceous species were collected outside the plots (Marietta 1979). Large numbers of individuals of several species were present, resulting in an overall average density of 298 plants per one-m^2 plot. This large density was due in part to small, few stemmed species that were abundant in the community for only two to four weeks. Most notable were *Anemone caroliniana, Crotonopsis linearis, Aristida longespica,* and *Krigia occidentalis.* Other prevalent species such as *Evolvulus sericeus, Iva angustifolia,* and *Bigelowia virgata* were present throughout most of the growing season. These seven dominant species (9.2% of the total species) made up 51% of the importance value and 75% of the total density. The remaining 69 species occurred in much smaller numbers, with densities ranging from 0.02 to 4.58 plants per plot and importance values ranging from 0.11 to 4.58.

The importance value did not include a coverage component. Therefore, the true ecological importance of less abundant but large species may have been underestimated. Individual specimens of perennials such as *Kramaria lanceolata, Neptunia lutea,* and *Astragalus distortus* covered up to 0.75 m^2 for periods of about 10 weeks.

Only 15 of the 76 species present in the community persisted through most of the growing season. These were *Iva angustifolia, Bigelowia virgata,* five sedges, and eight perennial grasses. Of the eight grass species, only five covered large areas for the entire year. In order of decreasing estimated cover per plant, they were *Sporobolus silveanus, Paspalum plicatulum, Schizachyrium scoparium, Andropogon ternarius,* and *Andropogon virginicus.*

Of the 76 species, 54 (71%) were perennials and the remaining 22 (29%) were annuals. However, of the top seven dominant species, three were perennials and four were annuals. Forty-four (58%) of these 76 species flowered during the spring, 13 (17%) flowered in the summer, and the remaining 19 (25%) flowered during the fall. The diversity index for the combined community was 4.01, with 17,851 plants represented. The combined index is higher than that for either portion of the community. However, in an open longleaf pine community near this site, a herbaceous diversity index of 4.73 was computed (Marietta 1979).

Successional Status of the Community.

The removal of topsoil from the northwest portion of the prairie-like community undoubtedly initiated secondary plant succession. Five of the northwest portion's 10 dominant species (*Iva angustifolia, Crotonopsis linearis, Krigia occidentalis, Aristida longespica,* and *Plantago virginica*) are annuals as compared to only two of the 10 dominant species on the relatively undisturbed southeast portion. However, 63% of the species in the northwest portion were perennials, indicating that many perennials survived the disturbance or migrated to the site after the disturbance. In comparison, 75% of the species in the southeast portion were perennials.

Warner (1942) listed *Iva angustifolia* and *Plantago* species as early weed-stage indicators of plant succession on post oak soils and the transitional soils between prairies and pinelands. *Aristida* species were more common during late weed and low grass stages. If the northwest portion of our study site is changing to a low grass stage, the conversion process has been slow. Warner (1942) suggests that the low grass stage is succeeded by a tall grass stage dominated by species such as *Andropogon ternarius* and *Schizachyrium scoparium.* These grass species along with *Sporobolus silveanus* were prevalent in the southeast portion of our community. *Crotonopsis linearis,* which was abundant in both portions, is generally considered a component of the tall grass stage (Warner 1942). Because of edaphic factors, it is possible that prairie-like areas typified by the study site will contain a tall grass community indefinitely.

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IMMUNE RESPONSE IN C57BL/6J MICE TO ENTEROBACTERIAL COMMON ANTIGEN ADSORBED ON SHEEP RED BLOOD CELLS

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ABSTRACT

Enterobacterial common antigen (ECA) was passively adsorbed on sheep red blood cells (SRBC). Subsequently, this combination was used as an immunogen in C57BL/6J mice. The immune response was measured by direct hemolytic plaque assays and the formation of rosettes. The immune response to this immunogen combination was greatly increased over that to ECA or SRBC alone. The results suggest a method for the study of the primary immune response to ECA in mice.

INTRODUCTION

Enterobacterial common antigen (ECA) was first described by Kunin (1963). This antigen, which occurs in all members of the Enterobacteriaceae, has been studied intensively as a possible active or passive vaccine for gram-negative infections (Domingue et al. 1970). Gorzynski et al. (1963) demonstrated that with some enterobacterial strains, the antigen must be given subcutaneously to obtain an antibody response. Other strains of the organism are not immunogenic unless injected in particulate form. Immunogenicity of the antigen can be improved by separation of lipopolysaccharide from ECA by ethanol fractionation (Suzuki et al. 1964).

Gorzynski et al. (1970) have shown that mouse strains vary in their responsiveness to ECA. They demonstrated that C57BL/6Ha and CBA/St mice, more than other strains, give a pronounced humoral response to injection of ECA. However, Gorzynski et al. (1970) were unable to obtain high antibody titers. The present study was designed to extend these observations in mice using ECA passively adsorbed to sheep red blood cells (SRBC) to increase ECA's immunogenicity.

MATERIALS AND METHODS

Escherichia coli 0111, 056, and 014 were obtained from B. Davis at the Communicable Disease Center, Atlanta, Georgia. The strains were grown in tryptic soy broth for 24 hours at 37 C. The cells were col-

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lected by centrifugation, washed in phosphate-buffered saline (PBS) at pH 7.2 and lyophilized until used. Heat-killed supernatant (HKS) was produced by heating the cells at 100 C for 1 hour in PBS with subsequent centrifugation of the cell debris at 20,000 rpm for 30 min (Suzuki et al. 1964). The ethanol soluble fraction of *E. coli* 0111 and 056 was produced by addition of ethanol to HKS until the final concentration was 80% (Measel 1978). The mixture was left at room temperature for 24 hours and the precipitate was removed by vacuum filtration. Subsequently, the ethanol was removed by flash evaporation.

Sheep red blood cells (SRBC) were washed in PBS and incubated in a 1:20 dilution of ECA prepared from *E. coli* 0111 or 056 for 1 hour at 37 C. The cells were washed three times in PBS before being used. Proof of the adsorption was obtained by agglutination of the ECA-SRBC conjugates by anti-ECA produced in rabbits (Measel 1978).

C57BL/6J mice and Swiss outbred mice were obtained from Harlan Laboratories, Indianapolis, Indiana, or from our breeding stock. Injections in the form of SRBC coated with ECA were given intravenously (IV) or intraperitoneally (IP) in the amount of 0.1 ml in PBS containing 10^8 cells.

The number of spleen cells producing antibody to ECA was determined by using the slide modification of the hemolytic plaque assay (Mishell and Dutton 1967). Slides were developed for direct plaque forming cells (DPFC) by addition of complement (1:20) in the form of guinea pig serum. The number of rosette forming cells was determined by the method of Biozzi et al. (1967), except that Hanks balanced salt solution was used as the buffer. Cells used in the assay were SRBC or chicken red blood cells coated with ECA prepared from *E. coli* 056 and 0111 or HKS from *E. coli* 014.

RESULTS

Antiserum prepared in rabbits (Measel 1977) showed that ECA could be passively adsorbed to SRBC by simple hemagglutination techniques. ECA prepared from *E. coli* 0111 then was used as in immunogen in two strains of mice (Table 1). ECA alone was ineffective as an immunogen when measured by direct plaque forming cells. SRBC, when given intraperitoneally, gave the predicted response. However, ECA adsorbed to SRBC gave a strong response in both the C57BL and Swiss mice. In order to demonstrate that the increase in direct plaque forming cells was due to the ECA, assays also were done with chicken red blood cells (CRBC), which do not readily cross-react with SRBC. Although the CRBC did cross-react to a small degree, the increase in the response to the ECA-SRBC antigen assayed with CRBC-ECA was due to the ECA. The Swiss mice did not respond as markedly as the

TABLE 1. Frequency of direct plaque forming cells (DPFC) in mice injected intraperitoneally with various antigens.

Mouse Strain	Antigen[a]	Test Cells[b]	DPFC/10^6 Cells[c] Mean ± S.D. (Range)
C57BL/6J	ECA	ECA-SRBC	60 ± 10 (26 − 88)
	ECA-SRBC	ECA-SRBC	580 ± 78 (420 − 710)
	ECA-SRBC	ECA-CRBC	520 ± 12 (400 − 540)
	SRBC	SRBC	350 ± 23 (280 − 390)
	SRBC	CRBC	85 ± 6 (72 − 94)
Swiss	ECA	ECA-SRBC	24 ± 5 (10 − 34)
	ECA-SRBC	ECA-SRBC	410 ± 21 (368 − 450)
	ECA-SRBC	ECA-SRBC	438 ± 22 (400 − 482)
	SRBC	SRBC	340 ± 11 (270 − 370)
	SRBC	CRBC	110 ± 9 (80 − 126)

[a] Mice receiving SRBC or ECA-SRBC received 0.1 ml of 10^8 washed cells in phosphate buffered saline. Mice receiving ECA alone received 0.1 ml of ECA diluted 1:20. ECA was prepared from *E. coli* 0111.

[b] ECA coated red cells used in the analysis were prepared from *E. coli* 056.

[c] DPFC were assayed at day 5. The results are from three experiments, each of which consisted of two mice per group that were tested individually.

C57BL mice. Comparable results were obtained when the assay was performed using SRBC coated with ECA produced from the homologous *E. coli* 0111 or the heat-killed supernatant from *E. coli* 014, using the same protocol as demonstrated in Table 1. C57BL mice responded to intravenous injections at a slightly higher rate (640 DPFC/10^6 cells) when given the 0111 ECA-SRBC antigen and assayed at day 5 with the 056 ECA-SRBC or ECA-CRBC cells. ECA given alone caused lesser response (18-69 DPFC/10^6 cells). Responses to SRBC given alone were in the range of 250-400 DPFC/10^6 cells.

The kinetics of the immune response to injection of ECA adsorbed to SRBC were evaluated. The results are presented in Table 2. The ECA-SRBC rose to the maximum on day 5 post-immunization and slowly declined. The same pattern was seen when SRBC or ECA was injected alone. At all times during the study, the ECA-SRBC combination resulted in a higher response than the SRBC or ECA given alone. The same general pattern could be seen with rosette forming cells. The response began to peak at day 5, reached its maximum at day 7 and declined rapidly after day 9. The response to SRBC alone rose to a peak at day 5 and declined much more rapidly while the response to ECA alone was very weak with a maximum of 2 ^{h} 10^3 rosette forming cells per 10^6 total cells.

DISCUSSION

Other workers have shown that ECA coupled to SRBC is useful for the study of the immune response to ECA (Domingue and Neter 1967).

TABLE 2. Temporal trends in the frequency of direct plaque forming cells (DPFC) and rosette forming cells (RFC) from the spleens of C57BL/6J mice subsequent to immunization with ECA, SRBC and ECA conjugated SRBC[a].

Days Post Immunization	DPFC/10^6 cells in response to[b]:			RFC/10^6 cells in response to[b]:		
	ECA-SRBC[c]	SRBC	ECA	ECA-SRBC[c]	SRBC	ECA
0	0	3	0	400	360	420
1	5	3	3	420	340	380
3	200	150	20	5,000	4,600	600
5	600	300	80	24,000	20,000	1,600
7	400	225	60	26,000	16,000	2,000
9	300	150	40	20,000	9,800	1,800
11	55	35	8	11,500	8,800	1,600

[a] Mice receiving SRBC or ECA-SRBC received 0.1 ml of 10^8 washed cells suspended in phosphate buffered saline. Mice receiving ECA alone received 0.1 ml of ECA diluted 1:20, IP. ECA was prepared from *E. coli* 0111.

[b] The results are a mean of two experiments, each of which consisted of three mice per group that were tested individually. ECA coated SRBC used in the analysis were prepared from *E. coli* 056.

[c] ECA-CRBC were used in the assay at day 5 with the mice having a DPFC average of 660/10^6; whereas, CRBC alone used to assay ECA/SRBC antigen yielded 260 DPFC/10^6 cells. RFC assayed with ECA-CRBC to the antigens ECA-SRBC yielded a count of 22,000/10^6 cells and to CRBC alone, 16,000/10^6 cells.

However, this approach had not been previously explored in mice. Mice respond poorly to ECA injected alone, whereas the injection of SRBC coated with ECA results in a strong immune response and allows the study of ECA as an active vaccine. The fact that C57BL/6J mice responded more markedly was no surprise, since greater sensitivity of this strain to ECA had been reported by Gorzynski et al. (1970). They demonstrated that low antibody titers to ECA could be obtained in C57 and CBA mice, but it was difficult to obtain an immune response in Swiss mice. This was confirmed in my study by the large number of antibody producing plaque cells and rosetting cells expressing surface immunoglobulin obtained in C57BL mice compared to the same results in Swiss mice. Although no attempt was made to study indirect plaques, it is assumed that they would increase in number later in the response sequence (Measel 1977).

It is uncertain if ECA could be used as an immunogen for humans. However, it has been shown that antibodies to ECA can protect rabbits from experimentally produced pyelonephritis (Domingue et al. 1970). These antibodies also increase opsonization of enteric bacteria (Measel 1981). This method does allow the study of ECA in mice as an active vaccine. Further work must be done to elucidate the role of ECA antibodies in protection of the host against invasion by enteric bacteria.

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GROWTH POINTS IN THE SOCIOLOGY OF MATHEMATICS

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ABSTRACT

Sociology's underdeveloped perspective on mathematics does it no credit. Sociologists tend to be more interested in using quantification as a source of legitimation than in confronting mathematics as a central element of culture. Yet mathematics may be viewed as an institution with a normative core developing alongside experience of the physical world, susceptible to both "internalist" and "externalist" programs of investigation. There is a need to examine how the symbolic system of mathematics structures the development of thought and how the acceptance of mathematical ideas is related to their utility. The use of the evolutionary approach has generated some distinctive concepts which can assist cross-cultural work. Smaller-scale studies continue to provide insight into the relation between mathematical theory and social structure.

A NEGLECTED FIELD

The sociology of mathematics is an important but underdeveloped field. That it is important can hardly be doubted, for mathematics is a vast and strategically vital cultural phenomenon in Western industrial societies. Mathematics forms an integral part of the technology underlying industrial organization. The discipline of mathematics is a prominent ingredient of academic curricula, which touches us all directly or indirectly. In some respects the cultural position of mathematical ideas bears comparison with that of religious ideas, although their functions differ. Sociological studies of religion are frequent and familiar enough: why then the relative neglect of mathematics?

The answer is that mathematics and the related field of logic tend to be reified, i.e. they have come to possess the "thing-like" quality of a material object. They appear fixed and inviolable—part of our intellectual environment which we rest upon and take for granted in the deepest sense. Paradoxically, religion—whatever its transcendent and universal claims—is unlikely to be reified in the same way, at least by sociologists. This is because religion varies from one culture (or subculture) to another. If Christianity differs from Buddhism we are at least inclined to ask how and why does it differ and to inquire about

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the differential effects on the social and economic structure. By contrast mathematical and logical ideas appear to differ from society to society only in the extent of their development, not in their essential content; so, those ideas do not seem to invite parallel sociological scrutiny.

Despite this impediment to investigation, perusal of the sociological literature on mathematics reveals that the cupboard is by no means bare, but research work is patchy and its development, in some respects, distorted. What one tends to find are limited "externalist" accounts which typically focus on events at some distance in the past. "Externalist" as opposed to "internalist" accounts are those which seek to analyze the influences on mathematics of ideas and activities which belong outside it (Barnes 1974:99-124). An example is the way in which the idea of perspective among Renaissance artists led to projective geometry (Wilder 1979). In the same context one can note the well known work of Merton (1938, 1968:585-681, 1973) which continues to be a potent influence in the sociology of science. He and other writers (Hessen 1931; Zilsel 1941; Kargon 1966; Needham 1969) have analyzed socio-economic changes implicated in the phenomenon of the "Scientific Revolution"—that period from Copernicus to Newton which was marked by the mathematization of science (and in mathematics especially by the introduction of coordinate geometry and calculus).

Sociological work relating to mathematical developments of more recent periods is substantially lacking and few even of the externalist sociological accounts have been forthcoming. It is as though mathematics since the time of Newton is seen as a subject developing simply on the basis of its own "internal logic"—perhaps with some additional promptings from physics. The subject is not simply reified but also its vast scope and abstract technical nature contribute to its overwhelming character. As religion becomes demystified—at any rate to sociologists—mathematics becomes mystifying. Most sociologists have responded by turning to the more secure discipline of mathematics for support rather than making that cultural phenomenon an object of sociological scrutiny. Quantification has become both a methodology *and* a source of legitimation, a phenomenon to which the pages of the *American Sociological Review* bear voluble though not eloquent witness.

REALISM AND RELATIVISM

How can one make progress from this unsatisfactory position and expose mathematics to deeper sociological inquiry? Apparently the most direct route is to attempt to de-reify the subject, and one or two braver souls have chosen this course. Bloor (1973), for instance, has made use of Wittgenstein's (1956) ideas to develop a distinctive sociological perspective. Bloor found fault with the "realist" view of mathematics, in which mathematical and logical forms are seen as being "like material objects in the sense that they are set over and against the knowing subject who moves (in thought) amongst and through them." Instead, he followed Wittgenstein in stressing the centrality of the essentially social process of rule-following involved in basic mathematical operations such as counting and using formulae. Wittgenstein (1955:v-46) asserted that "mathematics forms a network of norms." Bloor (1973) judged that Wittgenstein had been "proposing a non-realist theory of the objectivity of mathematics" and concluded that mathematics may be appropriately viewed as an institution with no part excluded from sociology scrutiny. (For Wittgenstein's position, see also Phillips 1977:119-141.)

Elsewhere Bloor (1976) elaborated further his conception of the sociology of knowledge and sought to demonstrate its applicability to mathematics. He characterized his approach to that subject as "naturalistic", for he developed a sociologically extended version (Bloor 1976:74-94) of J. S. Mill's empiricist account. Mill (1856) essentially viewed mathematics as a collection of beliefs—or mental events—concerned with the physical world and arising from experience of it. Bloor sees this as a useful starting point, but he is critical of Mill for ignoring the objectivity of mathematical ideas (a feature stressed particularly by Frege 1959). However, Bloor (1976:87) builds on Mill by introducing objectivity in the form of institutionalized belief. In addition, Bloor (1976:87-92) employs the notions of model and metaphor to account for the wide range of application of mathematical ideas.

Bloor (1976) proceeds to identify a striking contrast amongst those who have approached mathematics sociologically. If mathematical activity and its normative structure simply form an institution, then one may expect that varying forms of mathematics will be observable in different cultures. Alternatively, if what Bloor characterizes as the "realist" view is adopted, then a single version of mathematics will be found everywhere, although no doubt there will be variations in the extent of its development. So, a sort of test of opposing views can be constructed by determining whether or not there are "alternative" mathematics. Bloor (1976:95-116) firmly believes there are, and he points to instances such as the "arithmetic" (or what we characterize as algebra) of the Alexandrian Diophantus, in which there are some (to us) strange concepts and processes.

Despite the suggestiveness of his ideas it is necessary to take issue with Bloor's relativist position. In order to decide whether or not there are alternative mathematics one needs to have a clear conception of what "a mathematics" is—in a way which goes beyond the experience of Western mathematics itself. Since such a definition is lacking, the quest for alternatives is misguided. In connection with this issue one may reasonably inquire what might be meant if it is suggested (for instance) that $2 + 2 = 5$. Short of saying that one or more of the symbols involved in this statement is being used in an unfamiliar way, one would simply conclude that it is false and has no place in mathematics. This is in no way to deny that the history of mathematics has been marked by conceptual variation, a phenomenon which is a fit subject for sociological analysis. In fairness to Wittgenstein it should also be pointed out that from his notes on mathematics he may be taken to be critical of *both* the relativist and anti-relativist positions.

SYMBOLIC SYSTEMS

The sociologist must focus not only on the essential character of mathematics but also on methods of numeration, for in this discipline there is a symbiotic relation between particular designations and that which is designated. The classification of number words and symbols is particularly well advanced (Menninger 1969), and it has proved possible to analyze many practical, social and scientific implications. However, a basic unsolved problem concerns the specification of the social circumstances in which particular kinds of numeration become institutionalized.

Within number systems the more important types of variation include the use of a particular base, the presence or absence of a symbol for zero, the employment of positional notation ("place value") and the means of fractional representation (Resnikoff and Wells 1973:Chapter 1). Different systems have their relative strengths and weaknesses. For instance, the Babylonian scheme possessed the advantages of positional notation but allowed ambiguities owing to the lack of a symbol used consistently to indicate the absence of a number (Kline 1972:5-7; Resnikoff and Wells 1973:23), while the Ancient Egyptian system used the base ten but was not positional (Struik 1967:20-25; Kline 1972:16-18; Gillings 1972:20-23). The contemporaneous Chinese (Shang) numeral system had the capacity to express any desired number, however large, with no more than nine numerals, and Needham (1959:5-15) judges that it provided a more positive influence on scientific development than those of Babylonia and Egypt. In each of the ancient civilizations the number system had structural implications for numerology (Needham 1956a), mysticism (Kline 1972:13) and astrology.

Classical Greek mathematics was marked by the existence of a close connection between the stratification of people and types of knowledge. The distinction emphasized was that between calculation used for practical purposes in the marketplace (logistika) and the intellectual contemplation of numbers (arithmetica), a dichotomy corresponding to the social division between those in commerce and the "lovers of wisdom" (philosophers). Numerations which were employed for practical purposes made extensive use of letters of the alphabet (Menninger 1969:262-263; Kline 1972:131-134), and in the Alexandrian period whole numbers appear to have been written to a decimal base but without positional notation and with limited use of a symbol for zero (Kline 1972:132-133).

Since the Ancient Greek period mathematicians have successively modified (or extended) the number concept. These extensions have been accompanied by disputes about whether particular types of numbers can properly be said to exist, e.g. irrational numbers, the number zero, negative numbers, complex numbers, and infinity (Nagel 1935). These controversies are important to the sociologist for the light which they shed on prevailing ontologies and cosmologies, but it must also be asserted that it is the way in which numbers are represented and hence used which is most closely related to their acceptance. Sometimes the use is to be considered as internal to mathematics itself, sometimes external in the sense indicated above. For instance, the Greek stress on abstract truth and the playing down of the commercial utility of mathematics helped to produce the pure geometrical emphasis for which Euclid is renowned, together with the failure to conceptualize the irrational number. Later the Hindus, who were more oriented to practical and commercial concerns, began to operate with the latter type of quantity and also introduced negative numbers, probably through their usefulness in representing debits as opposed to assets.

In this short account of symbolic usages it must be stressed that one is fundamentally concerned with a system of manipulating numbers, operating with them and so on, mathematical development being structured by the elaboration of symbolism which assists this process. For example, the transition from arithmetic to algebra required distinction of particular expressions and formulae from entire classes of expressions and formulae. Of considerable importance in this connection was the use of literal coefficients in forms and equations, an innovation dating from the Sixteenth Century (Kline 1972:259-263). In the further development of generalizing power—perhaps the essence of mathematics—were the two basic but also polar ideas of "variable" and "function"—notions which were clarified only in the Nineteenth Century. There also have emerged such generalizing procedures as mathematical induction and the duality principle, which either confirm or generate results while also providing insight.

It has been much emphasized that in the early development of calculus, symbolic usages were employed which now would be forbidden. However, advances were made despite an absence of rigor (Boyer 1959:169), and sometimes it has been claimed that this reflects a different value system from that evident in modern mathematics. Yet, the latter assertion is doubtful since so many Eighteenth Century mathematicians expressed dissatisfaction with a lack of rigor and/or strove (albeit unsuccessfully) to supply the missing element. Whether or not values have been relatively stable, what is undeniable is that the history of mathematics has been marked by periods of creative (if somewhat insecure) innovation and subsequent consolidation.

EVOLUTIONISM

In the sphere of symbolism—as elsewhere within mathematics—there is a strong tendency to think in terms of a progression starting with the Classical Greek period. Certainly from that time on, mathematics acquired a persistent cumulative character. This has led several authors—notably Wilder (1974) and Fang and Takayama (1975)—to adopt the evolutionary perspective, and it is important to evaluate the success of an approach which is familiar from its use elsewhere in sociology.

Wilder (1974) holds the refreshing view that not only the researches of anthropologists on early mathematics, but also the conceptual categories and theories of anthropology itself, can be of great assistance to historians and sociologists of mathematics. He maintains that mathematics is a human artifact evident in many cultures in which pragmatic rather than idealistic criteria of acceptability prevail. In a central section of his book, Wilder (1974) sets out eleven "forces of mathematical evolution" (1974:163) and ten "laws governing the evolution of mathematical concepts" (1974:199-201). Wilder's eleven forces are environmental and hereditary stress, symbolization, diffusion, abstraction, generalization, consolidation, diversification, cultural lag and resistance, and selection. Many of these concepts were introduced by anthropologists but an exception seems to be his own notion of "hereditary stress"—or tension between ideas within mathematics itself—which he puts to effective use in analyzing such phenomena as the reaction of the Pythagoreans to the possibility of incommensurables.

One problem in connection with Wilder's (overambitiously labelled) "laws" is whether to evaluate their significance in descriptive or explanatory terms (Crowe 1978). There are difficulties with the latter view since in many of his illustrations that which is doing the "explaining" is not identifiable independently of that which is explained. However, if the emphasis is on description, then the account is enlightening; e.g., Wilder's law 4 links the intriguing phenomenon of simultaneous multiple discovery in mathematics to systematic changes in the conceptual structure of a theory. Law 6 is similarly suggestive, for it seeks to point up the impetus given to mathematical innovations by developing social institutions (e.g. art). However, Wilder does take his emphasis on pragmatic criteria of acceptability in mathematics too far, for he refers to but does not systematically incorporate aesthetic considerations among mathematicians and he neglects to analyze changing perceptions of mathematical truth (Richards 1980).

In their turn, Fang and Takayama (1975) formulate a theory applying to the sciences which is one of sociocultural evolution, based upon innovation (via invention, discovery, alteration and diffusion), continuation (via socialization) and extinction. Fang and Takayama (1975:127) claim that evolution raises "the upper level of societal potentiality." They stress that elements of both solidarity and conflict are involved in change and the basic idea of evolution is refined with the useful distinction between "local" and "global" developments which operates at both a conceptual and an institutional level (1975:136-146). In a way which is suggested by a consideration of Wilder's (1974) work, the theory in its explicitly stated form seems in need of supplementation from structuralist ideas, but these are referenced (Fang and Takayama 1975:137) without being systematically incorporated.

Fang and Takayama (1975) illustrate their theory with strategically important examples: Classical Greece, seen as the birthplace of the exact science; a critical phase in the development of Japanese mathematics; and striking innovations in Western mathematics (particularly the introduction of non-Euclidean geometries). In considering Greek mathematics, Fang and Takayama (1975) make considerable use of the theme of rationalization. An original phase of rationalization is viewed as concurrent with "a latent state of equalization" and "the initial stage of mathematization" (1975:152). Part of the argument consists of saying that cerain politico-legal developments and economic innovations were accompanied by equalization (and presumably individuation) of citizens. The process of equalization must be considered in conjunction with the existence of certain values, such as emphasis on abstract intellectual ability and a public conscience. These were manifested in debate in the market-place, the social role of groups such as the sophists and the emergence, implicit and later explicit, of rules of inference expressed in logic and also in geometry (cf. Szabo 1967). Geometry was favored because it lent itself to axiomatic deductive formulation, thus supplying the truth or "certainty" sought by Greek philosophers.

This attempt to develop concepts which can assist the analysis of an emergent rational viewpoint is certainly worth pursuing and suggestive of further comparative work (see also Richter 1973:62-85). One such possibility is implied by Fang and Takayama (1975) themselves, for they contrast Weber's (1951:151) claim that in China there was "no rational science, no rational practice of art, . . . natural science or technology" with Needham's work (1954, 1956a, 1959) and conclude that Weber's view at least partially has been refuted. The need to investigate the conceptual and institutional basis of Chinese mathematics—partly to assist further comparison with the Greek system—seems pressing. However, more attention must be paid to the different senses in which Weber (1951) used his key notion than is given by Fang and Takayama (1975). In particular a rational or axiomatic system of concepts (as in Euclid) must be sharply distinguished from the rational employment of mathematics in the pursuit of practical ends and in empirical studies (in which the Chinese engaged).

The approach of Wilder (1974) and Fang and Takayama (1975) may be characterized as historical analysis on the grand scale. For the sociology of mathematics to prosper there is a need for this type of study (the conclusions of which may be difficult to verify) to be complemented by micro-studies of groups of mathematicians. Particularly effective in the latter connection is the work of C. S. Fisher (1966, 1967, 1973).

MATHEMATICS AND SOCIAL STRUCTURE

Focusing on some late Nineteenth Century mathematical work, Fisher (1966) has provided an analysis of "the death of a mathematical theory." His concern was for the virtual disappearance of the "Theory of Invariants", a theory which he viewed—surely correctly—as "a social category within the world of mathematics" (Fisher 1967).

Among algebraists this theory was believed to have been effectively superseded by work of the German mathematician Hilbert in 1893, but Fisher considers that Hilbert's paper took on symbolic meaning after the event and assumed the status of an explanation for the theory's demise (Fisher 1966). Fisher provides evidence that, in fact, the beginnings of the theory's decline occurred earlier and are mainly to be accounted for by various structural factors which are necessary conditions for the maintenance and transmission of a theory. He directs attention towards "the general *environment* in which the mathematics is done, the specialists' *commitment* to the theory, their relationship to their *students*, and the *places* in which they worked" (Fisher 1967;

italics in original). He affirms that a speciality is practised in different institutional contexts and its fate becomes linked to the social conditions of the scholars working in those settings. Fisher analyzes, for instance, the situation in Great Britain where the theory originated and points out that there were no schools of mathematical thought, owing to exceptionally unhelpful conditions in the universities. On the other hand in the United States a productive school of invariant theory developed at the University of Chicago, but when graduate students left, they found little encouragement in other institutions towards research. Fisher reckons that Invariant Theory could arise again, and in general he ascribes its decline and subsequent dormant condition to social factors.

Some later writers (e.g. Fang and Takayama 1975:226-233) have contested the details of Fisher's account, but its central importance is that it seeks to highlight such factors as the consequences of the way in which mathematicians are grouped, patterns of communication and—at any rate implicitly—the way power is exercised (e.g. by eminent mathematicians over their research students). In short one can say Fisher attempts to relate mathematical theory and social structure. The work of Bloor is also germane to the same theme. For as part of his general thesis that logic and mathematical inference can be grasped sociologically, he argues that theories and proofs—and therefore presumably also the demise of theories—are frequently arrived at by "processes of negotiation" among mathematicians (Bloor 1976:117-140). He illustrates by reference to Lakatos' (1963-64) analysis of the protracted debate over Euler's formula for polyhedra, which can be taken to show that the interaction between mathematicians is directly related to the successive modifications in the formulation of a result and its changing theoretical status.

My own studies have sought to analyze recent sociological microstructures among academicians in the U.K. and U.S.A. With particular reference to the disciplines of mathematics, civil engineering, psychology and classics, I have examined patterns in the role performance of university professors, how they evaluate their jobs and what students expect of them (Startup 1972, 1976, 1979a, 1979b). With respect to research activity in departments in both countries one can show that while civil engineering tends to produce social solidarity in the form of an elaborate departmental division of labor and psychology facilitates a fluid pattern of research relationships, mathematics generates a modified tree structure with low researcher mobility and poor communication between subfields (Startup 1979a:66-75; cf. Hargens 1975). This kind of evidence suggests that the structure of the discipline—and for a scientific subject, especially its theoretical structure—is interdependent with the social processes involved in the production and communication of disciplinary ideas.

Most recently I have sought to examine this particular relation *within* mathematics, taking into account both the research and teaching spheres. With respect to teaching, the following example serves: In the mathematics department of a U.S. university there was controversy concerning the most effective way of training research mathematicians. Limited use had been made of the teaching method of the mathematician R.L. Moore (Moise 1965; Whyburn 1970), a method which is axiomatic (Wilder 1967) while placing little or no reliance on books. Instead, the instructor challenges students on an individual basis by presenting them with problems and statements of possible theorems (perhaps numbered in order of increasing difficulty) for evaluation and, where appropriate, solution. The method involves the inculcation of self-reliance, competitiveness and pleasure in creative endeavor. Nevertheless, the experience with the method had been mixed. Significantly, most of the favorable experience with the method had been in topology, a field characterized by relative narrowness and a short "past." In specialized areas of historically more developed fields such as algebra the use of the method tended to frustrate the instructor, for student progress was too slow. In summary, the utility of a particular kind of pedagogical relationship varied between fields of mathematics.

CONCLUSION

The relatively underdeveloped state of sociological work on mathematics does no credit to sociology. It seems that some sociologists are rather more interested in quantification as a source of legitimation for their own discipline than they are in seriously confronting mathematics as a central element of modern culture. Perhaps they are also overwhelmed by the vast edifice of mathematics—certified as objective truth—and made to feel that only limited "externalist" programs of investigation are possible.

The directness of Bloor's (1973, 1976) approach, with a perspective derived from the sociology of knowledge, presents a refreshing contrast. That author develops a view of mathematics as an institution developing alongside experience of the physical world, no part of which is withdrawn from sociological analysis. However, it may be judged that Bloor does go astray in respect to his articulation of a relativist position. The quest for "alternative mathematics" is undirected in the absence of a conception of mathematics which goes beyond that evident in the experience of Western mathematics itself. This is in no way to deny the usefulness of exploring the ontological and cosmological perspectives within a culture from which mathematics is viewed (Richards 1980; Restivo in press) and the extensive conceptual variation within the discipline.

The essential feature of mathematics is that it constitutes a system at both a formal symbolic and conceptual level possessing immense generalizing power. Certain elements which have received comparative analysis are purely conventional, e.g. the base of a number system. In proceeding there is a need to examine the connection between the general acceptance of mathematical ideas—for example "imaginary" numbers—and their utility. Putnam (1975) has gone so far as to state that the criterion of truth in mathematics is the success of its ideas in practice. However, that issue cannot be decided exclusively on *a priori* grounds and therefore can form a focal point for sociological analysis.

Judging from the work of Wilder (1974) and Fang and Takayama (1975), the evolutionary approach has considerable life left in it, although these accounts are probably better construed as descriptive rather than explanatory in function. For the skeptic it may be worth emphasizing the usefulness of some of the concepts employed: by Wilder, for instance, in examining tensions within and between systems of ideas, and by Fang and Takayama in the analysis of an emergent rational viewpoint. Additional impetus may be provided to comparative work encompassing preliterate societies but also—particularly promising—China (Needham 1956b) and Japan (Shimodaira 1972).

The smaller scale studies of Fisher (1966, 1967, 1973), which analyze environment, group-life and patterns of communication, are fundamentally concerned with the relation between mathematical theory and social structure. A still more general focus of empirical work is provided by the idea that the theoretical structure of mathematics—and one might add the inherent difficulty of its organizing concepts (e.g. differential ratio and real number)—is interdependent with the social processes involved in the production and communication of disciplinary ideas. An illustration is provided by the way in which particular fields of mathematics lend themselves to a special type of pedagogical relationship. A topical way of developing this theme even further is provided by the investigation of the impact of new technologies, e.g. the effect of electronic calculators on the teaching of arithmetic and the advent of computer-assisted proofs (De Millo et al. 1980).

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LAND SNAILS (GASTROPODA: PULMONATA) FROM CIMARRON COUNTY, OKLAHOMA

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ABSTRACT

Sixteen species of land snails are reported from a survey of 40 localities in Cimarron County, northwesternmost Oklahoma. Some aspects of distribution are discussed. A role of the broken country of northern Cimarron County as a past or present "bridge" between eastern and western populations of some species is suggested.

INTRODUCTION

Cimarron County, Oklahoma, is located at the western end of the state's northwestern extension, commonly known as the Panhandle. The county is bounded by the states of Colorado, Kansas, New Mexico and Texas. It lies between latitudes 36° 30′ and 37° N and longitudes 102° 02′ and 103° W. Elevation ranges from about 1097 m (3600 ft) on the eastern border to 1516 m (4973 ft) atop Black Mesa near the Oklahoma/New Mexico boundary.

Physiographically, most of the county lies within the High Plains Section of Fenneman (1931:11). However, the northwestern part is an extension of the Raton Section of adjacent northeastern New Mexico (Fenneman 1931:37). The northern part of the county is drained by the Cimarron River. The southern and eastern parts are in the drainage of the North Canadian River, which in Cimarron County is commonly known as Beaver River (Webb 1970:43). Large areas of the High Plains have only internal drainage.

Rocks in Cimarron County range in age from Triassic to Quaternary (Schoff 1943). The High Plains Section of the county is underlain by the Ogallala Formation of Pliocene age. In the Raton Section Mesozoic strata are extensively exposed. Of these, the Dakota and Cheyenne Sandstones, of Cretaceous age, are especially prominent, the former producing the rim of escarpments in many places and the latter occurring on slopes below. Black Mesa, in the extreme northwestern part of the county, is capped by the extrusive Raton Basalt, judged to be of Pliocene age by Baldwin and Muehlberger (1959:Fig. 13). The

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basalt overlies the Dakota Sandstone and other Cretaceous strata, which are exposed below it in scarps bounding the mesa.

The climate of Cimarron County is semi-arid, with annual precipitation averaging 400-500 mm (16-20 in). Droughts may be severe, as in the infamous drought of the 1930's.

Attempts at paleoecological analysis of mollusks taken in archeological contexts suggested a need for more precise information concerning the present fauna of the county. Knowledge of land snail distribution in both the High Plains and Raton sections is scant. It seemed that Cimarron County, which incorporates both sections and one of the few stream valleys (Cimarron) to cross the High Plains, might be in a key location zoogeographically.

SNAIL HABITATS AND SAMPLING METHODS

The habitats that yielded terrestrial gastropods were of only three types—wooded floodplains; bluffs, hillslopes and canyon walls; and marshy areas associated with springs.

Wooded floodplains occurred along the Cimarron and Beaver rivers and the lower parts of their major tributaries. In such habitats dominant trees were plains cottonwood (*Populus sargentii*) and black willow (*Salix nigra*). Snails were taken in decaying wood and in leaf litter, mainly under and alongside logs.

Bluffs, hillslopes and canyon walls yielded snails from the leaf litter beneath shrubs. The sumac, *Rhus aromatica*, was the chief producer of such litter. In the northwestern and northern parts of the county, bluffs usually were capped with the resistant Dakota Sandstone, with the Kiowa Shale and Cheyenne Sandstone often exposed below it, on slopes. Collections usually were made in or just below the area of outcrop of the Dakota Sandstone where shrubs and small trees grew. Three collections were made in areas of basaltic talus below the rim of Black Mesa. Scarps formed on the Ogallala Formation along Beaver River and Aqua Fria and Corrumpa creeks were low, with resistant limestone forming a caprock.

Search was made for springs with associated marshy areas supporting lush, paludal vegetation that might harbor snails. Negro Spring on the north slope of Black Mesa, near the New Mexico border, sustained a small area of marsh-associated rushes, sedges and tall grasses. Most other springs visited were in pastures where vegetation had been closely grazed to the water's edge by livestock. Schoff (1943) reported a number of springs in the county. The two springs with greatest outflow reported by him (his numbers 484 and 498, with discharges of about 190 and 230 liters per minute, respectively) were visited but they were greatly diminished in flow and no land snails were found around them. Springs reported by Schoff within the (ungrazed) confines of the state park around Lake Carl Etling were dry or had only very slight flow and supported no marshy areas. It seems likely that the amount of marshy habitat associated with springs was much greater in the last century, before settlement of the county.

Most of the great expanse of High Plains atop the Ogallala Formation is cultivated. Snails were not sought there. Drift inspected from along Goff Creek, which drains such an area in the eastern part of the county, revealed no shells of snails, suggesting their absence or extreme rarity in the watershed. An area of sand dunes in the extreme northeastern part of the county was also unproductive. It is likely that a few exotic species may occur in lawns of Boise City, the only urban area of consequence. Search for these was not made.

The survey was conducted in 1982 and 1983. In floodplain habitats, hand-picking of specimens was employed in an effort to eliminate drift specimens that are common on floodplains. At other localities, 1-2 kg of leaf litter were collected in bags and later sorted, sifted and inspected in the laboratory.

All specimens ultimately were deposited in the invertebrate collections of the Department of Biological Sciences, University of Texas at El Paso.

LOCALITIES OF COLLECTIONS

All localities are in Cimarron County, Oklahoma, and are listed west to east and north to south. Abbreviations: Cn. = Canyon; Fm. = Formation; Ss. = Sandstone.

1. NW¼, SW¼, SW¼, S31, T6N, R1E. Environs of Negro Spring on N slope of Black Mesa.
2. SW¼, SW¼, SW¼, S31, T6N, R1E. Basaltic talus below N rim of Black Mesa in canyon above Negro Spring.
3. SW¼, SW¼, NW¼, S18, T5N, R1E. Wooded floodplain of Carrizozo Cr., 3.3 km W of center of Kenton.
4. SW¼, SW¼, SE¼, S8, T6N, R1E. Wooded floodplain of N Carrizo Cr., 0.35 km S of Colorado state boundary.
5. NW¼, NW¼, SW¼, S33, T6N, R1E. Basaltic talus below S rim of Black Mesa.
6. NW¼, SW¼, NW¼, S28, T6N, R1E. Bluffs immediately S of N Carrizo Cr., among blocks of Exeter Ss.
7. NW¼, SW¼, SE¼, S28, T6N, R1E. Basaltic talus below N rim of Black Mesa.
8. SW¼, NW¼, SW¼, S34, T6N, R1E. Wooded floodplain of Cimarron R., between road at base of Black Mesa and river.
9. NW¼, NW¼, SE¼, S10, T1N, R1E. Scarp in Dakota Ss. in S valley wall of Cienequilla Cr.
10. SW¼, NE¼, NE¼, S15, T5N, R1E. Area N of Kenton-Boise City Highway at "101 Pass," 2.6 km E of center of Kenton. Hillslope from base of Dakota Ss. downward into outcrop of Cheyenne Ss.
11. SE¼, SW¼, NW¼, S23, T2N, R1E. Wooded floodplain of Beaver R.

12. Center, NE¼, NE¼, S35, T2N, R1E. Floodplain of small creek between low hills formed on Dakota Ss.
13. SW¼, NE¼, SW¼, S18, T5N, R2E. N-facing hillslope from below Dakota Ss. down through Cheyenne Ss.; S of Kenton-Boise City Highway at "101 Hill."
14. NE¼, NE¼, NW¼, S6, T4N, R2E. Rocky canyon slopes (Cretaceous Ss.) along road W of "Youth Camp" on W side of Lake Carl Etling in Black Mesa State Park.
15. SW¼, SW¼, SE¼, S32, T5N, R2E. Floodplain of S Carrizo Cr., immediately below dam of Lake Carl Etling.
16. SW¼, SE¼, SE¼, S9, T6N, R2E. E-facing slope of bluff from base of Dakota Ss. down through Cheyenne Ss.; 0.4 km S of Colorado state boundary.
17. NW¼, SW¼, SW¼, S11, T5N, R2E. Wooded floodplain of Cimarron R., S of river and E of N-S road.
18. SE¼, SE¼, NE¼, S13, T1N, R2E. Low bluff in Ogallala Fm., on S side of Aqua Fria Cr., 1.3 km SSE of center of Felt.
19. NE¼, SE¼, SE¼, S28, T6N, R3E. N-facing slope below Dakota Ss. and S of E-W road.
20. NE¼, NW¼, NE¼, S27, T6N, R3E. Below Dakota Ss. on N slope of isolated hill immediately SW of creek in Red Cn. and of road that descends long hill here, NW to SE.
21. NE¼, NE¼, S24, T2N, R3E. Low bluff immediately S of Beaver R. on NW side of U.S. Highway 56/64.
22. NE¼, SE¼, NW¼, S7, T5N, R4E. Slopes of steep canyon below Dakota Ss.; along ranch road, 1.05 km S of Cimarron R.
23. NW¼, NE¼, SE¼, S18, T6N, R4E. Bluffs in Dakota Ss. along an upper, eastern branch of Squaw Cn., S of E-W road; 1 km S of Colorado state boundary.
24. SE¼, NW¼, NW¼, S29, T5N, R4E. Woods along springbrook NW of ranch home of R.C. Vincent.
25. NE¼, SE¼, NE¼, S17, T5N, R4E. From under stones alongside outflow of small spring on E-facing hillside near old stone corrals.
26. NW¼, NW¼, SW¼, S28, T5N, R4E. Slope below Dakota Ss. on N-facing bluff S of creek and E-W road.
27. SW¼, SE¼, NW¼, S34, T6N, R4E. Bluffs in Cretaceous Ss. along small creek and on both sides of NW-SE road.
28. SW¼, SE¼, SW¼, S2, T5N, R4E. S-facing bluff, from below Dakota Ss. down to Cheyenne Ss., immediately N of E-W road and 0.35 km N of Cimarron R.
29. E½, NW¼, SE¼, S25, T6N, R4E. On hillslope along and below outcrop of Dakota Ss., 1.4 km NW of Razor Blade Mesa.
30. SE¼, SW¼, SE¼, S36, T6N, R4E. SE-facing hillslope with outcrop of Cheyenne Ss.; 1.4 km SW of Razor Blade Mesa.
31. NE¼, NW¼, SE¼, S18, T5N, R5E. N slope of W part of Sugarloaf Mt., below rimrock of Dakota Ss.
32. NE¼, NE¼, NE¼, S7, T2N, R5E. Wooded floodplain of Beaver R., N of river and W of U.S. Hwy. 385.
33. NW¼, NE¼, NE¼, S9, T5N, R5E. Floodplain of Cimarron R., 0.25 km N of river and on E side of U.S. Highway 287/385.
34. SE¼, NE¼, SE¼, S4, T2N, R5E. Bluffs in Ogallala Fm., on N side of Beaver R.; immediately W of Boise City trash dump.
35. NW¼, SW¼, NW¼, S3, T5N, R6E. Wooded floodplain of Cimarron R., S of river and 0.4-0.5 km N of Burnett Ranch buildings.
36. NE¼, NW¼, SW¼, S3, T5N, R6E. Bluffs in strata of Dockum Group, 0.1 km E of Burnett Ranch buildings.

37. NW¼, NW¼, NE¼, S22, T2N, R6E. Scarp in Ogallala Fm., along N valley wall of Beaver R.; S of U.S. Hwy. 287 and opposite a roadside park.
38. SW¼, NW¼, SW¼, S24, T2N, R6E. Scarp in Ogallala Fm., in NE valley wall of Beaver R.; SW of U.S. Highway 287.
39. NE¼, SW¼, SE¼, S13, T6N, R7E. Wooded floodplain of Cimarron R., W of river; N of E-W road and 1.25 km S of Colorado state boundary.
40. SE¼, SE¼, NE¼, S13, T1N, R7E. Scarp in Ogallala Fm., S of small arroyo on W side of N-S road and 2 km S of bridge over Beaver R.

ANNOTATED LIST OF SPECIES

Land snails collected in the present survey (Table 1) are discussed in this section; some earlier records are discussed thereafter. All snails reported belong to the Order Pulmonata. Families are listed in the phylogenetic sequence of Solem (1978) and genera and species are listed alphabetically within families. Members of each genus are discussed together.

PUPILLIDAE

1. *Gastrocopta armifera* (Say)
2. *Gastrocopta cristata* (Pilsbry and Vanatta)
3. *Gastrocopta holzingeri* (Sterki)
4. *Gastrocopta pellucida* (Pfeiffer)
5. *Gastrocopta procera* (Gould)

In Cimarron County, *Gastrocopta armifera, G. cristata* and *G. holzingeri* were found mainly along rivers and creeks in riparian woods. Most collections of these species were made on the floodplain of the Cimarron River. However, at locality 12 *G. armifera* and *G. holzingeri* occurred under shrubs along the narrow floodplain of a small upland creek and at locality 25 *G. cristata* was found under stones alongside a small upland spring. In riparian habitats *G. armifera* and *G. holzingeri* range westward to the foothills of the Sangre de Cristo Mountains. Several collections indicate that populations of *G. armifera* extend eastward along the Cimarron River floodplain into Kansas and north-central Oklahoma, where it becomes a common and widespread species. It may, at present, breach the southern High Plains only along the Cimarron River. The situation with *G. holzingeri* is similar. There may be, however, a hiatus in the distribution of the latter species from western Cimarron County eastward to about the longitude of Meade County, Kansas, where it was reported by Leonard (1959:Fig. 74). Unlike the above species, *G. pellucida* and *G. procera* were widespread in both riparian and upland habitats. Of the two, *G. pellucida* seems more tolerant of xeric conditions. It is able to exist at lower elevations of the Chihuahuan

TABLE 1. Numbers of specimens of land snails taken at 40 localities in Cimarron County, Oklahoma. Localities (see text) are listed west to east and north to south.

	Locality																		
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Gastrocopta armifera				20		62		4				2					11		
Gastrocopta cristata								4			1						11		
Gastrocopta holzingeri			1			57		3				4							
Gastrocopta pellucida	20	4			122		17	9	1	40			21	68					
Gastrocopta procera	19	9	4			4	4	36	1		1	9	1	21			1	2	
Pupilla muscorum	108	23				32	2												
Pupoides albilabris	2	1	1		2	15	3	7				1	2	14			1	4	
Pupoides inornatus						3													
Vallonia gracilicosta	714	973	50	123	346	35	978	78	171	387	92	369	41	275		135	118		58
Vallonia parvula			19	1		111		30			3	54							
Helicodiscus parallelus	9	1		1	2	2	5	12	1	39				11		1			
Helicodiscus singleyanus	2	3	4				4	18						1					
Succineidae	3				2	1	9	2		1	2		1	6	4	1		3	1
Hawaiia minuscula	12	7	4	2	3	2	4	6		36	1	4	1	3		1	8	1	2
Zonitoides arboreus	2	8	4	16		4	2	36											
Deroceras laeve	3							1							4				

	Locality (continued)																				
Species	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
G. armifera														68		66				34	
G. cristata						1								25		10	6			30	
G. holzingeri																					
G. pellucida	5		69	2	2		6	33	14	22	3	4			1	2		12	5		
G. procera	1			2	3			5	1	2			4	8		9	10		10	1	
P. muscorum																					
P. albilabris			2	3	2			2	2	2		1	4	3	6	4	1	3	3	14	7
P. inornatus																					
V. gracilicosta	213	22	315	28	78		243	251	27			73		87	68	54	182			22	
V. parvula	4			32	9			109								3			69	15	
H. parallelus	2		4				3									1				1	
H. singleyanus	3				2			3								8			2		
Succineidae			3			2	1	1	2							16	1			1	
H. minuscula	6	1	9	3	5	2	6	1								7				5	
Z. arboreus																28					
D. laeve					1									2							

Desert in southern New Mexico. *Gastrocopta procera,* on the other hand, is restricted southwestward to higher elevations in New Mexico.

6. *Pupilla muscorum* (Linnaeus)

This species was restricted to the extreme northwestern corner of the county in the area of Black Mesa. It was most common at localities 1 and 2, near the New Mexico boundary, on the north slope of the mesa. It is at the eastern terminus of its range here, insofar as the southern Plains states are concerned. Branson's (1972:315) assertion that *P. muscorum* is a "characteristic species of the high plains" is puzzling as it is known from the High Plains (physiographic) Section of Kansas, Oklahoma and Texas only as a fossil. It continues on westward along the broken country of the Cimarron Valley and the Mesa de Maya to the Sangre de Cristo Mountains of New Mexico. Shells of *P. muscorum* usually possessed a small parietal denticle. In addition, a few specimens had a small basal tooth.

7. *Pupoides albilabris* (Adams)
8. *Pupoides inornatus* (Vanatta)

Like *Pupilla muscorum, Pupoides inornatus* was restricted to the northwestern corner of Cimarron County, which comprises the eastern edge of its range. It occurs in the Raton Section of northeastern New Mexico and adjacent Colorado but is not a montane species. *Pupoides albilabris* resembles *Gastrocopta pellucida* in being tolerant of xeric conditions in the southwestern states. It was found at many localities and in various kinds of habitats. It was the only species found at locality 40, an upland hillside (Ogallala Formation) in the southeastern part of the county. Although widespread, it did not occur in large numbers at any locality.

VALLONIIDAE

9. *Vallonia gracilicosta* Reinhardt
10. *Vallonia parvula* Sterki

Vallonia gracilicosta was the most widespread species taken in this survey, being found at 31 of the 40 localities. It was often the most abundant species at a locality as well. More than 200 specimens were taken at each of 11 localities (Table 1) and almost a thousand at localities 2 and 7 on the northern slope of Black Mesa. Its widespread and common occurrence in Cimarron County is surprising because the species is near the eastern edge of its range here. *Vallonia gracilicosta* was found in both upland and riparian habitats. It was especially common under shrubs along canyon walls and on bluffs. *Vallonia parvula,* on the other hand, showed a preference for riparian habitats, although extending headward along floors of canyons for considerable distances. It shows a similar preference for riparian habitats, westward, where it extends to the foothills of the Sangre de Cristo Mountains in New Mexico. Eastward, it becomes more common in non-riparian habitats.

HELICODISCIDAE

11. *Helicodiscus parallelus* (Say)
12. *Helicodiscus singleyanus* (Pilsbry)

Helicodiscus parallelus was widespread and occurred in all the general types of habitats sampled. *Helicodiscus singleyanus* also occurred widely but was taken at fewer stations than *H. parallelus*. Neither species was common at any locality, although *H. parallelus* comprised 8% of the specimens taken at locality 10.

SUCCINEIDAE

13. Specimens of succineids were found mainly as empty shells. Dissection of internal anatomy is necessary for identification to species. Live specimens from Locality 15, below Lake Carl Etling, were identified by Dr. Dorothea Franzen as *Catinella* sp. (*in litt.*, 12 May 1982). It is highly likely that many specimens from upland localities are *Succinea vaginacontorta* Lee, as this species has been reported from similar habitats in nearby Sherman County, Texas, by Franzen (1971:136-137). It seems to be a widespread species of the High Plains (Franzen 1971:141).

ZONITIDAE

14. *Hawaiia minuscula* (Binney)

This small snail occurred widely and in various kinds of habitats. It seems to have broad ecological tolerances.

15. *Zonitoides arboreus* (Say)

This snail was found only on the floodplains of the Cimarron River and its westernmost tributaries in the county, except for a few specimens taken on the northern slope of Black Mesa at localities 1, 2 and 7. From this area it extends westward in both riparian and montane habitats. There is probably a marked hiatus in its distribution eastward from Cimarron County. In southern Kansas, Leonard (1959:Fig. 50) mapped it as occurring only in the eastern half of the state.

LIMACIDAE

16. *Deroceras laeve* (Müller)

This slug is a widespread species but restricted to damp habitats. Thus, in semi-arid Cimarron County it was restricted to the moister areas of floodplains and around springs.

ADDITIONAL RECORDS

Previous records of land snails from Cimarron County are in the form of listings that indicate the county only with no further data. Wallen and Dunlap (1953) listed 16 species from the county. Branson and Wallen (1958) added one and Branson (1961) added two species to the fauna. Branson (1972) reported 15 species of land snails from the area of Black Mesa, including six species not listed previously. He listed seven locality numbers but did not indicate where the localities were to be found.

Eleven of the species listed in the above papers were not taken in the present survey. Three of these species are succineids—*Succinea concordialis* Gould, *S. grosvenori* Lea and *S. luteola* Gould. As mentioned above, dissection would have been necessary to establish indentity of these succineids and there is no indication that this was done. A record of *Vallonia cyclophorella* Sterki may have been based on thin-lipped, submature specimens of *Vallonia gracilicosta,* a very common species in the county. Such specimens were frequently noted in my collections. A record of *Helicodiscus nummus* (Vanatta) may have resulted from confusion with *Helicodiscus singleyanus,* a common species in the county. It is possible that records of some of the remaining species could have been based on fossil materials. Four of these species—*Gastrocopta tappaniana* (Adams), *Pupilla blandii* Morse, *Vertigo milium* (Gould) and *Vertigo ovata* Say—were represented by fossils, which I examined from sediments of the banks of South Carrizo Creek. I especially searched around springs for living specimens of these species, thinking that they might have persisted to the present in marshy areas. *Carychium exiguum* (Say) and *Punctum minutissimum* (Lea) occur to the west in New Mexico and likely occur as fossils in Cimarron County. Possibly they still live in the Black Mesa area as well.

CONCLUSION

Mesas capped with basaltic lava extend from Raton Mesa in Colfax County, New Mexico, irregularly eastward along the Mesa de Maya to Black Mesa in northwestern Cimarron County. South of these mesas the Cimarron River and its tributaries have produced a dissected country of bluffs and scarps that support a sparse oak-conifer woodland in favorable places. These mesas and valleys, together with the floodplain of the Cimarron River and its tributaries, may have provided routes along which some species of land snails moved, from highlands to the west, farther eastward into the High Plains than elsewhere in the southern plains. Thus, several species extend, at present, along this "peninsula" of more favorable habitats into Cimarron County: *Pupilla muscorum, Pupoides inornatus, Gastrocopta holzingeri* and *Zonitoides arboreus.* Evidence for similar, former extensions eastward is provided by fossils of *Discus cronkhitei* (Newcomb) and *Pupilla blandii* Morse that occur along South Carrizo Creek in deposits of Holocene or late Pleistocene age. These species are now found to the west in New Mexico but do not extend as far east as Cimarron County.

For some species, the peninsula noted above may become a bridge along which there is interconnection between populations inhabiting more mesic regions of the Rocky Mountains to the west and regions to the east of the High Plains. At the present time, *Gastrocopta armifera* seems to maintain such a tenuous connection between western and eastern populations across this bridge provided by the Cimarron Valley. *Gastrocopta holzingeri* and *Zonitoides arboreus* seem to have a hiatus in their distribution east of Cimarron County at present but populations east and west of the High Plains might likely reestablish connections with a slight amelioration of climate. With fluctuations of the climate in the Quaternary in mind, it seems likely that during times of Pleistocene range expansions contact between eastern and western populations of such species might first have occurred along the bridge postulated, whereas during times marked by range contraction, such as the Holocene, perhaps gene flow was last interrupted here.

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TISSUE LIPID AND FATTY ACID CHANGES IN CHANNEL CATFISH (*ICTALURUS PUNCTATUS*) FRY FED A FAT-FREE DIET

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ABSTRACT

Channel catfish (*Ictalurus punctatus*) fry maintained on a fat-free diet from onset of feeding to an age of 20 weeks increased their carcass levels of hexadecenoic and oleic acids, apparently through *de novo* synthesis. Carcass levels of linoleic acid, linolenic acid and fatty acids of higher molecular weight in both the linoleic and linolenic families declined as the fish grew. Tissue levels of docosahexaenoic acid fell below the limit for detection after the tenth week of the feeding trial.

INTRODUCTION

Channel catfish (*Ictalurus punctatus*) fingerlings fed diets containing animal lipids such as beef tallow and menhaden oil grow more rapidly than do those fed diets containing vegetable oils such as safflower oil and soybean oil when lipids comprise 10% of the diet (Stickney and Andrews 1971, 1972; Yingst and Stickney 1979). The difference vanishes when environmental temperature is below optimum for the species (Stickney and Andrews 1971; Gatlin and Stickney 1982). Research has not yet established which, if any, fatty acids are essential in the diet of channel catfish. The decreased growth of channel catfish fingerlings fed vegetable oils may be a function not of essential fatty acid deficiency, but may instead result from the inhibition of *de novo* fatty acid synthesis, perhaps caused by excessive levels of dietary linolenic acid (Stickney et al. 1983).

The essentiality of linolenic-acid-family fatty acids has been demonstrated for rainbow trout, *Salmo gairdneri* (Castell et al. 1972a, b, c; Yu and Sinnhuber 1972, 1975). Linolenic-acid-family fatty acids also may be essential for other fishes (Cowey and Sargent 1977). Linoleic acid appears to be essential for *Tilapia zillii* (Kanazawa et al. 1980) and may also be required by *T. aurea* (Stickney and McGeachin in press).

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This study documents temporal changes in body lipid percentage and fatty acid composition of channel catfish fry fed a fat-free diet over a five month period from onset of feeding.

MATERIALS AND METHODS

The experiment was conducted at the Aquaculture Research Center of the Texas Agricultural Experiment Station. Fish were maintained in 38-liter glass aquaria which received inflowing well water of 26-30 C at the rate of 950 ml/min. Supplemental aeration was provided through airstones.

Channel catfish fry from a single spawn were utilized in the study. Several hundred late sac-fry were distributed among a few aquaria on 16 June 1982 and fed to satiation several times daily. After approximately one month, feeding was reduced to twice daily. Fry were fed a diet containing 63.5% casein (about 60% protein), 18.5% dextrin, 9.0% cellulose, 6.0% minerals, 0.5% vitamins and 2.5% carboxymethylcellulose as a binder. Vitamin and mineral premixes were formulated according to NRC (1977) recommendations.

Fish were sampled weekly for 16 weeks and then biweekly through week 20. The study was terminated when the supply of fish was exhausted. Sufficient numbers of fish were obtained during each sampling period for analysis of moisture and lipid (Folch et al. 1957). Methyl esters (AOCS 1960) were prepared from the lipid samples and analyzed for fatty acid patterns on a Varian Model 2400 gas chromatograph equipped with flame ionization detector and a 3-m column as described by Gatlin and Stickney (1982). Major fatty acids were identified by comparison with standards.

Mean fish weights were obtained by dividing the total weight of each sample by the number of individuals. Samples of at least 10 g were required for the analyses. In no instance was fewer than five fish used to make up a sample, even when individual weights averaged in excess of 5.0 g.

Each sample was made into a slurry with a tissue homogenizer. Three replicate samples were utilized for moisture and three for lipid percentage determinations. The extracted lipids were used for methyl ester preparation and triplicate analyzes were run on the gas chromatograph.

Analysis of variance was applied to sample means, followed by Duncan's multiple range test. Statistical analyses were run on the Texas A&M University computer utilizing the Statistical Analysis System, SAS-79 (Helwig and Council 1979). Significant differences were evaluated at the 0.05 level.

TABLE 1. Mean dry fish weight and mean lipid percentage (of dry weight) for channel catfish fry fed a fat-free diet. Mean lipid percentages followed by the same superscript letter are not significantly different at the 0.05 level.

Time (weeks)	Mean dry fish weight (g)	Mean lipid percentage
0	0.002	26.7^{a}
1	0.006	18.1^{bcde}
2	0.011	15.0^{cde}
3	0.018	16.1^{bcde}
4	0.025	11.8^{e}
5	0.034	12.2^{de}
6	0.053	14.7^{cde}
7	0.055	14.9^{cde}
8	0.081	12.5^{de}
9	0.058	16.9^{bcde}
10	0.074	23.7^{ab}
11	0.090	15.4^{bcde}
12	0.159	20.5^{abcd}
13	0.187	16.5^{bcde}
14	0.440	12.2^{de}
15	0.331	17.1^{bcde}
16	0.245	20.1^{abcde}
18	0.563	18.4^{bcde}
20	1.166	22.3^{abc}

RESULTS AND DISCUSSION

Mean fish weight increased from 0.002 to 1.166 g dry weight (0.03 to 5.6 g wet weight) during the 20 week experiment (Table 1). Carcass lipid percentages were variable, ranging from 11.8 to 26.7% on a dry weight basis (Table 1). The highest lipid percentage was obtained from the fish which were sampled just prior to first feeding. Thereafter, lipid percentages fell to a low at four weeks and fluctuated thereafter.

Levels of most fatty acids present in the carcasses of channel catfish fry changed during the study (Table 2). There was a general increase in hexadecenoic acid throughout the experiment, with a concomitant decrease in stearic acid. The level of oleic acid gradually increased through week 14, after which it declined slightly and then appeared to stabilize.

Linoleic acid initially declined and then remained relatively constant in terms of its contribution to total fatty acid percentage. Arachidonic acid, a linoleic-acid-family fatty acid, declined throughout the study and may have been altered to linoleic acid to help maintain the level of the latter fatty acid. The absence of linoleic acid in the sample of week 20 appears to have been a function of the fact that the fish increased in weight considerably during the final two week period and

TABLE 2. Mean fatty acid percentages (based on three replicates) of major fatty acids in channel catfish fry fed a fat-free diet for 20 weeks. Within columns, fatty acid percentages followed by the same superscript letter are not significantly different at the 0.05 level.

Time (weeks)	Myristic acid	Palmitic acid	Hexadecenoic acid	Stearic acid	Oleic acid	Linoleic acid	Linolenic acid	Eicosaenoic acid	Arachidonic acid	Docosahexaenoic acid
0	3.9^{e-h}	19.6^{d-f}	4.7^{j}	12.1^{a}	26.5^{i}	4.3^{a}	0.8^{a}	0.6^{g}	5.4^{a}	9.3^{a}
1	3.7^{gh}	22.8^{a}	6.8^{i}	11.9^{a}	33.1^{h}	1.1^{e-g}	0.2^{c}	1.0^{e-g}	4.3^{b}	7.6^{b}
2	4.0^{e-h}	21.0^{bc}	7.2^{i}	9.8^{b}	35.1^{gh}	0.9^{f-h}	0.1^{c}	1.5^{c-e}	2.8^{c}	4.5^{c}
3	3.9^{e-h}	20.9^{bc}	8.0^{hi}	9.6^{b}	36.4^{f-h}	1.1^{e-g}	0.1^{c}	1.4^{de}	2.1^{d}	3.2^{d}
4	4.3^{e-h}	17.9^{g-i}	9.2^{gh}	8.3^{c}	35.4^{gh}	2.5^{b-d}	0.2^{c}	1.4^{de}	1.5^{e}	2.1^{e}
5	3.5^{h}	17.0^{ij}	9.0^{gh}	8.4^{c}	33.8^{gh}	2.9^{b}	0.2^{c}	1.5^{c-e}	1.6^{e}	2.3^{e}
6	3.8^{f-h}	18.2^{gh}	10.1^{fg}	7.2^{d}	36.8^{f-h}	2.1^{b-d}	0.3^{bc}	1.7^{b-d}	1.2^{f}	1.2^{f}
7	4.1^{e-h}	16.6^{j}	10.9^{ef}	5.8^{e}	36.2^{f-h}	2.7^{bc}	0.3^{bc}	1.6^{cd}	0.8^{g}	0.7^{g}
8	4.8^{c-g}	17.2^{h-j}	12.2^{de}	5.1^{f}	36.0^{f-h}	2.4^{b-d}	0.3^{bc}	1.6^{cd}	0.8^{g}	0.5^{g}
9	4.0^{e-h}	17.4^{h-j}	11.6^{e}	4.9^{fg}	38.0^{e-h}	2.1^{b-d}	0.3^{bc}	1.4^{de}	0.6^{gh}	0.6^{g}
10	5.6^{b-d}	19.4^{d-f}	13.4^{cd}	3.8^{hi}	39.8^{c-g}	1.9^{c-e}	0.3^{bc}	1.5^{c-e}	0.5^{hi}	0.5^{hi}
11	5.8^{a-c}	19.0^{e-g}	15.0^{ab}	3.4^{i}	38.4^{d-h}	1.6^{d-f}	0.2^{c}	1.6^{cd}	0.4^{ij}	0.0^{h}
12	4.5^{d-h}	20.1^{c-e}	13.1^{cd}	3.5^{i}	44.2^{b-d}	1.8^{c-e}	0.3^{bc}	2.1^{ab}	0.1^{jk}	0.0^{h}
13	4.1^{e-h}	21.6^{b}	11.0^{ef}	4.4^{gh}	48.2^{b-f}	0.9^{f-h}	0.2^{c}	2.2^{a}	0.1^{jk}	0.0^{h}
14	3.5^{h}	20.3^{cd}	11.6^{e}	2.7^{j}	50.3^{a}	0.6^{gh}	0.2^{c}	1.9^{a-c}	0.0^{k}	0.0^{h}
15	5.2^{b-e}	18.9^{fg}	13.8^{bc}	3.5^{i}	43.0^{b-e}	2.4^{b-d}	0.4^{b}	1.6^{cd}	0.2^{jk}	0.0^{h}
16	6.8^{a}	18.8^{fg}	15.5^{a}	3.4^{i}	41.8^{b-f}	2.5^{b-d}	0.2^{c}	1.2^{d-f}	0.1^{jk}	0.0^{h}
18	5.1^{b-f}	20.6^{b-d}	14.0^{bc}	2.3^{j}	46.0^{ab}	2.0^{b-d}	0.4^{b}	1.6^{cd}	0.2^{jk}	0.0^{h}
20	6.1^{ab}	21.6^{b}	15.8^{a}	2.3^{j}	44.8^{bc}	0.0^{h}	0.1^{c}	0.7^{fg}	0.0^{k}	0.0^{h}

reserves of linoleic acid were depleted. While linoleic acid has not been identified as having essential fatty acid activity in channel catfish, that possibility has not been ruled out.

Linolenic acid contributed less than 1% to the total fatty acids in slurry samples throughout the study. There was some depletion of that fatty acid during the first few weeks of the study, after which the percentage remained relatively constant.

Since no measurements of cholesterol, glycerol and other chromatographically-inert contributors to total lipid percentage were made, it was not possible to quantify the absolute levels of linolenic acid and other fatty acids from one week to the next. Thus, slight declines or increases in relative percentage do not necessarily imply that the fatty acids were changing in absolute amounts. The facts that most of the polyunsaturated fatty acids had been depleted to below detection levels and that linoleic and perhaps linolenic acid were declining at the end of the study suggest that growth could not have been maintained much longer. The study is not definitive in demonstrating whether fatty acids of the linoleic or linolenic acid families are essential to catfish, but from knowledge of other species of animals (including other fishes), one or both families should be essential.

Docosahexaenoic acid levels declined from the onset of sampling through week 10, after which the levels of that acid fell below detection limits. Other related fatty acids such as eicosapentaenoic acid were present in trace amounts early in the study, but were below detection limits after the first two or three weeks of sampling. Eicosapentaenoic acid is a major fatty acid in such lipids as menhaden oil but is not retained well by channel catfish which do not receive a dietary supply (Stickney and Andrews 1971, 1972; Yingst and Stickney 1979).

This preliminary study has revealed that channel catfish can survive and grow from the onset of feeding to a weight of nearly 6 g on a fat-free diet. Indications from the levels of certain fatty acids in the carcasses of the fry are that continued growth might not have been possible due to the elimination of essential fatty acids. General maintenance of tissue levels of two saturated fatty acids, hexadecenoic acid and oleic acid, in growing catfish fry—despite constantly diminishing levels of other fatty acids—is an indication that those two fatty acids are produced *de novo* or are formed from chain elongation and desaturation of other fatty acids. The depletion of linoleic- and linolenic-acid-family fatty acids during the study provides evidence that neither family can be produced *de novo* in required amounts. It is assumed that fatty acids from one or both families are required for normal growth and metabolism in channel catfish, but the dietary levels required for maintenance of the fish remain undetermined.

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ABSENCE OF LEPROSY-LIKE DISEASE IN THE NINE-BANDED ARMADILLO (*DASYPUS NOVEMCINCTUS*) IN AND AROUND TAYLOR COUNTY, TEXAS

by GERALD T. WILSON, PATRICIA HORTON,
WM. CLARK STEVENS *and* ROY E. SHAKE

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Abilene Christian University
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ABSTRACT

A sample of 30 nine-banded armadillos (*Dasypus novemcinctus*) collected in and around Taylor County, Texas, was examined for presence of naturally acquired leprosy-like disease. No evidence of mycobacteriosis was evident in any of the animals examined. The 8 counties of central Texas involved in this study lie outside the region of Texas in which human leprosy is endemic.

INTRODUCTION

Mycobacterium leprae, the causative agent of leprosy, has never been cultivated *in vitro*. Initial attempts to transmit the disease to laboratory animals met with limited success. But, in 1971, Kirchheimer and Storrs reported successful transmission of the disease to the nine-banded armadillo (*Dasypus novemcinctus*). In 1974 and 1975, researchers at Gulf South Research Institute in New Iberia, Louisiana, determined that 14 nine-banded armadillos trapped in southern Louisiana were infected with a natural leprosy-like disease identical to that seen in experimentally infected animals (Walsh et al. 1975 and 1976).

The leprosy-armadillo connection has been a matter of controversy for some time. At the time our study was being undertaken, noted researchers held opposing views concerning the very existence of the disease in wild armadillos, as well as the possible origin of the infection (Kirchheimer 1977). However, subsequent studies have revealed additional occurrences of the disease in the armadillo populations of Louisiana and Texas (Walsh et al. 1977; Smith et al. 1978; pers. comm. from W. F. Kirchheimer and R. M. Sanchez, U.S. Public Health Service Hospital, Carville, LA).

MATERIALS AND METHODS

Armadillos were obtained from several sources. Local trappers provided most. In a few instances, fresh carcasses were obtained that

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had been killed by pets, vehicles or gunshot wound. When obtained live, animals were maintained by the authors until necropsy. For humanitarian reasons, animals were euthanized as soon as possible and maintained only if they appeared to be adjusting well to captivity. Maintenance procedures generally followed those outlined by Storrs and Greer (1973).

Animals were anesthetized with Ketalar (Parke-Davis Co., Detroit, MI), using 25 mg per kg of body weight injected intramuscularly in the hind leg. Euthanasia was completed with an intravenous or intracardiac injection of N-[2-(m-methoxy-phenyl)-2-ethyl-butyl-(1)]-gamma-hydroxybutyramide, 200 mg; 4-4′methylene-bis(cyclohexyl-tri-methyl-ammonium iodide), 50 mg; tetracaine hydrochloride, 5 mg with 0.6 ml dimethylformanide in distilled water (T-61 euthanasia solution, National Laboratories Corp., Somerville, NJ), using 0.3 cc per kg of body weight.

Ear smears were prepared by the methods outlined by Walsh et al. (1977). Each ear was slit with a scalpel close to the base and the wound was then scraped at a right angle several times. Materials obtained in this manner was then smeared on a slide. Impression smears were obtained from each ear by teasing apart the tissue from the removed edge, and an impression of the tissue was made on a glass slide.

Nasal smears were prepared by inserting cotton swabs into each nasal passage and smearing the material obtained on a slide. Additional impression smears were made from the tongue, spleen, liver, and inguinal lymph nodes after aseptic removal from each animal. Tissue samples of ears, footpads, abdominal skin, tongue, spleen, liver and inguinal lymph nodes were removed aseptically and fixed in 10% neutral buffered formalin. These tissue samples were mailed to the Armed Forces Institute of Pathology (Washingon, D.C.) for histopathological examination by Dr. Wayne Meyers and Dr. Chapman Binford.

One kidney and one lung were removed from each animal, fixed in 10% neutral buffered formalin, and kept for further examination in cases where mycobacteriosis might be evident.

In addition, tissue samples from the inguinal lymph node, liver and spleen were aseptically removed, placed in sterile petri dishes and frozen to await the outcome of all slide and histopathological examinations. Should mycobacteriosis have been identified in any animal, these samples would have been used for inoculating slants of Lowenstein-Jensen and Middlebrook 7H10 agar according to procedures previously described by Binford et al. (1977).

Non-culturability serves as an indicator that an acid-fast organism is *Mycobacterium leprae*. On the other hand, successful culture of

Mycobacterium spp. indicates the mycobacteriosis in question is not an infection with *M. leprae* or else it is the result of a mixed etiology with *M. leprae* and other members of the genus (Binford et al. 1977).

All slides prepared as previously described were allowed to air dry and were heat-fixed for 2 to 3 seconds. Slides were stained immediately using the Ziehl-Neelson technique for acid-fast organisms.

Slides were flooded with Ziehl's carbolfuchsin and allowed to steam for 7 min using an electric staining rack. The slides were then cooled to room temperature for 5 min, rinsed in deionized water, and placed in horizontal immersion racks. Decolorization was achieved by successive immersion of the slides into 3% solution of acid alcohol until the solution remained clear. The decolorization was followed by rinsing with deionized water and counterstaining with methylene blue for 4 min. Slides were then rinsed with deionized water and allowed to air dry.

All slides were prepared in duplicate and 30 microscopic fields of each were examined under oil immersion for the presence of acid-fast organisms. With the staining technique employed, acid-fast organisms would have appeared as red rods among, or within, blue stained tissue cells. All other bacteria present would have stained blue.

RESULTS

Thirty armadillos were examined from an 8 county region of central Texas for the presence of acid-fast bacteria. Nineteen animals were examined from Taylor County; two each from Jones, Shackelford, Eastland and Coleman counties; and 1 each from Stephens, Callahan and Brown counties (Figure 1). Mycobacteriosis was not diagnosed in any of the animals examined in this study.

DISCUSSION

Walsh et al. (1977) found rates of infectivity for naturally acquired leprosy-like disease in armadillos to range between 4 percent and 9.6 percent at selected sites in Louisiana. However, in an expanded study, their examination of 451 armadillos from Louisiana revealed 47 infected animals, for an overall rate of infectivity of 10.42 percent. These high rates of infectivity have been disputed by Kirchheimer (1977); however, investigators from Texas found infected armadillos, in a sample of 20, collected from southern Louisiana (Smith et al. 1978).

Armadillos from several Texas counties (Figure 2) have been examined for evidence of naturally acquired leprosy-like disease (Walsh et al. 1975, 1976, 1977; Kirchheimer and Sanchez 1976; Kirchheimer 1977; CDC 1978; Horton 1980; Smith 1983; pers. comm. from W. F.

FIGURE 1. Texas counties from which we examined armadillos for leprosy-like disease. Numbers indicate sample sizes.

Kirchheimer, U.S. Public Health Service Hospital, Carville, LA; pers. comm. from M.M. Anderson, Dept. of Pathology, San Diego Zoo, San Diego, CA). Walsh et al. (1977) found 1 infected animal among 61 examined from Anderson County, but found no evidence of infection in 27 animals collected from 13 other counties in Texas (pers. comm. from C. H. Binford, Armed Forces Institute of Pathology, Washington, D.C.). Positive cases of naturally acquired leprosy in 2 animals captured in Brazos County were identified in 1978 (pers. comm. from M. M. Anderson, Dept. of Pathology, San Diego Zoo, San Diego, CA). The Center for Disease Control (CDC), Atlanta, reported 1 naturally infected armadillo from Brazos County, Texas. Their study also included 1 non-infected animal from Burleson County (CDC 1978). Smith (1983) reported results of a two-year survey of 450 armadillos caught in 16 Texas counties which showed about 5 percent infectivity with naturally occurring leprosy. While the occurrence of naturally

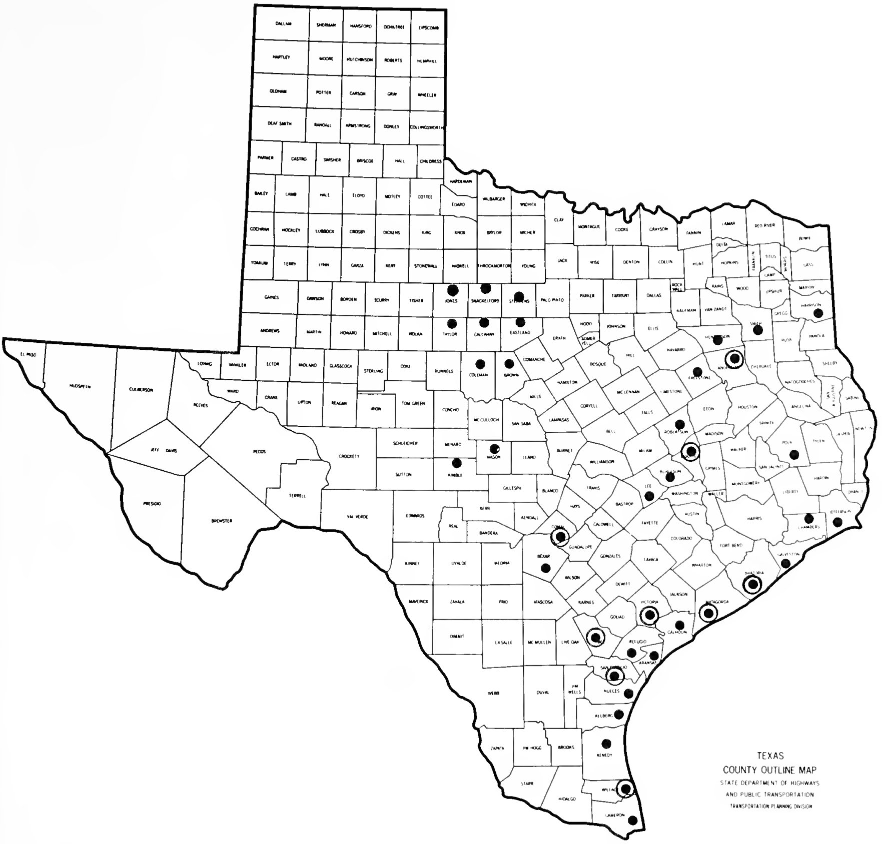

FIGURE 2. Counties from which armadillo populations have been sampled for mycobacteriosis. Encircled dots indicate documented presence of mycobacteriosis in one or more armadillos.

acquired leprosy in the armadillo population of Texas does not approach the rates of infectivity found by Walsh et al. (1977) in the population of Louisiana, it is evident the disease does occur in Texas.

There have been approximately 1,005 cases of leprosy reported in Texas between the years 1920 and 1978. Some 55 counties along the Gulf Coast and Rio Grande River valley, plus an area surrounding El Paso, constitute the endemic area of the state for human leprosy. The area involved in this study has a historically low rate of infectivity. Four cases of leprosy have been reported from Taylor County since 1921, and no case has been reported from other counties surveyed in this study (Texas Department of Health 1980).

Felice et al. (1976) found no association between human leprosy and armadillo contact among 19 leprosy patients in Louisiana. Information received by the authors indicates such an instance of documented close-contact with an armadillo previous to the onset of leprosy in a 70 year old male caucasian from southern Texas (pers. comm. from J. D. Balentine, A. Fisher and J. R. Cantey, Medical University of South Carolina, Charleston, S.C.).

In view of the fact that the source of infection and mode of transmission of *Mycobacterium leprae* are very poorly understood, it seems imperative that more extensive investigations be undertaken in regard to armadillo infection and the possible association between human leprosy and armadillo contact.

The disease under investigation in this study is currently referred to as naturally acquired leprosy and naturally acquired leprosy-like disease. It should be noted that since the intial report of this desease in 1975 by Walsh et al., neither microscopic, immunologic, serologic nor histologic studies have revealed evidence to indicate the disease is caused by an agent other than *Mycobacterium leprae.* The term *leprosy-like disease* may become obsolete in time.

ACKNOWLEDGEMENTS

This research was funded by the Research Council of Abilene Christian University, the support of which is gratefully acknowledged. Drs. Wayne Meyers, Gerald P. Walsh, and Chapman Binford of the Armed Forces Institute of Pathology, Washington, D.C., are recognized for their consultations and confirmation of pathology results of this research.

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COVER PHOTO

Occurrence of leprosy-like disease
in Texas armadillos (encircled dots)

by Wilson et al., p. 73-79

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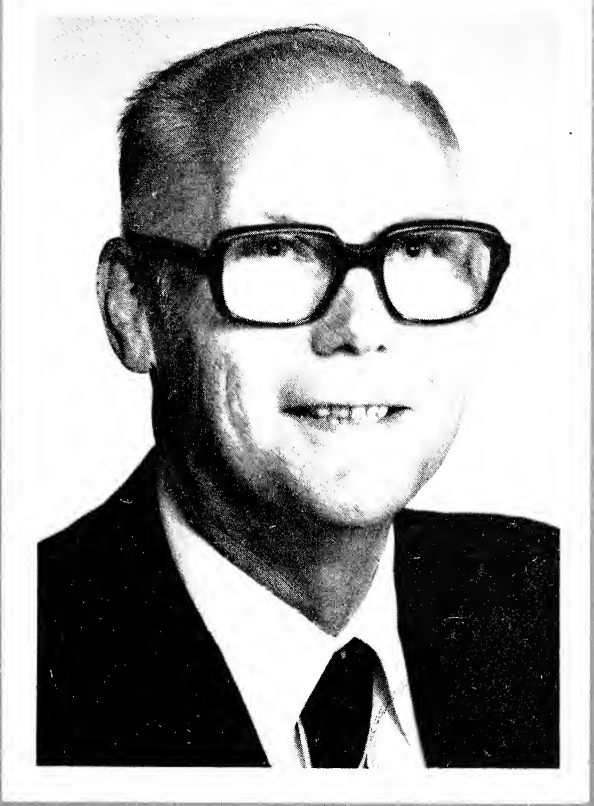

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THE EARTH'S MAGNETOSPHERE— A MAGNETOHYDRODYNAMICAL GENERATOR[1]

by FRANCIS S. JOHNSON[2]

University of Texas at Dallas
Richardson, TX 75080

ABSTRACT

The solar wind—a high-speed, low-density outflow of plasma from the sun through interplanetary space—interacts strongly with the earth's geomagnetic field or magnetosphere, severely deforming it at distances of about 10 earth radii and greater. It is widely accepted that magnetic merging, or reconnection, occurs between magnetic fields embedded in the solar wind plasma and the earth's magnetic field. A large-scale magnetohydrodynamical generator operates with a power output of millions of megawatts, supplying power to magnetohydrodynamical loads where the electromagnetic energy that has been generated in one region of space is put back into the plasma in another region. Problems that remain in an otherwise very comprehensive picture of the overall interaction include difficulties in understanding how an electrical field can exist along the X line or neutral line where the merging occurs and where the magnetic field strength goes to zero, and in the momentum and energy balance at the magnetospheric boundary where plasma must be acclerated to the Alfvén velocity (in a coordinate system in which no electric field is seen) in order to balance the tension of the magnetic field lines.

The interaction of the solar wind with the earth's magnetic field is conceptually a simple problem—a high-velocity, low-density plasma

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[1] Text of address presented in plenary session at the Texas Academy of Science 87th Annual Meeting, University of Texas at San Antonio, San Antonio, Texas, 16 March 1984. Dr. Johnson presented the address upon the occasion of his being named "Distinguished Texas Scientist" for 1984 by the Academy. He became the fifth person to be so honored; the other four are heart surgeon Michael DeBakey (1979), physicist Ilya Prigogine (1980), ecologist Perry Adkisson (1982), and geoscientist Michel Halbouty (1983).

[2] Francis S. (Frank) Johnson is a world-renowned aerospace scientist whose scientific papers, which number about 100, bear such titles as "Rocket Observations of Atmospheric Ozone," "The Ultraviolet Spectrum of the Sun," and "Atmosphere of Mars." After service as Weather Officer with the U.S. Air Force during WWII and post-war duty with the Naval Research Laboratory, Dr. Johnson advanced to Manager, Space Physics Research, for Lockheed Missles and Space Company; while with Lockheed, he earned a Ph.D. degree in meteorology at UCLA. Subsequently, he held various appointments in research and administration before assuming his present position as Cecil H. and Ida M. Green Honors Professor of Natural Science at The University of Texas at Dallas. Dr. Johnson has served as advisor to the National Academy of Sciences, the National Academy of Engineering, the National Science Foundation, and NASA. Other honors include the Space Science Award from the American Institute of Aeronautics and Astronautics; the Henryk Arctowski Medal from the National Academy of Sciences; the Exceptional Scientific Achievement Medal from NASA; The John A. Fleming Award from the American Geophysical Union; and, election as "Fellow" of AAAS, the American Geophysical Union, and the American Meteorological Society.

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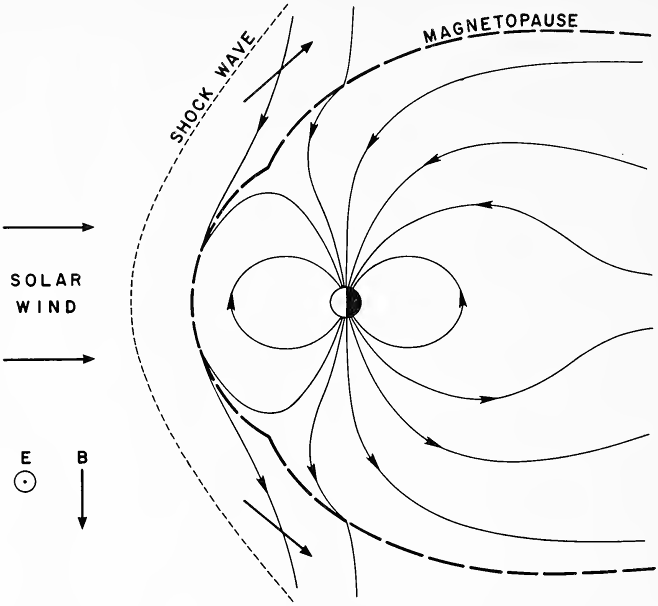


FIGURE 1. The deformation of the earth's magnetic field by the solar wind. A long tail, consisting of two lobes—one of field lines directed towards the earth and connecting with the north polar region of the earth, and the other of field lines directed away from the earth and connecting with the south polar region—extends far to the right. The interplanetary field is assumed to be directed southward.

interacting with a dipole magnetic field. The physics of the interaction is important in astrophysics, and, to a considerably lesser extent, laboratory plasma physics. It is surprising that some rather fundamental properties of the interaction are poorly understood, casting some doubt on the applicability of commonly held concepts in astrophysical problems.

Some major aspects of the interaction are not in doubt. The earth's magnetic field is severely confined and deformed, especially on the sunward side, and the flow of the solar wind is largely deflected around the magnetosphere. The field in the sunward direction does not extend farther than about 10 earth radii. A shock wave occurs, much as would be expected for supersonic flow in general. Figure 1 shows the gross features of the interaction, with the shock wave, the confinement of the earth's magnetic field on the sunward side, and the flow of the solar wind around the magnetic obstacle. The solar wind is highly rarefied; it generally consists of 5 to 10 ions, mostly protons, per cubic centimeter and an equal number of electrons, moving with a velocity of about 500 km/sec. It contains magnetic field of solar origin, and values of 5 nT are common. There is a considerable degree of disorder in the field, but it is normally easy to determine from spacecraft observations

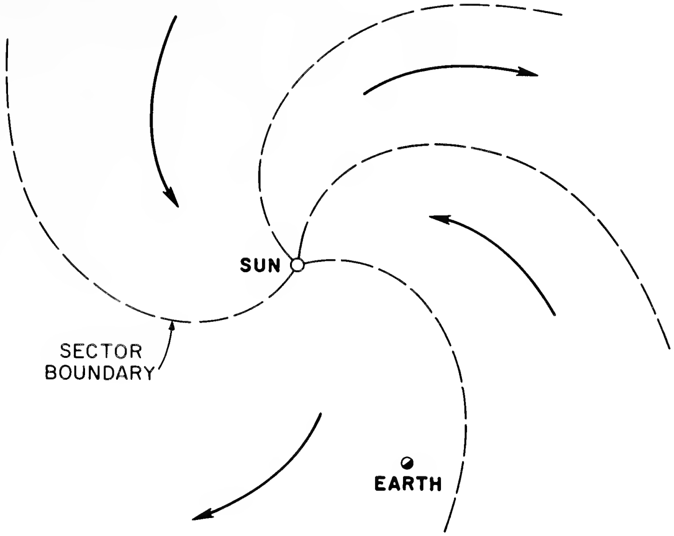


Figure 2. The gross features of the interplanetary magnetic field near the ecliptic plane, consisting frequently of two sectors where the field is directed towards the sun and two away from the sun. The curvature of the field lines and of the sector boundaries results from the rotation of the sun.

whether the field is directed generally towards or away from the sun, and whether or not it has a component in the north or south direction relative to the ecliptic. Because of the rotation of the sun and the interaction between the magnetic field and the moving plasma, the magnetic field lines are curved in space at what is called the garden-hose angle, an analogy to the apparent curvature of a stream of water from a garden hose when the nozzle is swung around. This is illustrated in Figure 2. The rotation period of the sun is 27 days, and the transit time for the solar wind to reach the earth is three or four days. Because of this overall field configuration, the direction of the magnetic vector towards or away from the sun is highly correlated with the component in the dawn-dusk direction—the direction of the earth's motion in its orbit. There are usually one or two sectors in the space around the sun where the field is directed outward, and of course an equal number inward. The sectors have lifetimes of many months, and of course they rotate with the sun. In a three dimensional view, the magnetic field is directed toward the sun in one hemisphere (north or south) and away from the sun in the other hemisphere, and the two regions of oppositely directed field are separated by a warped disk approximately in the equatorial plane of the sun; the warping of the disk determines the number of sectors seen near earth as the sun rotates.

A major question concerning the interaction between the solar wind and the earth's magnetic field relates to a process known as magnetic merging. In magnetospheric research such merging is usually referred to as reconnection. It is generally believed that such merging occurs more or less steadily, leading to interconnection between the magnetic field embedded in the solar wind and the earth's magnetic field. To more easily visualize this, the magnetic field in the solar wind is usually represented as southward in direction, as indicated in Figure 1. There is evidence that the fields are more interconnected when the interplanetary field is southward than when it is not. However, magnetic field lines can only connect one way, so any interconnection that occurs when the interplanetary field is not southward is more tortuous, but the sense and effect of the interconnection remain more or less the same.

The original reason for suggesting the existence of interconnection lies in the polar zones. The auroras that occur there constitute a long standing scientific mystery. Much more is known about them now than was the case a few decades ago, but still a complete and adequate explanation for them has not yet emerged from the improved observations made in space. However, it was clear even before the era of satellite observations that there was a large-scale pattern of motions associated with auroras, and it was to explain those motions that interconnection between the earth's magnetic field in the polar regions and the interplanetary magnetic field was first suggested by Dungey in 1961.

Dungey's (1961) concept was that electrical conductivity along the magnetic field lines was high, and field-aligned currents could transfer energy and momentum from the solar wind to the earth's polar regions. The potential difference across the polar caps between about 65° magnetic latitude on the dawn side of the earth and the same latitude on the dusk side is about 100,000 volts, the dawn side being positive. Although electrical conductivity across the field lines is generally very poor, since ions and electrons gyrate about magnetic field lines rather than moving across them in the direction of the electric field, the situation becomes different in the ionosphere. There collisions occur so frequently that ions can make progress across the field lines, and significant current flows in the direction of the electric field, typically several hundred thousand amperes. This provides Joule heating in the polar regions at a rate that is significant compared with other heat inputs there. The dissipation of electrical energy is quite variable, and occasionally the Joule heating becomes the major heat source for the upper atmosphere. Figure 3 shows the large-scale pattern of ionospheric convection. It is largely consistent with a potential difference of about 100,000 volts being applied across the polar zone. The solar wind must polarize to a degree and slow down slightly in its motion in response to $\bar{J} \times \bar{B}$ forces in order to provide the electrical energy that flows along

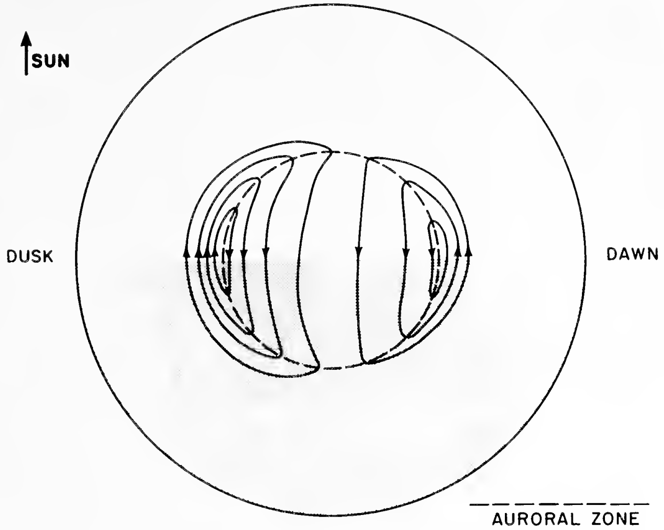


FIGURE 3. The large-scale pattern of ionospheric convection over the north polar zone. The pattern is largely what one would expect from impressing a potential difference of 100,000 volts between the cells on the dusk and dawn sides, the dawn side being positive.

the interconnecting magnetic field lines to the polar zone. ($\bar{J}$ is the current density and $\bar{B}$ the magnetic induction.)

The magnetic tail of the earth is surprisingly long. The rate of ionospheric plasma drift across the polar cap in response to the impressed potential difference is such that the ionospheric plasma moves across the cap in two or three hours, during which time the solar wind moves a distance of about 5×10^6 km, or about 800 earth radii. Since all the magnetic field lines emanating from the polar caps are thought to connect into the solar wind, one should expect a tail of about this length. The observations suggest an identifiable tail even farther away from the earth. This long tail is divided into two lobes, as indicated in Figure 1, but extending much farther in the antisunward direction than indicated in the figure. The tail is very long compared to its diameter, and a neutral sheet separates the two lobes; these lobes consist of a bundle of magnetic field lines directed towards the earth and connected with the north polar cap, and another bundle directed away from the earth and connected with the south polar cap.

One of the most interesting aspects of this picture is that of magnetohydrodynamical power generation and dissipation at the boundaries of the magnetosphere. It is clear in Figure 1 that the earth's magnetic field is markedly confined on the sunward side by the impact pressure of the solar wind. There is good agreement between the momentum of the undisturbed solar wind and the strength of the magnetic field just

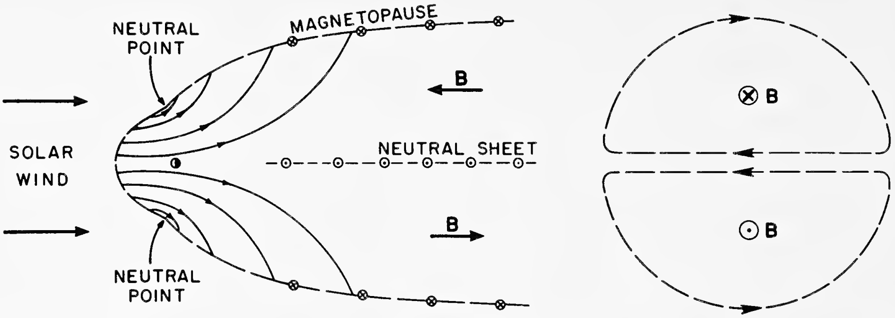


Figure 4. The Chapman-Ferraro current system required to confine the earth's magnetic field and to produce the extended tail. The pattern on the right represents a view along the tail towards the earth, where solenoid-like currents flow around the two tail lobes.

inside the boundary of the magnetosphere, the boundary being called the magnetopause. This supports the concept that the magnetic field, which the solar wind is unable to penetrate, is confined by the impact pressure of the solar wind. Along the sides of the tail, the magnetic field is also confined by the pressure of the solar wind against it.

Surface currents or currents in relatively thin transition layers must flow at boundaries such as the magnetopause and the neutral sheet between the two tail lobes to account for the sudden change in magnetic field there. The plasma interacts with the magnetic field and balances its pressure, and currents are induced in the plasma to prevent the penetration of the magnetic field into the plasma. The $\bar{J} \times \bar{B}$ force provides the interaction for the force balance between the magnetic field and the plasma, and the current agrees with the discontinuity in the magnetic field.

Figure 4 indicates diagrammatically the nature of the current systems at the surface of the magnetopause and across the neutral sheet, representing the case where the earth's field is totally confined and there is no interplanetary field. When an interplanetary field is present with no interconnection with the earth's field, another current system must be present at the magnetospheric boundary to exclude the interplanetary field from the region occupied by the earth's field, and of course the two current systems are superimposed. With some interconnection between the two fields, the currents are somewhat reduced, so that the earth's field is not totally confined and the interplanetary field not entirely excluded from the magnetosphere. With these two provisions in mind, that additional currents are needed to exclude the interplanetary field from the magnetosphere and both current systems must be somewhat reduced to allow for interconnection between the earth and interplanetary fields, Figure 4 provides useful insight into the nature of the current systems at the magnetic boundaries. These currents are fre-

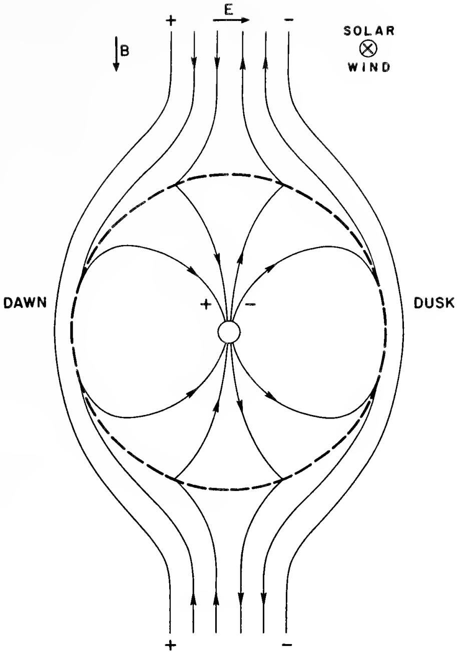


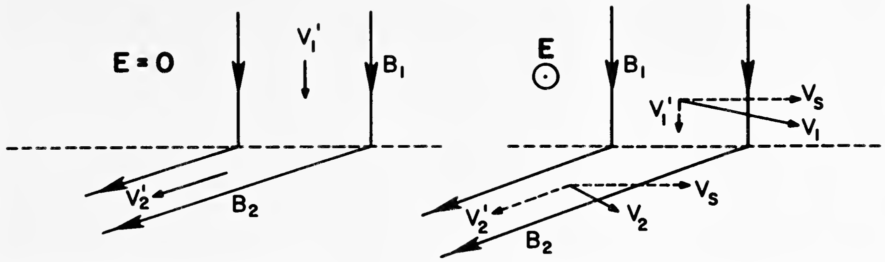
FIGURE 5. The nature of the electrical interconnection between the solar wind, the magnetosphere, and the polar zones of the earth. The dawn-to-dusk field originates in the solar wind. The interplanetary magnetic field is assumed to be directed southward.

quently called Chapman-Ferraro currents because Chapman and Ferraro (1931) first recognized an interaction of this type between magnetic fields and plasmas in an astrogeophysical context. The Chapman-Ferraro current across the front of the earth's magnetosphere is about 10^7 amperes, and a considerably larger total current flows between the two lobes of the tail. These currents are induced in the plasmas that confine the earth's magnetic field, and important energy flows are associated with them.

The statement made earlier to the effect that a potential difference of about 100,000 volts is established across the polar caps by means of highly conductive paths along magnetic field lines that extend into the solar wind also means that the same potential difference exists across the magnetosphere, directed in a dawn-to-dusk sense. Figure 5 illustrates the situation. Relative to an observer on earth, an electric field $\overline{E}$ is seen to exist in the solar wind such that the solar wind velocity $\overline{V}_s$ is given by $\overline{V}_s = \overline{E} \times \overline{B}^2$. The magnetic field is assumed to be directed southward, as discussed earlier. The electric field $\overline{E}$ is directed in the dawn-to-dusk sense. With typical values of B (5×10^{-9} T) and $\overline{V}_s$ (500 km/sec), $E = 2.5 \times 10^{-3}$ volts/m indicating that the width of the slice of solar wind plasma connected magnetically to the earth's polar cap is about 4 × 10^7 m, or 6 earth radii. The electrical equipotentials associated with the extremes of the plasma slice connect with the dawn and dusk boundaries of the magnetosphere and of the polar cap.

A flow of 10^7 amperes across the sunward side of the magnetosphere, with a potential difference of 10^5 volts between the dawn and dusk sides, indicates an electrical power dissipation there of 10^{12} watts (approximately the total electrical generating capacity on earth). Where does this energy come from and where does it go? One might suspect that it represents an energy drain on the solar wind, just as we have said in the case of Joule heating in the polar caps. Examination of the current paths shown in Figure 4 shows that this source is located on the magnetospheric boundary. The current paths across the sunward side of the magnetosphere are parts of continuous loops that extend over and under the tail of the magnetosphere, where the relationship between current flow and potential drop is just the opposite to that on the sunward face of the magnetosphere. The top and bottom boundaries of the magnetosphere represent generators that deliver electrical power to the sunward face of the magnetosphere, and also to the neutral sheet separating the tail lobes—another region of electrical power dissipation. This energy flow can also be considered in terms of the Poynting vector, but, as in the case of the flow of electromagnetic energy from a battery to a resistor, examination of electrical currents is more illuminating here than use of the Poynting vector.

Figure 6 shows the magnetic field configuration at the top boundary of the magnetosphere. It is instructive to look at what is happening first in a reference system that moves along the magnetospheric boundary with the solar wind velocity outside the magnetosphere, and later in a reference system fixed relative to the earth and sun (e.g. with its origin at the center of the earth, its x axis passing through the sun, and its z axis pointing northward in space). The moving reference system is one in which no electric field is seen, as in that frame the solar wind plasma is not moving across the magnetic field. The total pressure, magnetic plus plasma, must be the same in the solar wind and in the magnetosphere; otherwise, the magnetosphere would expand or contract until they were the same. In the solar wind the plasma pressure is dominant, and in the magnetosphere the magnetic pressure is dominant, so it is largely a case of the plasma pressure in the solar wind confining the earth's magnetic field. In this moving reference system, there is no conversion of plasma energy into electromagnetic energy. However, in addition to the pressure-balance requirement just mentioned, there has to be a rate of momentum change in the plasma to balance the component of the tension of the magnetic field tangential to the boundary. This condition is met if the plasma flows along the magnetic field lines inside the boundary at the "Alfvén" velocity, $V_2'^2$ =



MOVING COORDINATE SYSTEM
(a)

STATIONARY COORDINATE SYSTEM
(b)

FIGURE 6. The assumed magnetic configuration at the boundary of the magnetospheric tail. (a) Plasma velocity as seen in a coordinate system moving downstream with the solar wind, so that there is no electric field. In this reference system the plasma accelerates as it passes through the magnetospheric boundary. (b) Plasma velocities as seen in a coordinate system fixed with respect to the earth and sun, in which a dawn-to-dusk electric field exists, and in which the plasma loses energy as it passes through the magnetospheric boundary.

$B_2^2/\mu_0\rho_2$, where ρ is the density, the subscript 2 refers to the region inside the boundary, and the prime indicates that the velocity is relative to the moving coordinate system. The difference in plasma pressure inside and outside the boundary accelerates the plasma to this velocity. As indicated in Figure 6a, a low-velocity (compared to solar wind velocity) flow occurs toward the magnetospheric boundary, where the flow changes direction and accelerates. The rate of gain of tangential component of momentum per unit area is $(\rho_2 V_2' \cos\theta)V_2' \sin\theta$, where θ is the angle between the magnetic field direction inside the magnetosphere and the magnetopause boundary. The tangential component per unit area of the magnetic force on the boundary is $[(B_2^2/\mu_0)\cos\theta]\sin\theta$; hence these two are equal if $V_2'^2 = B_2^2/\mu_0\rho_2$, i.e., if the velocity inside the magnetospheric boundary is the Alfvén velocity. There is no change in the enthalpy of the plasma as it crosses the boundary; i.e., its energy is conserved (Lee and Roederer 1982), and no plasma energy is converted into electrical form.

If one now looks at the flow pattern from a coordinate system that is fixed relative to the earth and sun, as shown in Figure 6b, there is an electric field, and the plasma drifts relative to the observer with a velocity $\bar{V} = \bar{E} \times \bar{B}/B^2$, and because the plasma is moving relative to the observer there are $\bar{V} \times \bar{B}$ forces. Viewed from this coordinate system, the plasma slows down from V_1 to V_2 as it passes across the magnetospheric boundary. The energy that it gives up is converted into electromagnetic energy. The rate of generation of electrical energy at the boundary is $\bar{\alpha} \cdot \bar{E}$ per unit area, where $\bar{\alpha}$ is the surface current given by the change in the tangential component of magnetic induction across the boundary. Thus

$$\alpha = (B_{t2} - B_{t1})/\mu_0 = B_{t2}/\mu_0$$

(since $B_{t1} = 0$). Mechanically, the rate of doing work per unit area is the product of the component of the solar wind velocity parallel to the boundary and the tangential component of the magnetic force per unit area, or

$$(E/B_{n1})(B_2^2/\mu_0)\cos\theta\sin\theta = (E/B_{n1})(B_{t2}B_{n2}/\mu_0) = EB_{t2}/\mu_0$$

(since $B_{n1} = B_{n2}$). Thus the rate of doing mechanical work against the tension of the magnetic field equals the electrical power generated. The mechanical force on the plasma is the rate of change of the tangential component of momentum, or

$$\rho_2 V_2'^2 \sin\theta\cos\theta = \rho_2 V_2'^2 B_{t2}B_{n2}/B_2^2$$

As before, if $V_2'^2 = B_2^2/\mu_0\rho_2$, the tangential component of the plasma force is $B_{t2}B_{n2}/\mu_0$, the same as the magnetic force indicated above. Thus the topside magnetopause portion of the magnetospheric tail acts as a magnetohydrodynamical generator in which energy is extracted from the solar wind plasma as it flows through the boundary into the magnetosphere, and electrical energy is generated. The energy is transferred by currents along the magnetospheric boundary to the front of the magnetosphere and to the region between the tail lobes.

An overriding constraint on the flow across the boundary is that there must be mass continuity, or $\rho_1 V_1'/B_1 = \rho_2 V_2'/B_2$. If the magnetic field directions on the two sides of the boundary do not make equal angles with the boundary, one cannot simultaneously satisfy the requirements on balancing the tangential forces at the boundary (i.e., magnetic forces and the plasma force associated with the rate of change of the tangential component of momentum) and on continuity of mass flow (Hudson 1971). The exception is when the field direction outside the boundary is perpendicular to the boundary (as shown in Figure 6), in which case the magnetic field on that side of the boundary does not contribute to the tangential component of force on the boundary, and no requirement exists for the plasma velocity there to equal the Alfvén velocity, as viewed in the moving frame of reference. The continuity requirement is satisfied by a velocity less that the Alfvén velocity, and this circumstance essentially ensures the stability of the configuration, since for a magnetic field direction outside the magnetopause different from normal, the lack of balance between the tangential components of the magnetic tension and momentum change is such that the configu-

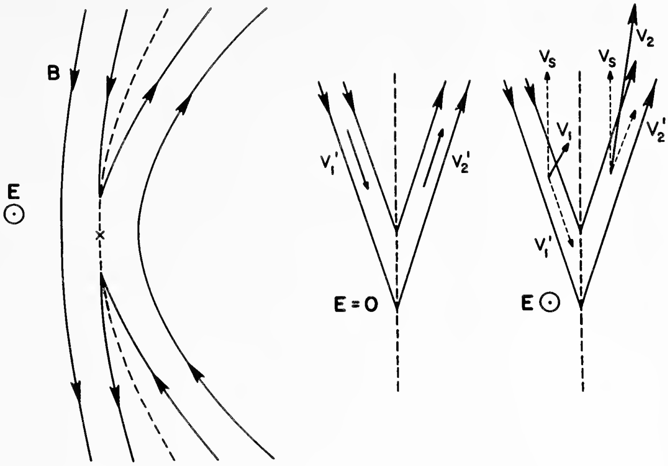


FIGURE 7. The assumed magnetic configuration at the front side of the magnetosphere where magnetic merging or reconnection occurs. As in Figure 6, velocities as seen in a moving and a fixed coordinate system are shown. In the fixed system, an electric field is directed out of the plane of the figure even at the X line where the magnetic induction is zero.

ration will change towards the normal configuration. A problem remains concerning the acceleration of the plasma as it crosses the boundary, as seen in the moving coordinate system. A large pressure change, about a factor of two, is required to produce such a velocity change, and it has not been shown that this requirement is satisfied. Further, the plasma is so rarified that it is by no means clear that gas dynamical concepts are applicable to flow along the field lines, the mean free paths being long compared to dimensions of interest in the problem. Plasma pressures are generally not isotropic, and the energy density of the plasma can be regarded as being made up of components perpendicular and parallel to the magnetic field, considerably complicating the nature of gas dynamical concepts that should be applied.

Figure 7 illustrates conditions at the front of the magnetosphere, where the magnetospheric boundary currents are in the same direction as the electric field. While Figure 6 applies to the "generator region," where plasma energy is converted into electromagnetic energy, Figure 7 applies to the "load region," where electromagnetic energy is converted into plasma energy. Here the condition that the magnetic field directions on the two sides of the boundary make equal angles with the boundary is quite naturally fulfilled. In order to balance the tangential component of magnetic forces at the boundary, it is necessary that the plasma velocity be equal to the Alfvén velocity when viewed from a coordinate system moving so that no electric field is seen at the point in question. As viewed from a stationary coordinate system, the plasma is accelerated as it passes through the boundary. Although the theoretical picture is equally applicable for plasma flow into or out of the magnetosphere, the accepted picture is that solar wind plasma flows into the magnetosphere as the magnetic merging proceeds.

Two particularly vexing problems remain in the overall picture. As viewed in a stationary coordinate system, a dawn-to-dusk field exists, and along the X line (shown in Figure 7) where the magnetic merging occurs, the magnetic field strength is zero. Thus, with no magnetic effects to limit conductivity, there is difficulty in accepting that an electric field can exist there. The other difficulty is that very little evidence has been seen in spacecraft observations for the extensive plasma acceleration that the picture involves (Heikkila 1975). The release of 10^{12} watts in such a tenuous plasma should produce easily detectable effects. It is now frequently stated that the effects have been seen (Cowley 1982), but the original claims that the observational evidence does not support the merging, or reconnection, picture remain credible. Thus the issue remains in doubt, and further observational evidence is needed to establish firmly whether the large magnetohydrodynamical generators and loads described here actually operate at the boundaries of the magnetosphere. However, there is no alternative concept that offers as much in the way of explanation of the large-scale behavior of the earth's magnetosphere.

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SIMPLIFIED ANALYSIS OF A CONSTANT-VOLUME GAS THERMOMETER

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ABSTRACT

Behavior of a constant-volume gas thermometer was analyzed. Corrections to first order in pressure were applied to the virial expansion of the state-equation for helium gas as well as to the gradient between room temperature and sample temperature. Further, changes in volume of the pressure gauge were taken into account. The resultant transcendental equation is not only more elegant than "brute force" variational methods, but also saves considerably in computer time. A representative set of data also is presented.

INTRODUCTION

The measurement of temperature has always been important to basic and applied physics. One device for measuring temperature is the constant-volume gas thermometer (Guildner 1982). A constant-volume gas thermometer usually consists of three interconnected compartments—a gas bulb at the sample temperature T_B (for example, 4.2 K), a pressure gauge at room temperature T_R (about 300 K) and a connecting tube that takes up the temperature gradient between sample temperature and room temperature. The standard approach (White 1979) is to fill the volume (V) of the gas thermometer with a fixed amount of helium gas at low pressure, then apply the ideal gas law with virial corrections when a stable pressure P is measured by the pressure gauge. This article presents a simplified analysis of the temperature calculations based on first order corrections in P.

ANALYSIS

I followed Keesom (1942) in correcting for the non-ideality of helium gas, by expanding each PV term in the gas equation to first order in P; that is,

$$PV = A + BP$$

where A and B are the first and second virial coefficients, respectively. For helium,

$$A = A_0T/273.15$$

with $A_0 = 0.999488$ in amagat units (Keesom 1942). The values of **B** as a function of temperature were taken from the same reference. By substitution,

$$PV = \frac{A_0T}{273.15} + BP.$$

Therefore,

$$\frac{PV}{T + 273.15\ BP/A_0} = \frac{A_0}{273.15} = \text{constant.}$$

Define

$$f(T) = \frac{P\ V(T)}{T + 273.15\ B(T)\ P/A_0} = \text{constant.}$$

Then each compartment of the gas thermometer contributes a term of the form of f(T), resulting in the equation

$$S(T_B) = f(T_B) + \frac{1}{T_R - T_B} \int_{T_R}^{T_B} f(T)dT + f(T_R) = \text{constant.}$$

Here, $f(T_B)$ is the gas bulb term,

$$\frac{P\ V_B\ (T_B)}{T_B + 273.15\ B(T_B)\ P/A_0},$$

where $V_B(T_B)$ denotes the volume of the gas bulb at temperature T_B. Change in bulb volume (V_B) due to thermal expansion is taken into account by using the coefficient of linear expansion of the bulb material. The second term in $S(T_B)$ represents the contribution from the connecting tube, assuming a linear temperature gradient from the bottom of the tube (at sample temperature T_B), to the top of the tube (at room temperature T_R), with

$$B \simeq B(\frac{T_R + T_B}{2}).$$

After integration, the second term is

$$\frac{P\,V_{L2}}{T_R - T_B}\ln\left(\frac{T_R + C}{T_B + C}\right),$$

where V_{L2} is the volume of the connecting tube and

$$C = 273.15\,B\left(\frac{T_R + T_B}{2}\right) P/A_0.$$

$f(T_R)$, the pressure gauge term, is

$$\frac{P\cdot(V_{L1} + aP)}{T_R + 273.15\,B(T_R)\,P/A_0},$$

where the volume of the pressure-sensing capsule inside the pressure gauge is assumed to vary linearly with the pressure P,

$$\text{Volume} = V_{L1} + aP,$$

and V_{L1} and a are parameters to be determined.

To find the parameters V_{L1} and a, the gas thermometer was calibrated at the known temperatures of helium boiling point (4.213 K) and the triple point of water (273.16 K) with a fixed amount of helium gas, resulting in two simultaneous equations involving V_{L1} and a. These two parameters were considered constant for all the experiments.

To find an unknown temperature, the gas thermometer was calibrated at a known temperature T_0. Hence,

$$\begin{aligned} &S(T_B) \text{ at unknown temperature } T_B \\ &= S(T_0) \text{ at known temperature } T_0 \\ &= W \end{aligned} \tag{1}$$

Eq. 1 could be evaluated to give a constant value W because the only unknown variable, T_B, occurred on the left-hand side. To solve this equation algebraically for T_B was quite difficult, however, because of the nonlinear temperature dependence of terms. Hence, a successive approximation and iteration method was used.

Initially, the following approximations were used in the gas bulb term and the connecting tube term on the left-hand side of Eq. 1:

$$V_B(T_B) \simeq V_B(T_0), \tag{2}$$

$$B \simeq 0; \text{ and} \tag{3}$$

$$\frac{1}{T_R - T_B} \ln\left(\frac{T_R + C}{T_B + C}\right) \simeq \frac{1}{T_R + C} \simeq \frac{1}{T_R}. \tag{4}$$

The only T_B variable remaining in the gas bulb term was renamed T_1. The motivations for the above approximations were that the gas bulb had the highest percentage of the total volume of the gas thermometer, and that its temperature changed the most. T_1 was the first approximation to the sample temperature, and roughly corresponded to the ideal gas temperature.

Eq. 1 simplified to give

$$\frac{1}{T_1} = \frac{1}{V_B(T_0)} \left[\left(\frac{W}{P} - \frac{V_{L2}}{T_R} - \frac{V_{L1} + aP}{T_R + 273.15\, B(T_R)\, P/A_0} \right) \right].$$

Then, correction was made for neglect of the ln function in Eq. 4 by substituting T_1 into the left hand side of Eq. 1, while keeping the approximations in Eq. 2 and Eq. 3. The T_B variable in the gas bulb term was renamed T_2. A better estimate of the sample temperature was thus obtained:

$$\frac{1}{T_2} = \frac{1}{T_1} + \frac{V_{L2}}{V_B(T_0)} \left[\frac{1}{T_R} - \frac{1}{T_R - T_1} \ln\left(\frac{T_R + C_1}{T_1 + C_1} \right) \right]$$

where

$$C_1 = 273.15\, B\left(\frac{T_R + T_1}{2}\right) P/A_0.$$

Then the thermal contraction of the gas bulb and the neglect of the virial coefficient B were accounted for by substituting T_2 into the left hand side of the full Eq. 1, except for the one T_B variable in the gas bulb term which was renamed T_3. After some algebra, the third estimate for the sample temperature came forth:

$$T_3 = \frac{V_B(T_2)}{V_B(T_0)} \left\{ \frac{1}{T_1} + \frac{V_{L2}}{V_B(T_0)} \left[\frac{1}{T_R} - \frac{1}{T_R = T_2} \ln\left(\frac{T_R + C_2}{T_2 + C_2} \right) \right] \right\}^{-1}$$

$$- 273.15\, B(T_2) P/A_0,$$

where

$$C_2 = 273.15\ B(\frac{T_2 + T_R}{2})\ P/A_0.$$

Next, the number W′ was calculated by substituting T_3 for every T_B on the left hand side of Eq. 1. Namely,

$$S(T_3) = W'. \tag{5}$$

If W′ was different from W by more than 10^{-3}%, T_3 would be decreased or increased in steps of 0.001:

$$T_3 = T_3 \pm 0.001, \tag{6}$$

and a new W′ calculated each time using Eq. 5. The T_3 with a negligible difference between W′ and W was adopted as the solution to Eq. 1. Since W′ was generated using the full Eq. 1, errors involved in the approximations in Eq. 2, Eq. 3 and Eq. 4 were actually eliminated.

Herein lies the advantage of the analysis over other numerical methods like the Newton method: the trial solutions of Eq. 1, namely T_1, T_2 and T_3, were generated by the analysis using physical reasoning rather than guesses. (A misjudged trial solution may consume many computer dollars before converging to the correct solution.) At the start of the iterative step in Eq. 6, T_3 was already so close to the solution of Eq. 1 that only a few, usually less than 7, iterations were needed to convert T_3 to the final solution, which was then called the sample temperature for the pressure P.

As an aid for computer programming, the major steps are listed below:

1) Evaluate the constant W using Eq. 1 with the known initial conditions of temperature and pressure.
2) Calculate the temperature estimates T_1, T_2 and T_3 using their respective expressions.
3) Evaluate W′ using Eq. 5 and compare it with W.
4) If W′ is different from W, change T_3 using Eq. 6 and evaluate W′ again. Continue iterating until a T_3 is found such that $|W' - W|$ is negligible. The T_3 is then the solution for Eq. 1.

The accuracy of the gas thermometer was limited by taking only the first-order corrections in P, and also by thermomolecular pressure fluctuations in the connecting tube. However, the latter uncertainty was estimated to be less than 0.5% (White 1979).

An independent confirmation of the accuracy of the thermometer was obtained when the magnetic ordering temperatures of the same batch of *Pd*Mn alloys was measured using the gas thermometer in a resistivity experiment and also measured using a calibrated germanium resistor in

TABLE 1. Values of gas pressure and successive approximations of sample temperature.

No.	Pressure (in. of water)	T_1(K)	T_2(K)	T_3(K)	Sample Temperature (K)
1	5.100	4.206	4.208	4.219	4.219
2	5.650	4.665	4.667	4.678	4.678
3	6.170	5.099	5.102	5.113	5.113
4	6.580	5.443	5.445	5.456	5.456
5	7.120	5.896	5.899	5.910	5.910
6	8.020	6.653	6.656	6.667	6.667
7	9.150	7.607	7.612	7.622	7.622
8	10.320	8.602	8.608	8.817	8.617
9	11.010	9.190	9.197	9.206	9.206
10	12.210	10.218	10.225	10.234	10.234
11	13.100	10.983	10.992	11.000	11.000
12	14.520	12.211	12.221	12.228	12.228
13	15.100	12.714	12.725	12.732	12.732
14	16.540	13.970	13.983	13.989	13.989
15	17.360	14.689	14.703	14.709	14.709
16	18.130	15.367	15.381	15.387	15.387
17	19.720	16.769	16.786	16.791	16.791
18	20.560	17.515	17.534	17.538	17.538
19	21.510	18.363	18.383	18.387	18.387
20	22.330	19.098	19.119	19.123	19.123
21	23.490	20.142	20.165	20.168	20.168
22	25.490	21.956	21.082	21.985	21.985
23	28.520	24.739	24.770	24.772	24.772
24	31.700	27.718	27.754	27.755	27.755
25	35.420	31.252	31.296	31.296	31.296
26	38.720	34.447	34.498	34.496	34.496
27	41.830	37.508	37.565	37.563	37.563
28	45.500	41.192	41.257	41.255	41.255
29	49.850	45.662	45.737	45.737	45.737
30	54.440	50.499	50.585	50.588	50.588
31	59.380	55.859	55.956	55.964	55.964
32	62.320	59.095	59.199	59.210	59.210
33	64.780	61.926	62.038	62.053	62.053
34	65.260	62.393	62.504	62.521	62.521
35	69.600	67.444	67.567	67.593	67.593

an AC susceptibility experiment. The two sets of ordering temperatures agreed within the experimental error of 1% (Ho et al. 1981a,b).

For temperatures higher than 273.16 K, the higher order corrections in P begin to jeopardize the analysis while for temperatures lower than 4.213 K, the sensitivity of the pressure gauge is the limiting factor.

EXPERIMENTAL RESULTS

Table 1 presents the values of gas pressure and successive approximations of sample temperature in a typical experiment. The improvement

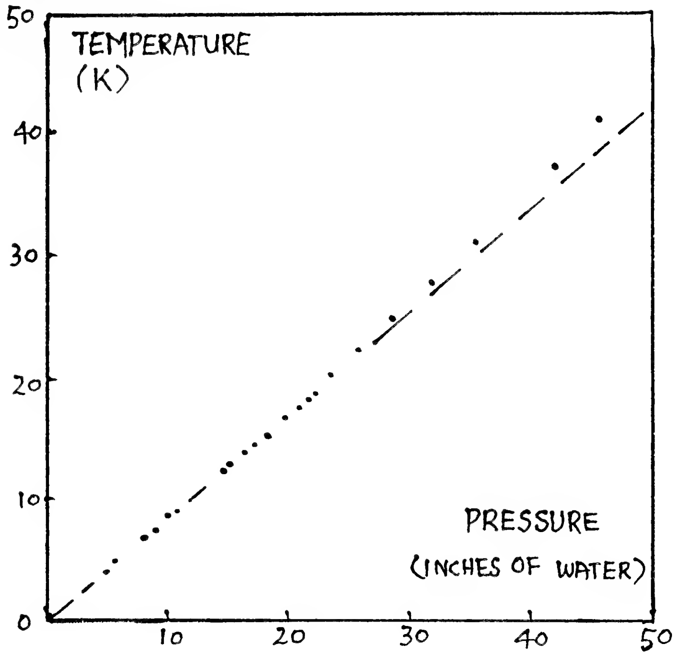

FIGURE 1. Temperature-pressure curve of the constant-volume gas thermometer.

in accuracy from T_1 to T_3 is evident. The sample temperature and T_3 were identical in this case, as changing T_3 by ±0.001 brought W′ more than $10^{-3}\%$ away from W. The temperature versus pressure data are also plotted in Fig. 1. The X-axis is given in inches of water because the dial of the Wallace and Tiernan pressure gauge is calibrated in inches of water. (One inch of water = 248.58 Pa.) It can be seen that the data diviated from a straight line as the temperature increased from the helium calibration point.

CONCLUSION

This article presents a simplified analysis of the constant-volume gas thermometer to convert the pressure readings into temperature readings, accurate to the first order in P. The advantage of the above analysis was that a considerable amount of computer time was saved compared to a "brute force" variational method. A typical calculation including resistivity analysis for 50 data points took less than 5 seconds with an IBM-360 computer.

ACKNOWLEDGMENTS

It is a pleasure to thank Dr. G. Williams for the many fruitful discussions. Thanks are due also to Dr. R. Roshko, M. Colp, and G. Roy for their technical assistance, and to Dr. S.J. Brient, for careful reading of the manuscript. The helpful advice from the editor, associate editor for mathematics and statistics, and reviewers is highly appreciated.

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FORMULA FOR PRIME NUMBERS WITH LARGE RESIDUE INDICES

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ABSTRACT

I present a general algebraic formula that gives some prime numbers having very large residue indices involving a simple expression of the exponents for the period length of the prime number. Three special cases are described and associated properties noted.

INTRODUCTION

I want to thank one of the reviewers of this article for the following explanation of the theory involved: Fermat's theorem states that if q is a prime and x is not divisible by q, then $x^{q-1} \equiv 1 \bmod q$. If e is the smallest exponent for which $x^e = 1 \bmod q$, then we say that x belongs to the exponent e, modulo q. In this paper we are only interested in cases for which $x = 10$, so that e represents the number of digits in the repeating portion of the reciprocal of q.

I have developed a general algebraic formula for some prime numbers having very large residue index values and established a very simple relationship between the prime's period length, L(q), and the exponents m and p where

$$q = \frac{10^{mp} \pm 1}{10^m \pm 1}, \tag{1}$$

and p and q are sometimes prime numbers and m is a positive integer.

The period length, L(q), of the reciprocal of the prime q is given by

$$L(q) = Kmp \tag{2}$$

where m and p are as defined above and K = 1 (Case I below) or 2 (Cases II and III below).

The beautiful simplicity of the pattern exhibited by the other prime period lengths, being factors of the longest period, may be of interest to the reader.

DEVELOPMENT OF FORMULA

Yates (1982) gives

$$i(q) = \frac{q-1}{L(q)} \tag{3}$$

as the general definition of residue index, where q is a prime number and L(q) is the period length (number of decimal positions in the repeating digits) of the reciprocal of q.

Using (3) and substituting LMAX(q) for q − 1,

$$i(q) = \frac{LMAX(q)}{L(q)}, \tag{4}$$

which is a ratio of two period lengths—LMAX(q) being the theoretical maximum length of q and L(q) being the actual (or true) period length of q.

Case I

Using −1 in Equation (1) and m = 1,

$$q = \frac{10^p - 1}{10 - 1}, \tag{5}$$

a string of the numeral 1, i.e., when

$p = 1, q = 1;$
$p = 2, q = 11;$
$p = 3, q = 111$ ($q \neq$ prime when $p = 3$);
. .
. .
. .

Beiler (1964) called this string of 1's repunits, or q = R(p). According to Yates (1982, pp. 142-150), R(p) is known to be prime for p = 2, 19, 23, 317. In this case Equation (2) becomes L(q) = p and the i(q) of Equation (3) ranges in value from (11 − 1)/(2) = 5 to (R(317) − 1)/317, a number on the order of 10^{313}.

The relationships between the periods of the reciprocals of the prime *factors* of R(p) − 1 are given in Table 1 for p = 19 and 23. Note the relation between the periods of the reciprocals of the prime *factors* of LMAX(q) = R(p) − 1 for p = 19 and 23. The same holds true for p = 317.

TABLE 1. Tabulation of L(q) and LMAX(q) for the repunits R(19) and R(23). Their residue index, i(q), is given by the ratio of the elements of column 2 to the corresponding ones of column 1. Periods of the prime factors of LMAX(q) are enclosed in parentheses immediately below each factor having a period.

Column 1 L(q) = p	Column 2 LMAX(q) = R(p) − 1
19	$2 \,.\, 5 \,.\, \underset{(1)}{\underline{3^2}} \,.\, \underset{(6)}{\underline{7}} \,.\, \underset{(2)}{\underline{11}} \,.\, \underset{(6)}{\underline{13}} \,.\, \underset{(18)}{\underline{19}} \,.\, \underset{(3)}{\underline{37}} \,.\, \underset{(9)}{\underline{333667}} \,.\, \underset{(18)}{\underline{52579}}$
23	$2 \,.\, 5 \,.\, \underset{(2)}{\underline{11^2}} \,.\, \underset{(22)}{\underline{23}} \,.\, \underset{(22)}{\underline{4093}} \,.\, \underset{(22)}{\underline{8779}} \,.\, \underset{(11)}{\underline{21649}} \,.\, \underset{(11)}{\underline{513239}}$

The longest period of any of the factors in column 2 of Table 1, LMAX(q), is 18 for the first entry and 22 for the second. Yates (pers. comm. 1972, Samuel Yates, 157 Capri D, Kings Point, Delray Beach, FL 33445) pointed out to me the explanation of these relationships: LMAX(R(19)) = R(19) − 1 is equal to 10R(18), and R(18), not being prime, has factors whose periods are 18 and *factors* of 18; likewise, for LMAX(R(23)) = R(23) − 1.

Case II

Using +1 in Equation (1) and m = 1,

$$q = \frac{10^p + 1}{10 + 1}, \tag{6}$$

TABLE 2. Partial list of p's generating prime q's in Equation (6) with corresponding L(q) and LMAX(q).

Column 1 p	Column 2 L(q)	Column 3 LMAX(q) = q − 1
5	10	$9090 = 2 \,.\, 5 \,.\, \underset{(1)}{\underline{3^2}} \,.\, \underset{(4)}{\underline{101}}$
7	14	$909090 = 2 \,.\, 5 \,.\, \underset{(1)}{\underline{3^3}} \,.\, \underset{(6)}{\underline{7}} \,.\, \underset{(6)}{\underline{13}} \,.\, \underset{(3)}{\underline{37}}$
19	38	$909090909090909090 =$ $2 \,.\, 5 \,.\, \underset{(1)}{\underline{3^4}} \,.\, \underset{(6)}{\underline{7}} \,.\, \underset{(6)}{\underline{13}} \,.\, \underset{(18)}{\underline{19}} \,.\, \underset{(3)}{\underline{37}} \,.\, \underset{(18)}{\underline{52579}} \,.\, \underset{(9)}{\underline{333667}},$
		. . . .

TABLE 3. List of m's generating q's in Equation (7) with corresponding L(q) and LMAX(q).

Column 1 m	Column 2 L(q)	Column 3 LMAX(q) = q − 1
2	12	$9900 = 2^2 \,.\, 5^2 \,.\, \underset{(1)}{\underline{3^2}} \,.\, \underset{(2)}{\underline{11}}$
4	24	$99990000 = 2^4 \,.\, 5^4 \,.\, \underset{(1)}{\underline{3^2}} \,.\, \underset{(2)}{\underline{11}} \,.\, \underset{(4)}{\underline{101}}$
6	36	$999999000000 = 2^6 \,.\, 5^6 \,.\, \underset{(1)}{\underline{3^3}} \,.\, \underset{(6)}{\underline{7}} \,.\, \underset{(2)}{\underline{11}} \,.\, \underset{(6)}{\underline{13}} \,.\, \underset{(3)}{\underline{37}}$
8	48	$9999999900000000 = 2^8 \,.\, 5^8 \,.\, \underset{(1)}{\underline{3^2}} \,.\, \underset{(2)}{\underline{11}} \,.\, \underset{(8)}{\underline{73}} \,.\, \underset{(4)}{\underline{101}} \,.\, \underset{(8)}{\underline{137}}$

and Equation (2), with K = 2, becomes L(q) = 2p. q is prime for p = 5, 7, 19, 31, 53, 67, and 293. The corresponding L(q)'s become, respectively, 10, 14, 38, 62, 106, 134, and 586. This relationship, along with the corresponding LMAX(q) substituted for q − 1, is given in Table 2. For the discussed members of this case, the largest period of any of the *factors* of LMAX(q) may be obtained by doubling the number of 9's in q.

In Table 2, the *period length,* L(q), may be obtained by doubling the longest period of any of the factors of LMAX(q) and adding 2. (Example: In the first entry of Table 2, the longest period of any of the factors of 9090 is 4. Doubling 4 and adding 2 gives 10, the corresponding L(q).) Also, in Table 2, the values of i(q), Equation (3), are given by the ratio of the items in column 3 to the corresponding ones in column 2. Again, the value of i(q) becomes very large and ranges from 909 to LMAX(q)/586 for p = 293, a number on the order of 10^{289}, another exceedingly large number.

Case III

Using +1 in Equation (1), setting p = 3, and letting m be a positive variable integer, Equation (1) becomes

$$q = \frac{10^{3m} + 1}{10^m + 1}, \tag{7}$$

and Equation (2) becomes L(q) = 6m.

Setting m = 2,4,6, and 8 in Equation (7), the values for L(q) and LMAX(q) become those given in Table 3. Note that m is equal to the number of 9's in the prime number q. The *longest period* of any of the *factors* of LMAX(q) is also equal to the number of 9's in q; again, m is the exponent of 2 and 5 in the factored form of LMAX(q). The other factors of LMAX(q) have periods which are factors of m. The i(q)'s of this case range in value from 9900/12 = 825 to LMAX(q)/48, a large number of order 10^{14}, or 100 trillion. Note this is a much smaller number than the largest of Cases I and II.

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COMPUTER LITERACY FOR PRESERVICE TEACHERS OF SECONDARY MATHEMATICS AND SCIENCE: A COLLEGIATE COURSE

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ABSTRACT

This paper describes a computer literacy course for preservice secondary mathematics and science teachers. The course was designed to provide "hands-on" experience with computers and to introduce structured programming principles implemented in two different programming languages.

INTRODUCTION

In 1980, several of the faculty of Texas Tech University sought and received a National Science Foundation grant under the LOCI (Local Course Improvement) program. They designed and evaluated a new course aimed at providing a computer literacy component that had been missing in our course sequence for preservice elementary mathematics teachers (Anderson et al. 1983). Having good success in this endeavor, one member of the original group sought and received from Texas Tech a Summer Teaching Development Assignment for the summer of 1983 to design a computer literacy course for preservice secondary mathematics teachers. The computer literacy course that resulted involves both batch processing, using a large computing system, and interactive programming with microcomputers. For the large system, a very structured language like WATFIV is used, whereas BASIC is used for the microcomputer segment of the course. The purpose of this paper is to describe the computer literacy course that has evolved.

COURSE PHILOSOPHY AND OVERVIEW

The objectives of the new course are to develop preservice mathematics and science teachers' computer literacy, to give them hands-on experience with computers, and to show them how computers can aid them both in classroom work and in record-keeping. Course participants are expected to develop good programming skills and to do problem-solving using computers.

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Even though the goal of our course is not the training of programmers, many of the modern guidelines of structured programming are incorporated into the course. Structured programming grew out of the realization that mastery of three basic programming constructions would allow the programmer to handle any programming situation. These three constructions are sequential operations, IF-THEN-ELSE logic, and iteration (or repetition) as embodied in DO-WHILE, REPEAT-UNTIL, or FOR-NEXT loops. Structured programming stresses a programming style that breaks programs into interacting modules, each charged with executing one of the program's many functions. The objective of this programming style is to produce programs that are readable, verifiable, and maintainable by persons other than the original programmer.

There are obvious similarities between the structured programming approach and the natural approach that a good student takes to solving a mathematical problem. The thought patterns learned from structured programming should be carried over into students' attempts at other problem solving.

Programming concepts are stressed over syntax. Once a student can formulate the solution of a problem in the pseudocode of IF-THEN-ELSE logic and DO-WHILE iteration, it is a small matter for the student to code his or her program in one of the standard languages.

The course is designed to run approximately 13 weeks, with each week consisting of 3 h of in-class time. However, in each 3-h session, only 30 to 50 min are devoted to lecture. The remaining time is spent at a terminal or at a microcomputer in a laboratory setting with the instructor available to provide help at all times. After about 9 weeks devoted to a language such as WATFIV (however, other languages such as PASCAL certainly could be used), we began the microcomputer segment of our course.

We feel that this two-fold approach is very beneficial. Not only is the student introduced to a very structured, high-level language (like WATFIV or PASCAL) and a not-so-structured, high-level language like BASIC, but also the student encounters both batch-processing systems and interactive systems. An additional benefit accrues in that we require some of the key programs to be written in both languages, using the same algorithms. The rest of this paper is devoted to describing the course.

THE COURSE

Unit 1. Introduction to the computer and batch processing (1 week)

After introductory comments on computer organization and programs and programming languages, we introduce batch processing. A complete program file is presented to illustrate job-control language, the high-level-language program and the data section. The student is told how to logon and to execute the program. The student executes this short program during the second half of the class period. Some language is introduced in that the program to be executed is explained.

Unit 2. Introduction to a structured language (1 week)

The unit starts with some basic details of the language regarding variables, declaration statements, assignment statements, PRINT, READ, STOP and END.

After these introductory remarks, attention is turned to writing simple programs. To this end we take a problem and discuss in detail the procedure of going from the statement of the problem to the solution via the computer. As the problem is worked, attention is given to the use of the words "input data", "output data", and "algorithm". The proper approach to designing a program, we stress, uses the same thought processes that one uses in attacking a mathematical problem.

As our first problem, we elect a very simple case such as writing a program to compute and print the sum and the mean of two numbers. As we work the problem, we stress a pattern that is to be repeated for each problem subsequently discussed. We stress three steps in problem solving—analysis of the problem, which includes identifying the input and output data; writing and simplification of the algorithm; and, the final step of expressing the algorithm in the language selected.

From the start, we insist upon good programming constructs and good programming habits. We stress concepts and allow syntax to be secondary. Several examples are presented, illustrating in each instance the very definite sequence of steps necessary for solving problems. The student is then asked to execute each of the discussed programs after altering them in certain ways. This allows the student to gain experience not only in language usage but also batch processing.

Unit 3. Structured programming (2 weeks)

First, the DO-WHILE loop is discussed in detail. To do this, we return to our initial example of finding the sum and mean of two numbers and present the natural extension of finding such results for several hundred pairs of numbers. This, of course, provides the opportunity to introduce the concept of sentinel values. After the DO-WHILE loop has been established by using several examples, we turn our attention to IF-THEN-ELSE logic and the associated structure. To illustrate IF-THEN-ELSE logic, we first consider several natural examples associated with teaching, such as grade assignment. Another excellent example, keeping in mind that we are speaking to future secondary mathematics and science teachers, is writing a program to compute the roots of linear and quadratic equations. Last of all, we investigate the DO loop.

Having laid a foundation in programming, we decide upon a "term problem" to be programmed. Possibly, two or three such problems could be handled concurrently. The construction of a computerized grade book is a very good choice for such a project. Another choice is the construction of a complete company payroll program.

Suppose we decide upon the gradebook construction problem. We are far enough along in the course that we could use nested IF statements in writing an algorithm and the corresponding program. The program should accept scores for a course examination as input and then print not only the scores but also the number of scores in each percentage interval. With this foundation, we build a gradebook.

Unit 4. More on the language (1 week)

More information regarding the language is presented. This information includes the use of strings and the numerical "built-in" functions.

With this additional information, we again consider the term project. We write a program that allows inputting of a first name, a last name and a set of 6 integer test scores. For output, we make use of a table-type output where, for each student, we have one line of output consisting of the last name, the first name, the average and a grade. To figure the average we use the top 5 input scores. This requires the programmers to use certain "built-in" functions. To further heighten the interest, we allow the output in decimal format and assign grades using our previously formed nested IF format. DO-WHILE loops are used so that the student can see the advantage of writing a program that could handle classes of different sizes.

Unit 5. Arrays (1 week)

After introducing arrays and illustrating searching and sorting of arrays, we show how the additional tools can be applied to the term project. The students redo the gradebook construction program to allow inputting into array format and to further allow the installation of a sort routine. With the introduction of a sort routine, the program prints the last names in alphabetical order.

Unit 6. Formatted output (1 week)

Formatted output is introduced. The T descriptor (a tab approach) is presented. Upon grasping this concept, the student returns to the gradebook construction problem. The necessary program lines are added to give nicely designed output of the results already computed.

Unit 7. Step-wise programming and remote blocks (2 weeks)

In many applications, a program is required to execute many different processes, and it becomes important to segment these programs into smaller subprograms that focus on one algorithm at a time. Thus, the concept of modular design of programs is introduced. In addition, the concept of a main module or driver which controls the flow of logic in the program is developed. Hence, the student is introduced to subprograms and to subroutines.

We also illustrate the syntax for each structure as used in BASIC. Instead of a DO-WHILE loop, we use a REPEAT-UNTIL loop for BASIC. A pattern is provided that easily allows the user to identify the various structures.

Unit 8. Using a microcomputer (1 week)

From this point in the course forward, very little time is spent in the lecture mode; the foundation already has been laid. This week allows the student to get used to the microcomputer and to carry over the elementary aspects of computing. Built-in string functions are added during this week.

Unit 9. Structures in BASIC (1 week)

During this week, the student has a chance to see how the basic structures emphasized earlier can be implemented in BASIC. Since BASIC lacks some of the formal structuring found in WATFIV, we set forth a format style that is easy to read and easy to modify. The style, illustrated here with an IF-THEN-ELSE segment, is shown next (AA, BB, XX, YY and ZZ denote line numbers):

```
AA IF condition THEN XX ELSE YY
XX REM IF
     IF clause statements
BB GO TO ZZ
YY REM ELSE
     ELSE clause statements
ZZ REM ENDIF
```

Unit 10. Step-wise programming, drivers, subroutines (1 week)

Subroutines and subprograms are implemented using GOSUBs. Several Computer Assisted Instruction (CAI) programs are illustrated.

Unit 11. Arrays (1 week)

Search and sort programs are implemented using BASIC. The student finishes up his term project by converting his previously written program to BASIC.

Unit 12. Disk operations (1 week)

Knowledge of disk operations has been increasing since the introduction of the microcomputer component of the course. Some final points are made regarding files.

The student is expected to finish up the term project, not only in WATFIV or PASCAL but also in BASIC.

CONCLUSION

It is our belief that, when it comes to the training of teachers, it is not enough to discuss computers in the abstract or to train teachers to use pre-packaged software. It is not even enough to build interest in, and a positive attitude toward, computers and CAI. Secondary mathematics and science teachers must have a level of computer literacy which includes familiarity with basic programming structures and actual programming experience. There is no reason to demand less from future teachers in the realm of good programming habits than we normally require from our other students. The precepts of structured programming provide an elegant and viable route for introducing prospective teachers to habits of thinking which not only will open programming doors for them, but will sharpen their problem solving skills as well.

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LIABILITY FOR STUDENT INJURIES IN SCIENCE-RELATED ACTIVITIES

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ABSTRACT

Science classroom, laboratory, and field-trip activities are becoming increasingly vulnerable to litigation consequent to student injuries arising from allegedly negligent conduct on the part of the instructor. Increased notoriety of carcinogenic laboratory chemicals, a general increase in the tendency to sue, and sizable financial settlements place considerable pressure upon the science teacher to act with emphasized prudence and foresight. This study analyzes tort liability cases involving laboratory, off-campus, and field-trip accidents; administration of first aid; maintenance of facilities and equipment; and exposure to hazardous chemicals.

INTRODUCTION

Lieberman (1981), in his book *The Litigious Society,* has called this a "law drenched age." Everyone seems ready and willing to sue everyone else, and the school house and its occupants are not exempt. Rogers (1981) points out that the older attitude of "accidents will happen" has been replaced by a newer feeling of "someone must pay." He states there has been a reduction of public respect for the professions, resulting in "the increasing exposure of the professions to lawsuits brought by a less-than-adoring public."

This paper focuses on the area of educational litigation involving liability resulting from negligence. Tort liability, as this area of civil law is called, varies from state to state and can be one of the most complex and difficult fields of law (Connors 1981). Before discussion of individual cases and a specific look at Texas tort law, a brief summary of tort liability is given.

TORT LIABILITY

Gifis (1975) defines a tort as "a wrong; a private or civil wrong or injury independent of contract, resulting from a breach of a legal duty." Prosser (1971) states that tort is the area of law remaining after exclusion of crimes, contract breaches, property rights and governmental problems. Prosser (1971) states that the purpose of tort law is "to adjust losses arising out of human activities and to afford compensa-

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tion for injuries sustained by one person as the result of the conduct of another."

According to McCarthy and Cambrow (1981), there are three categories of torts: intentional torts, strict liability, and negligence. Intentional torts include assault, battery, defamation, false imprisonment, and trespass. Strict liability occurs when a person is injured as the result of an unusual hazard and there is no need to establish negligence. Negligence, according to McCarthy and Cambrow (1981), involves conduct that falls below an acceptable standard of care and results in injury. Gifis (1975) defines negligence as failure to exercise that degree of care which a person of ordinary prudence (Reasonable Man Doctrine) would exercise under the same circumstances.

Elements of Negligence

There are four elements of negligence, and all must be present to establish negligence (Connors 1981). In the context of student-injury torts, the four elements of negligence may be described as follows:

1. The teacher has a duty to provide an appropriate *standard of care* for the student—to protect the student against unreasonable risk of injury.
2. Teachers have a duty to protect their students from *unreasonable risk*. To prove negligence, the student must prove that the teacher breached the duty required.
3. The student must prove that the teacher's conduct is the *proximate cause* of injury, not necessarily the direct or indirect cause but closely related in time, space, or order. This is a complex principle of law. The classic example is lack of supervision.
4. *Actual* (real and substantial) *injury* is the fourth element of negligence.

The student must establish all four of these elements to prove negligence, and the burden of proof is on the student.

Legal Principles

The court compares the actions of the teacher to those of a "reasonable man" (Reasonable Man Doctrine) by asking if the person possesses at least average intelligence, physical attributes required by the profession, normal perception and memory, and special skills and knowledge as required by the profession. The court seeks to determine if this reasonable man could have foreseen the accident (Doctrine of Foreseeability). This is, perhaps, the strongest element in a tort suit. Courts have stated that teachers have three obligations to their students—adequate supervision, proper instruction, and maintenance of equipment.

Additional information on the general topic of tort liability is provided by Prosser (1971), Hammes (1979), Hazard (1979), Eberlein (1980)

Hagenau (1980), Nolte (1980), Connors (1981), McCarthy and Cambrow (1981), and Kemerer (1982).

AREAS VULNERABLE TO LITIGATION IN SCIENCE EDUCATION

Harty (1982) reports that "student injuries occur most frequently during physical education class, intramurals, and interscholastic sports. As a result, physical education teachers and coaches face the possibility of being sued more often than other teachers." This fact is reiterated by Clear and Bagley (1982), who commented on the one million high school and college athletic injuries reported during the 1975-76 academic year nationwide.

In my own experience, vocational shops and science laboratories are the next most frequent locations for potential lawsuits resulting from student injuries. Chemicals, equipment, "hands-on" procedures, and inadequate supervision are risk factors.

The remainder of this paper describes individual cases that point to possible areas of litigation arising from science activities. Since many of these were jury rulings, other locations, times, and participants could have resulted in different decisions, but they do serve as a good basis for discussion. As Hammes (1979) points out, "judicial opinions are instructive, but they must be perceived as guidelines rather than rules, due to the unique circumstances surrounding each specific situation."

Laboratory Accidents

The most frequently reported science-related injuries involve laboratory accidents. Several excellent articles address this general topic, including Sweeney (1977), Joye (1978), Corbridge and Clay (1979), McGarity (1980) and Palladino (1980).

Brungard v. Hartman (1978) is a Pennsylvania case, interesting primarily because of the defense. A coed was injured in a chemistry laboratory explosion, sued the college and professor and lost because sovereign immunity (a doctrine precluding a suit against the government without its consent) protected both the college and the professor. Between the original decision in 1974 and the appeal in 1978, the Pennsylvania Supreme Court abolished the defense of sovereign immunity in this type of case. On appeal, the student won.

In *Butler v. Louisiana State Board of Education* (1976), a freshman coed had blood extracted for a biology experiment, fainted, fell forward and broke six teeth. She sued the professor and school board, charging negligence as the proximate cause of the accident. No bed or table was provided for students to lie on if they felt faint. Despite a defense of contributory negligence, the court held for the student, stating the professor had the same duty of care as a licensed medical doctor in this instance.

In *Mastrangelo v. West Side Union High School District of Merced County* (1935), a high school junior was performing a chemistry experiment for the third time with the instructor's permission. The experiment, which was in the laboratory manual, was the making of gunpowder. During this exercise the student mixed and ground the chemicals in an iron mortar as a shortcut and mistakingly added potassium chloride instead of potassium nitrate, resulting in an explosion and the loss of an eye. The student sued, charging that negligence by improper instruction and supervision proximately caused the accident. The State Supreme Court of California held for the student, stating that "a teacher's duty goes beyond merely providing students with general textbook instructions" for experiments and should include instructions on substitutions. The Court strongly questioned the value of such an experiment compared to the potential risk.

A jury awarded $27,303 in the case *Jay v. Walla Walla College* (1959) to a student whose left retina was punctured in a chemistry laboratory explosion. The student was attempting to use a faulty fire extinguisher to entinguish flames in an adjacent laboratory when the research materials exploded. The college was held negligent in failing to provide adequate fire-fighting equipment.

Injury from exploding alcohol burners was the basis for lawsuits in 1974 and 1979. In *Station v. Travelers Insurance Company* (1974) and *Travelers Insurance Company v. Wilson* (1974), a student sued the school board and its insurer for severe burns, and the insurer filed a suit against the teacher for damage recovery. The teacher had set up an alcohol burner to run a turbine science project for two students. The burner went out just before the judges arrived. The girls attempted to relight the burner, causing an explosion which injured a nearby student. The court held for the injured student, awarding him almost $8,000 and finding the instructor negligent despite his defenses of contributory negligence (a defense whereby the teacher seeks to establish that the student is at least partially responsible for the accident and subsequent injuries) and assumption of risk (a defense whereby the teacher seeks to establish that the student has knowledge of the dangerous condition and still voluntarily exposes himself or herself to the hazard). The instructor appealed, lost, and had to pay the costs of appeal.

The second alcohol case is *Bush v. Oscoda Area Schools* (1979), a Michigan case, the outcome of which has yet to be reported. In this case, a physical science teacher, due to increased enrollment, was forced to hold laboratory activities in a regular mathematics classroom without proper safety features and with alcohol burners instead of Bunsen burners. A student picked up a burner, an explosion occurred, and she suffered second- and third-degree burns. Despite a defense of governmental immunity, the court held that a school district is subject to liability for negligence and remanded the case for trial.

A Texas case, *Wagner v. Alvarado Independent School District* (1980), illustrates the legal defenses still available in Texas, which are no longer available in many other states. A physics teacher had a class move one-gallon jars of various acids from an old building to the new classroom building with proper instructions and warnings. Later, two students went back without permission of the teacher to move two remaining bottles. One of the girls fell and was severely injured by the acid. She sued, claiming negligence. The school district moved for summary judgment based on governmental immunity, and the court agreed. On appeal, the defendants again won based on the *Barr* case to be discussed later.

A former college student was awarded $45,000 in 1982 for injuries sustained in a 1974 chemistry laboratory accident (*LaVoie v. State* 1982). The student was conducting a mixture-separation experiment using ether as a solvent. She returned from the fume hood to her laboratory table with a flask of ether which she placed near a lighted Bunsen burner. The fumes immediately ignited, burning her face and upper chest. She filed a claim alleging negligence by the State in not providing adequate warning. The laboratory instructor was quite near the student at the time of the accident and had provided no warnings the day of the experiment. The original decision of the Court of Claims for the student was upheld on appeal despite a defense of contributory negligence.

Off-Campus Accidents

Educators have been held responsible for their students in accidents occurring off the school grounds in some cases. Although few in number, these cases have serious implications for teachers.

In a non-science case, *Calandri v. Ione Unified School District* (1963), a student built a toy cannon as a manual shop project. He then took it home, attempted to fire it and blew away most of one hand. The court found the shop teacher negligent for failing to warn him of the dangers involved.

In *Simmons v. Beauregard Parish School Board* (1975), a thirteen year old student built a model volcano at home and brought it to school for activity day. The teacher made no suggestions, did not approve the project, and did not supervise or discuss the project at any time with the student. After activity day, the student was returning home with the project when he stopped to demonstrate it to several friends at the bus stop. An explosion seriously injured the student. The court found the teacher guilty of negligent supervision and instruction, and the jury awarded $104,000 as general damages for injuries and $1,104 for medical bills. The court found that the school board still owed its unsophisticated students a duty of reasonable instruction, supervision, and warning to prevent them from harming themselves in situations which might foreseeably arise in connection with their academic handiwork (Hagenau 1980).

In both of these cases, the decisions rendered by the courts place a heavy, almost impossible, burden on teachers to not only adequately instruct and supervise students while at school but also to fully inform them of all potential dangers connected with sanctioned projects or potential projects which could develop from classroom discussions.

Field Trips

Field trips provide not only an additional means of supplementing instruction with first-hand experiences, but also they provide unique opportunities for accidents. Despite the potential for injury, it appears that few lawsuits have actually developed from field-trip accidents (*Mancha v. Field Museum of Natural History* 1972; *Morris v. Douglas County School District No. 9* 1965).

In a 1977 survey of attorneys general, superintendents, educational organizations, and school boards in all fifty states, DuVall and Krepel (1978) found that only three states (California, Illinois, and Kentucky) had specific laws regarding field trips. In addition, they found that only one state (California) reported a recent legal case involving field trips. DuVall and Krepel conclude that "the teacher is subject to no greater tort liability on a field trip than when performing duties in the classroom *if reasonable care and foresight are exercised*" (emphasis added).

Brown and Brown (1969) make the following recommendations for field trips: use permission slips, visit the sight immediately prior to the trip, fully prepare and instruct the students, have a first-aid kit readily available, and provide adequate supervision. Zirkel and Gluckman (1983) further emphasize the importance of permission slips in alerting students and parents to potential risks and in establishing the responsibility of the school.

First Aid

Although this researcher found no cases directly related to science accidents and first-aid treatment, there have been several lawsuits involving teachers who either have administered no first aid or did it in a negligent manner (e.g. *Guerrieri v. Tyson* 1942). The awards in these cases usually have exceeded $500,000.

Maintenance of Facilities/Equipment

Another area in which no science-related cases were found but which has a potential for litigation is maintenance of facilities and equipment. The majority of related cases involved shop accidents. In *Amon v. State* (1979), the court held SUNY at Albany negligent for not providing a safety guard on a table saw that severed a student's right index finger. In *Shannon v. Washington University* (1978), a student received $10,000 for a back injury when he fell on an icy sidewalk. In *Castro v. Fireman's Fund Insurance Company, Inc.* (1980), a student received $7,500 when his drafting stool collapsed and injured his back. Except for the fall on the icy sidewalk, these accidents could have occurred just as easily in science laboratories.

Exposure to Hazardous Chemicals

A growing area for potential litigation is student and faculty exposure to hazardous chemicals, especially carcinogens, in the laboratory. This subject was initially highlighted by the media when several schools discovered picric acid on their stockroom shelves and needed assistance in discarding this potentially explosive chemical (McDermott and Edgar 1979). Then, in 1979, evidence was reported establishing formaldehyde as a carcinogen (National Institute for Occupational Safety and Health 1981). We are now told that thiourea and phenylthiourea, asbestos, hydrochloric acid and methanol vapors, and crude oil are potentially carcinogenic (Hounshell and Cobel 1979; Weisburger 1980; Fries 1981; Melnikow et al. 1981).

In most instances it takes several years for exposure to certain chemicals to be manifest as cancer, and it is extremely difficult to legally establish a causal relationship in a cancer claim (Zubrensky 1980). Student and faculty exposure to potential carcinogens should be minimized or avoided. In addition, especially at the pre-college level, experiments involving any hazardous chemical should be carefully managed or eliminated from the curriculum. The obvious question to ask is, "Is the educational benefit worth the physical and legal risk?"

TORT LIABILITY IN TEXAS

As Conners (1981) points out, tort lawyers usually sue the governing board and all individuals however remotely associated with the situation under litigation. This technique covers all potential financial sources and increases the possibility of finding negligence. However, in Texas both the Texas Education Code and the Texas Tort Claims Act severely limit the potential for lawsuits and the financial awards. Section 21.912 (b) of the Texas Education Code provides that:

> No professional employee of any school district within this state shall be personally liable for any act incident to or within the scope of the duties of his position of employment, and which act involves the exercise of judgement or discretion on the part of the employee except in circumstances where professional employees use excessive force in the discipline of students or negligence resulting in bodily injury to students.

This section provides for a limited waiver of immunity only when the operation, use, or maintenance of a motor vehicle is involved. Even the purchase of liability insurance, which in most states waives governmental immunity, does not waive this defense in Texas. *Barr v. Bernhard* (1978) is a good case to read to understand the court's view on this.

The Texas Tort Claims Act (Article 6252-19 of Vernon's Texas Civil Statutes), which became effective in 1970, provides for units of government in Texas to be "liable for money damages for personal injuries or death when proximately caused by the negligence or wrongful act or omission of any officer or employee acting within the scope of his employment or office arising" from the use or operation of a motor vehicle or from some condition or use of tangible property (Section 3). This act does not apply to public school districts or to junior college districts except regarding motor vehicles.

Article 6252-26 of Vernon's Texas Civil Statutes provides for the state to be "liable for and pay actual damage, court costs, and attorney fees adjudged against officers or employees of any agency, institution, or department of the state" (Section 1). This act limits liability for a personal injury, death, or deprivation of a right to $100,000 for a single person and $300,000 for a single occurrence, and to $10,000 for injury or damage to property.

Even with this qualified cloak of protection by governmental immunity, which many states have eliminated, Texas state employees should not feel free from lawsuits. If they are sued and exonerated, legal expenses are costly, and future employment may be difficult. Although Texas statutes allow public school districts to pay damage claims, court costs, and attorney's fees of employees, they are not required to do so (Kemerer 1982). The statutes, of course, do not cover willful or wrongful act or omission, gross negligence, or official misconduct. Kemerer (1982, p. 112) warns that:

> Since we can anticipate that lawsuits will continue to be brought against school districts and school professionals, and since we cannot be sure that Texas teachers will always be so well protected in the future, the best advice is to observe school policies and rules carefully and to be sure to act within the ethical standards of one's

profession in carrying out assigned duties. When all else fails, good common sense offers excellent protection.

RECOMMENDATIONS

Science teachers should constantly caution students, after adequately instructing them in procedures and potential dangers. As the courts require, teachers should try at all times to act and react as a reasonable person (Reasonable Man Doctrine) would in similar circumstances, and attempt to anticipate situations which could result in injury (Doctrine of Foreseeability).

Proper instruction should be documented by the keeping of lecture notes and laboratory directions with indicated dates of instruction. The instructor also should retain graded examinations with students' initials next to missed questions, indicating their understanding of the concepts upon subsequent review. Teachers also should thoroughly check out each student individually regarding the correct assembly and operation of laboratory equipment; for this, a checklist, which can be initialed and dated, should be used.

Laboratories should be fully equipped with adequate safety devices, and equipment should be properly maintained, with maintenance records kept current. Potentially hazardous experiments should be avoided when possible. Stockrooms should be checked periodically for outdated stock and hazardous chemicals.

If an accident occurs, the teacher should act promptly with minimal first aid followed by immediate referral for medical attention. The teacher should also carefully document each accident in case further questions arise.

Field trips should be carefully planned, with the site visited and evaluated prior to the trip. Detailed permission slips should be used for each trip.

Finally, teachers should attempt to caution students regarding the potential for injury arising from current study topics, laboratory experiments, assigned projects, and other student activities of which the teacher may be aware.

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REPRODUCTIVE ECOLOGY OF THE POCKET GOPHER, *GEOMYS PERSONATUS*, IN SOUTH TEXAS

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ABSTRACT

The reproductive ecology of *Geomys personatus* was studied from December 1979 through November 1980, in the lower Rio Grande Valley of Texas. A sample of 228 specimens (100 adult males, 109 adult females, 3 juvenile males and 16 juvenile females) was obtained. Sex ratios of the sample indicated equal numbers of adult males and females in the population. Males were reproductively active throughout the year, but most pregnancies occurred in the cooler months, i.e. October through February. Litter size was 1-4 ($\bar{X} = 3.3$). There was no correlation between body weight of females and litter size. Testis weight was the only reproductive parameter that was significantly correlated with a climatic variable (temperature). There was no evidence that precipitation caused immediate or delayed effects on reproductive activity.

INTRODUCTION

Studies of reproductive ecology of pocket gophers of the genus *Geomys* have focused on *G. bursarius* (English 1932; Wood 1949; Kennerly 1958; Vaughan 1962; Wilks 1963) and *G. pinetus* (Wing 1960; Brown 1971; Ewel 1971). Little is known of reproductive parameters in *G. personatus* (Williams 1982). Based on young animals (approximately one-fourth adult size) trapped in early April, Davis (1974) suggested that mating may occur as early as February. Williams (1982) pointed out that specimens collected in February by Allen (1891) included a 7 to 10 day old individual, indicating that mating can occur earlier than February. Kennerly (1958) found pregnant females in December, January, February, March and May. The mean number of embryos in 11 pregnant females was 3.18 (range 2 to 4) and the sex ratio was 2 males:3 females (Kennerly 1958). Kennerly's data were obtained from irregular collections made over a 2.5-year period and the only data provided on reproductive activity of males were two observations of simultaneous occupancy of burrows by a male and a female in January, suggesting that males were reproductively active at this time. Thus, there has been no study of the reproductive cycle of both sexes based on collections made at regularly spaced intervals throughout an

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entire year. Consequently, we sought to provide information on length of the reproductive season, sex ratio, population age structure, litter size, and the effect of temperature and rainfall on reproductive activity of *Geomys personatus megapotamus* in the lower Rio Grande Valley of Texas.

MATERIALS AND METHODS

Geomys personatus in Texas is restricted almost exclusively to the fine, deep sands between the Nueces River in the north and the Rio Grande in the south (Davis 1940; Williams 1982) and is the only species of *Geomys* occurring in the lower Rio Grande Valley of Texas (Starr, Hidalgo, Willacy, and Cameron counties; Hall 1981).

Collection began in December 1979, and continued at monthly intervals until November 1980. Pocket gophers were captured in "Victor" gopher traps during the last two weeks of each month. Eighteen pocket gophers were captured in Willacy County, four in Starr County and 206 in Hidalgo County. Localities are given in Doerr (1981).

At each capture, the date and location were recorded on a label and the label attached to the right hindfoot of the pocket gopher. The gopher then was sealed in a plastic bag, placed on ice and returned to the lab for processing (or frozen for later processing). In the laboratory, each animal was weighed to the nearest 0.1 g on an Ohaus triple-beam balance. Total length, tail length, hindfoot length, and ear length were measured to the nearest mm with a ruler.

Each gopher then was dissected to confirm the sex and to determine reproductive condition. Wet weights of ovaries and testes were measured to 0.001 g on a Mettler P163 balance. In females, the vagina was inspected for presence or absence of a copulation plug and the pubic symphysis was examined to determine if it was closed or open. Reabsorption, i.e. opening, of the pubic symphysis coincides with attainment of sexual maturity in female pocket gophers (Hisaw 1924); thus, females with closed pubic symphyses were classed as juveniles and females with open pubic symphyses were classed as adults. Uteri were inspected for the presence of embryos and/or placental scars. Number, location (right or left horn), weights and crown-rump lengths of embryos were recorded. If no embryos were found, the uteri were flushed with physiological saline and examined microscopically to determine if spermatozoa were present. Mammae were dissected to determine whether or not females were lactating. In males, a smear of the cauda epididymis was diluted with physiological saline and examined microscopically for the presence of spermatozoa. Abundance of spermatozoa was coded as follows: 1 = no sperm, 2 = few sperm, 3 = many sperm but epididymis not packed, and 4 = epididymis packed with sperm. Males were considered juveniles if their body weight was less than 130 g. This criterion was based on the observation that the smallest male with spermatozoa in the epididymis weighed 133.6 g. Thus, males 133 g or larger were considered potentially capable of producing sperm.

Data were analyzed on a monthly basis and the year was divided also into cool and warm seasons. Months when mean temperature was less than 22 C were considered cool months (October-March), and months when mean temperature was greater than 22 C constituted warm months (April-September). Mean monthly temperatures and total rainfall for each month were obtained from the National Oceanic and Atmospheric Administration data sheets for McCook, Hidalgo County, Texas.

Statistical procedures and tables used were those of Sokal and Rohlf (1969) and Rohlf and Sokal (1969). A probability value less than 0.05 was considered significant. Correlations, regressions and analyses of variance (ANOVA) were done on a Dec-10 computer using the Western Michigan University STP package. Chi-square and *t*-tests were done on a desk calculator.

RESULTS

Sex Ratio and Population Structure

A total of 228 pocket gophers (100 adult males, 109 adult females, 3 juvenile males, 16 juvenile females) was collected. Figure 1 shows the age and sex distribution on a monthly basis. There was no significant deviation from a 1:1 ratio of adult males: adult females, either overall or within a season. However, the sex ratio of juveniles (3 males:16 females) was significantly biased toward females (chi-square = 7.58, $P<0.01$). Juveniles comprised 8.3% of the total population. These individuals were collected primarily in the warmer months.

Reproductive Period

Figure 2 provides a comparison of the percentage of females exhibiting reproductive activity among months. Reproductive activity was based on the presence of embryos, lactating mammae, or placental scars. With the exception of one pregnant female captured in July, pregnancies occurred in the cooler months of the year (i.e., October-February). Most of the lactating females were collected in winter or spring, but one lactating female was captured in August. Pregnant or lactating females were found in January, February, April, July, August, October, and November. Females with placental scars occurred in all months except September, October, and November. These data suggest that reproduction may have occurred at any time of the year, but that

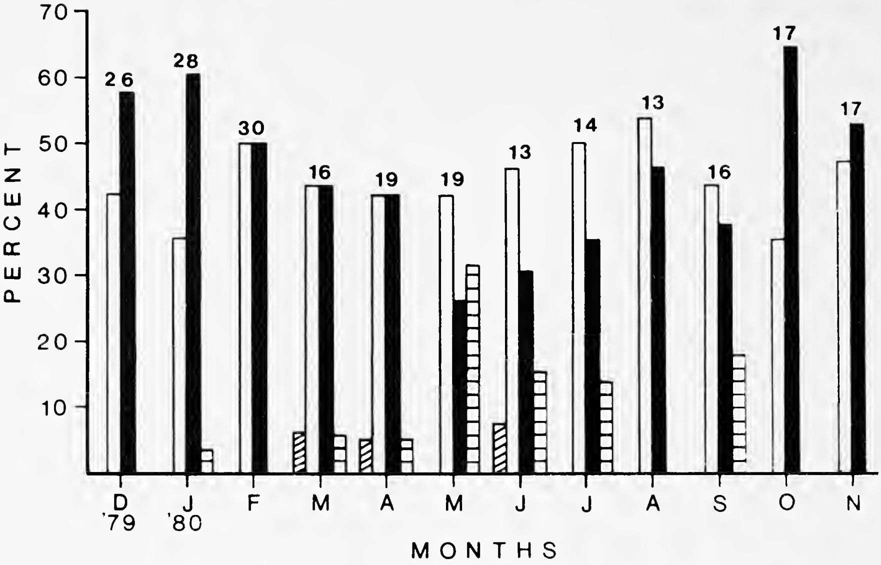

FIGURE 1. Distribution of age and sex groups by month of collection. Open columns represent adult males, solid columns indicate adult females, obliquely barred columns represent juvenile males, and horizontally barred columns indicate juvenile females. Numbers above the columns are sample sizes.

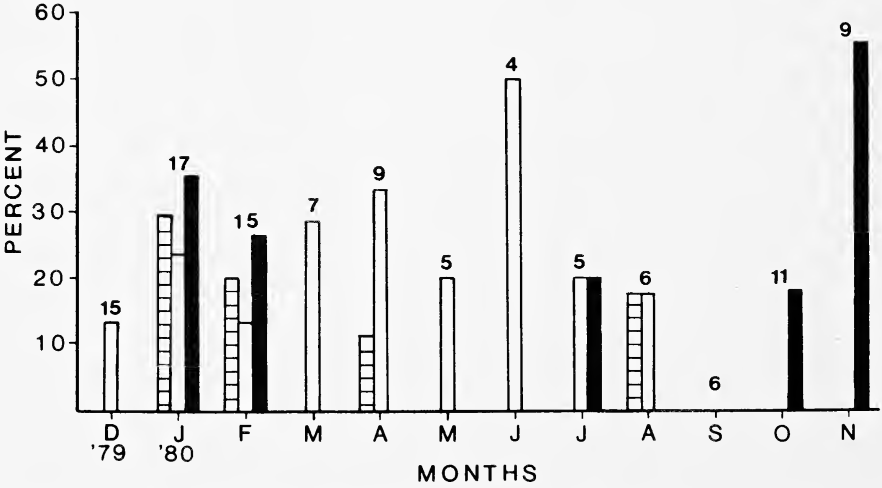

FIGURE 2. Percentage of females exhibiting reproductive activity by month of collection. Open columns represent females with placental scars, horizontally barred columns indicate lactating females, and solid columns represent pregnant females. Numbers above the columns are total sample size of adult females examined.

TABLE 1. Relative quantity of sperm in the epididymis of adult pocket gophers by month of collection. 1 = no sperm; 2 = few sperm; 3 = abundant sperm, but epididymis not packed; 4 = epididymis packed with sperm. N = sample size.

		% in Categories				Sum of	Sum of
Months	N	1	2	3	4	1 & 2	3 & 4
Dec	11	36.4	9.1	27.3	27.3	45.5	54.6
Jan	10	10.0	20.0	10.0	60.0	30.0	70.0
Feb	15	6.7	0.0	26.7	66.7	6.7	93.4
Mar	7	0.0	0.0	14.3	85.7	0.0	100.0
Apr	8	12.5	0.0	12.5	75.0	12.5	87.5
May	8	12.5	12.5	0.0	75.0	25.0	75.0
Jun	6	0.0	50.0	33.3	16.7	50.0	50.0
Jul	7	14.3	42.9	14.3	28.6	57.2	42.9
Aug	7	42.9	0.0	14.3	42.9	42.9	57.2
Sep	7	57.1	0.0	42.9	0.0	57.1	42.9
Oct	6	0.0	16.7	33.3	50.0	16.7	83.3
Nov	8	0.0	0.0	12.5	87.5	0.0	100.0

activity was greatest in the cooler months of the year, from October through February.

Reproductively active males were present in each month of the year (Table 1). Comparison of the sums of categories 3 and 4 versus the sums for categories 1 and 2 in Table 1 contrasts the percentage of males with large numbers of spermatozoa in the epididymis with those with few or no spermatozoa in the epididymis. Percentages were arcsin-square root transformed and the mean for the warmer months of the year (April-September) was compared with the mean for the cooler months (October-March) using a t-test. The mean for the cooler months, 83.6%, was significantly greater ($t = 2.355$, 11 df, $P < 0.05$) than the mean for the warmer months (59.3%). Testis weight of adult males (Fig. 3) also varied significantly among months ($F = 2.560$, 11 & 88 df, $P < 0.01$), but there was no significant difference in mean testis weight ($t = 1.629$, 98 df, $P > 0.1$) between animals collected in the warmer months ($\bar{X} = 0.862$) and cooler months ($\bar{X} = 1.083$). Thus, the data for males also indicate that breeding may have occurred at any time during the year but that breeding activity was greater in the cooler months.

Litter Size

Litter size based on embryo counts of 18 pregnant females ranged from 1 to 4 ($\bar{X} = 3.3$, SE = 0.19). Litter size based on counts of 23 females with placental scars ranged from 1 to 5. Three females each had an embryo much smaller in size relative to other embryos present. We interpreted the small embryo to be undergoing resorption. No females were found with both embryos and placental scars. There was

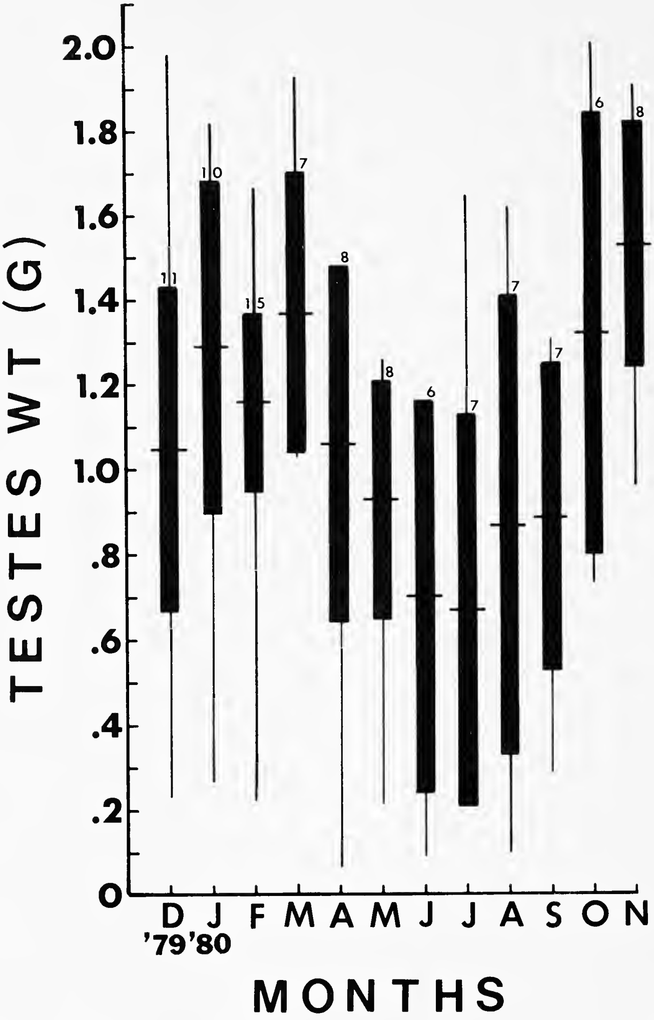

FIGURE 3. Testis weight by month of collection. Vertical lines show the range; horizontal lines represent the mean. Vertical bars indicate 95% confidence intervals about the mean. Numbers indicate sample size.

no significant correlation between body weight of female and litter size ($r = 0.385$, 16 df, $P > 0.1$).

Climatic Correlates of Reproductive Activity

Table 2 provides correlations between measures of reproductive activity and two climatic variables, temperature and rainfall. Because there may have been a time lag between occurrence of precipitation and a vegetative response, each of the measures of reproductive activity was examined also for correlation with precipitation during the preceding

TABLE 2. Correlation coefficients for measures of reproductive activity and climatic variables. NS indicates probability greater than 0.05. Number of months = 12. All percentages were arcsine-square root transformed.

Variables	Correlation Coefficient	Significance
Temperature vs % pregnant ♀♀	−.340	NS
Temperature vs % ♂♂ with sperm	−.190	NS
Temperature vs $\bar{X}$ testis weight	−.679	$P < .05$
Precipitation vs % pregnant ♀♀	−.270	NS
Precipitation vs % ♂♂ with sperm	−.502	NS
Precipitation vs $\bar{X}$ testis weight	−.163	NS
Preceding month's precipitation vs % pregnant ♀♀	.130	NS
Preceding month's precipitation vs % ♂♂ with sperm	−.023	NS
Preceding month's precipitation vs $\bar{X}$ testis weight	.001	NS

month. Testis weight was the only reproductive parameter that was significantly correlated with a climatic variable; testis weight showed a significant inverse correlation with temperature. There was no evidence that precipitation exhibited immediate or time-lagged effects on reproductive activity.

DISCUSSION

Sex Ratio and Population Structure

We found a 1:1 male:female sex ratio for adult *Geomys personatus*. Wilks (1963) reported a 1:1 sex ratio for a Texas population of *G. bursarius,* but most workers have reported a sex ratio of approximately 3 females:2 males for species of *Geomys* (Wood 1949; Kennerly 1958; Wing 1960; Vaughan 1962; Brown 1971) and *Thomomys* (Howard and Childs 1959; Hansen 1960). Smolen et al. (1980) found that the sex ratio of *Pappogeomys castanops* varied from 3:1 in favor of females to 1:1. In most of their samples, females were more abundant. Explanations offered for a deviation from a 1:1 sex ratio have included sampling bias (Kennerly 1958; Wing 1960) and differential mortality (Wing 1960; Vaughan 1962; Brown 1971).

The significant deviation from a 1:1 sex ratio that we observed in juvenile *G. personatus* probably is due to the difference in criteria used to distinguish between juvenile and adult status in males and females. Females were classed as adults if the pubic symphysis was open. This characteristic is associated with maturation of the reproductive organs (Hisaw 1924). Conversely, males were classed as adults based on their achieving a body weight equal to that of the smallest reproductively active male. Attainment of a particular body weight is not necessarily correlated with maturation of the reproductive organs; consequently, some males that were juveniles were likely classed as adults. Therefore, the bias we observed in favor of juvenile females was probably due to greater accuracy in identifying juvenile females compared to juvenile males.

Juveniles comprised only 8.3% of our total sample. Low frequencies of juveniles were recorded by Brown (1971) for *Geomys pinetis* (7.3%) and Wilks (1963) for *G. bursarius* (10.4%), but Wing (1960) reported that 24% of a population of *G. pinetis* was composed of immature individuals and Vaughan (1962) found that juveniles constituted 48% of a population of *G. bursarius.* The low frequency of juveniles that we observed is not surprising, considering the low frequency of pregnant females (16.5%).

Reproductive Period

Our data show that reproductively active males are present in each month of the year, but this does not necessarily mean that a given male remains reproductively active throughout the year once sexual maturity is achieved. Nevertheless, year-round reproduction has been observed by Wing (1960) and Brown (1971) for *Geomys pinetis* and by Miller (1946) for *Thomomys bottae.* Furthermore, in each of these studies females also were reproductively active throughout the year.

The length of the reproductive period of female *G. personatus* is difficult to establish with certainty from the data currently available. Kennerly (1958) found pregnant females in winter and spring (December, January, February, March, May) while we found most pregnancies occurred in winter and fall (January, February, July, October, November). The combined data of the two studies show that pregnant females were found in eight months of the year and that each season was represented.

As we suggested above, reproduction may occur throughout the year, but at low frequency from March through September. We may have failed to find reproductively active females in these months because of a combination of low frequency of reproductively active females and small sample size. Alternatively, reproduction in females may be limited primarily to the cooler months of the year with sporadic breeding during the warm season depending on prevailing environmental factors and nutritional condition of the females.

Climatic Correlates of Reproductive Activity

If reproduction occurs throughout the year and if there is no clear peak in reproductive activity, one would expect absence of correlation between measures of reproductive activity and climatic variables. This, no doubt, accounts for the lack of correlation between climatic variables and the percentage of males with spermatozoa in the epididymis. Year-round reproduction with no seasonal peak also may explain the lack of correlation between percent pregnant females and the climatic variables. Conversely, the data for testis weight indicate that temperature affects reproductive activity of males.

Miller (1946), Hansen (1960), and Brown (1971) attributed peaks of reproductive activity in pocket gophers to the moderation of temperature and increases in rainfall. Increased rainfall was thought to contribute to an increase in friability of soil, abundance of vegetation and nutrient availability. However, Ingles (1949) reported that reproduction occurred in a California population of *Thomomys monticola* when the ground was too wet for gophers to dig and when very little vegetation was present. Bandoli (1981) studied factors influencing burrowing activity of *Thomomys bottae* and found that precipitation was not a major factor influencing burrowing activity. Thus, lack of immediate or time-lagged effects of precipitation on reproductive activity in our study agrees with the conclusions of Ingles (1949) and Bandoli (1981).

Litter Size and Frequency

Geomys personatus apparently exhibits little variation in litter size, for the mean we obtained (3.3) and that reported by Kennerly (1958) (3.2) are very similar. Litter frequency of *G. personatus* is unknown, but Davis (1974) states that probably no more than two litters are reared yearly. If litter frequency is two per year, then a reproductive potential of 6.6 offspring per year is indicated. This is the greatest of any species of *Geomys* (see English 1932; Wood 1949; Kennerly 1958; Wing 1960; Vaughan 1962; Brown 1971 for comparisons). It should be noted that recent studies (Honeycutt and Schmidly 1979; Tucker and Schmidly 1981; Bohlin and Zimmerman 1982) show that the taxon known as *G. bursarius* when the above-referenced reproductive studies were done is actually a composite of three species—*G. attwateri, G. breviceps,* and *G. lutescens.*

Important aspects of reproduction in *G. personatus* that remain to be determined are litter frequency, length of gestation, age at sexual maturity, and age at weaning. Also, the length of the reproductive period in females needs to be ascertained more accurately. Obtaining these data will require mark-recapture studies and collection of large numbers of females.

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WOODY-SPECIES COMPOSITION OF THE UPPER SAN ANTONIO RIVER GALLERY FOREST

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ABSTRACT

The San Antonio River flood plain, south of San Antonio, Texas, supports a mature forest dominated by Texas sugarberry (*Celtis laevigata*). Major subdominants of the forest in descending order were boxelder (*Acer negundo*), cedar elm (*Ulmus crassifolia*), cottonwood (*Populus deltoides*) and gum bumelia (*Bumelia lanuginosa*). Greatest total density and total basal area were found at the river edge. Black willow (*Salix nigra*) and cottonwood were found solely at the river edge; whereas, live oak (*Quercus virginiana*), mesquite (*Prosopis glandulosa*), and desert hackberry (*Celtis pallida*) were found only at the upper limit of the flood plain. Species diversity increased as distance from the river increased. A total of thirty-three woody species were encountered in this flood plain forest.

INTRODUCTION

Riparian ecosystems, although narrow and small in aggregate area, add important diversity to their associated regions. Several authors have shown that many species found within certain regions are isolated in the riparian forests of those regions (Bell 1974; Petranka and Holland 1980; Ford and Van Auken 1982). The South Texas Plains are characterized by open prairies, savannahs, and dense thickets of small trees and shrubs. Widespread woody species include mesquite (*Prosopis glandulosa*), desert hackberry (*Celtis pallida*), and several acacias (*Acacia* spp.) (Correll and Johnston 1970). Some additional important species seem to be limited in distribution to the narrow riparian forests of the region. The species composition and structure of these riparian forests are undescribed.

The woody vegetation of riparian forests is under the influence of a complex environmental gradient composed of such factors as soil moisture, degree of bank slope, bank erosion, and flood frequency (Hosner and Boyce 1962; Bell 1974; Ford and Van Auken 1982). Several authors have stressed the importance of floods in influencing the distribution of plant species in riparian habitats (Hosner and Boyce 1962; Bell 1974). Work on another riparian forest has suggested that changes in com-

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munity composition, as a function of distance from the river, are coincident with decreased soil moisture and decreased soil depth (Ford and Van Auken 1982). Hosner and Boyce (1962) suggested that species inhabiting the flood zone are sorted out along the gradient in response to low oxygen and high carbon dioxide levels in the rooting zone, which occur during floods. Bell (1974) reported that the spatial distribution of established individuals in the flood zone indicates the flood tolerance of the species, which is probably an oversimplification.

This paper describes the phytosociology and distribution of the major woody species in the riparian forest of the upper San Antonio River.

STUDY SITE

The study site was located along the San Antonio River, in the northern portion of the South Texas Plains region (Gould 1969). Four mature plant communities, or stands, between 4 and 5 ha each were examined. Stands were located between 3.8 and 5.0 km south of Floresville, Texas, in Wilson County. The stands were determined to be mature by using a Markov chain analysis (Horn 1975).

The region is considered semiarid (Thornthwaite 1948), receiving approximately 70 cm of rainfall per year with maximums in May and September, with considerable variation (Carr 1967; Arbingast et al. 1976). Mean annual temperature is approximately 15.5 C (Arbingast et al. 1976), with a peak in July or August and a low in January (Carr 1967). The flood plain has deep (240-310 cm), usually well-drained, calcareous, friable, loamy soils of the Frio or Loire series (Taylor 1977).

METHODS

Sampling was limited to woody species including shrubs and vines. Only stems greater than 1 cm in diameter at breast height were measured. Nine belt transects (Greig-Smith 1964) consisting of adjacent 5 x 5 m quadrats were utilized in the sampling design in each of the 4 plant communities. All transects were parallel to the river, with transect 1 next to the river and number 9 next to a pasture, approximately 60 m from the river (Fig. 1A). In each stand, slope angles and distances were measured along 4 lines perpendicular to the river. These measurements were used to show the elevational relationship of the river flood plain (Fig. 1B). Slope angles were measured with a Brunton compass.

Woody plants were counted and measured in 40 to 100 quadrats per transect. Total area sampled in each strip was between 0.1 and 0.25 ha. Sample adequacy for each transect in each stand was estimated by using the t statistic as follows:

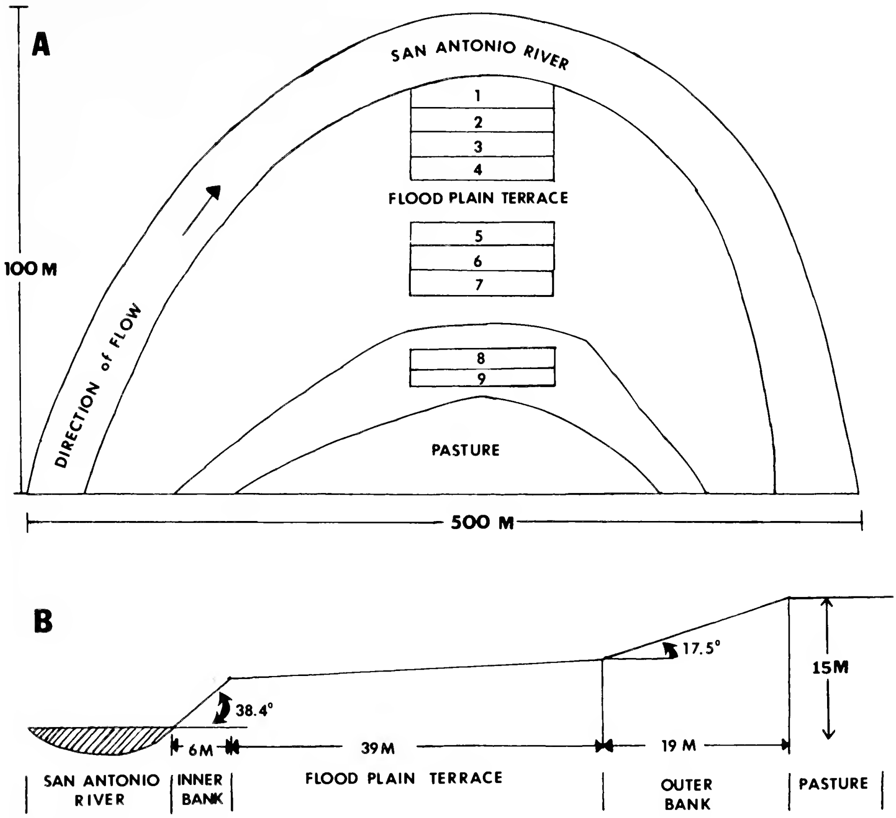

FIGURE 1. A. Schematic representation of a study site on the flood plain of the San Antonio River. Transect 1 was in the inner bank region, 2-7 were on the terrace and 8 and 9 were in the outer bank region. B. Elevation relations of the flood plain terrace of the San Antonio river. Values presented are means for all 4 study sites.

$$\%\ \text{error} = \frac{(\text{t value}) \cdot (\text{mean density})}{\sqrt{(\text{no. of quadrats})} \cdot (\text{standard deviation})} \times 100\%$$

The mean estimated error was 20% with a standard deviation of 6%; however, the range was 10 to 40%. The large error was due to the high sample variance found within these strips caused by numerous light gaps or tree falls. The estimated number of quadrats needed for a 5% error rate was often larger than the total forest area available for sampling.

In the field, plants were identified and measured. Scientific nomenclature followed Correll and Johnston (1970). Species diversity (H′) was calculated for each transect in each stand (Shannon and Weaver 1949). Density, basal area, and frequency as well as their corresponding relative values were also calculated (Cox 1980). Importance values were determined by taking the sum of the relative density plus relative basal area and dividing by 2. Importance values were used to determine which species dominated the community. Data from all 9 belt transects were used to determine each species' average density, basal area, and importance in each stand. Next, mean density, basal area and importance were calculated for each species using all 4 stands. Analysis of variance and Duncan's Multiple Range Test as well as linear correlations were used to compare forest parameters among strips (Steel and Torrie 1980).

RESULTS

The flood plain of the San Antonio River can be divided into three easily recognized, physically defined regions (Fig. 1). The inner bank is steep (38.4°) and narrow (6 m), the flood plain terrace is much broader (39 m) with a very slight slope (3.0°), and the outer bank is relatively narrow (19 m) with a noticeable slope (17.5°). 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 flood plain. Consequently, all measurements from all transects and all four stands were pooled to determine the overall community composition. Differences in species presence and species dominants did occur from the river edge to the outer bank.

Overall forest density was 1,531 ± 148 plants/ha (Table 1). Texas sugarberry (*Celtis laevigata*) had the highest density (473 plants/ha), followed by boxelder (*Acer negundo*) and cedar elm (*Ulmus crassifolia*). Mean total basal area was 25.98 ± 1.32 m^2/ha. Of this total, Texas sugarberry accounted for 41%, with a mean basal area of 10.63 m^2/ha. This value is three times higher than that of the next species, cottonwood (*Populus deltoides*—3.25 m^2/ha). Other species with high mean basal areas (Table 1), in descending order, were boxelder, cedar elm, black willow (*Salix nigra*), pecan (*Carya illinoinensis*), and American elm (*U. americana*).

The species with the largest mean importance value was Texas sugarberry (36%; Table 1). Other species with high importance values in descending order were boxelder, cedar elm, cottonwood, and gum bumelia (*Bumelia lanuginosa*). Eleven species had mean importance values of 1%, and 12 species occurred infrequently with importance values less than 0.5% (Table 1).

The higher mean numbers of species (14 to 16) occurred in the transects farther from the river, with the lowest number (12) found nearest the river (Fig. 2). Species diversity was positively correlated with distance from the river edge ($r = 0.78$, $n = 9$, $P < 0.0001$), with the lowest

TABLE 1. Density, basal area, and importance value (IV) for the major woody species found in the San Antonio River riparian forest. Values presented are the means for each species for the 4 stands sampled. The importance value is the sum of the mean relative density and relative basal area for each species divided by 2.

Woody Species	Density (plants/ha)	Basal Area (m^2/ha)	IV (%)
Texas sugarberry (*Celtis laevigata*)	473	10.63	36
Boxelder (*Acer negundo*)	334	2.16	15
Cedar elm (*Ulmus crassifolia*)	211	2.14	11
Cottonwood (*Populus deltoides*)	6	3.25	7
Gum bumelia (*Bumelia lanuginosa*)	112	.54	5
Mustang grape (*Vitis mustangensis*)	96	.32	3
American elm (*Ulmus americana*)	26	1.26	3
Black willow (*Salix nigra*)	9	1.63	3
Pecan (*Carya illinoinensis*)	9	1.46	3
Red mulberry (*Morus rubra*)	28	.47	2
Others (23 Species)*	227	2.12	12
			100
All species: mean ± S.E.	1531 ± 148	25.98 ± 1.32	

*Eleven species had mean importance values of 1%: trumpet creeper (*Campsis radicans*), hawthorne (*Crataegus mollis*), Texas persimmon (*Diospyrus texana*), chinaberry (*Melia acedarach*), live oak (*Quercus virginiana*), soapberry (*Sapindus saponaria*), peppervine (*Ampelopsis arborea*), dogwood (*Cornus drummondii*), poison ivy (*Rhus toxicodendron*), bull-briar (*Smilax bona-nox*), and mesquite (*Prosopis glandulosa*). Twelve species had IV's of 0.5% or less: brasil (*Condalia hookeri*), elderberry (*Sambucus canadensis*), hop tree (*Ptelea trifoliata*), Virginia creeper (*Parthenocissus quinquifolia*), osage orange (*Maclura pomifera*), desert hackberry (*Celtis pallida*), wax-leaf ligustrum (*Ligustrum quihoui*), possum-haw (*Ilex decidua*), Texas mulberry (*Morus microphylla*), ash (*Fraxinus americana*), whitebrush (*Aloysia grattisima*), and sycamore (*Platanus occidentalis*).

value on the inner bank next to the river (1.72 ± 0.35, $\bar{X}$ ± S.E.), and then increasing to 2.90 ± 0.09 in the outer bank region. Total mean density was lowest on the terrace, with higher values at the upper and lower edges of the forest (Fig. 2). Mean basal area was negatively correlated with distance from the river edge ($r = -0.77$, $n = 9$, $P < 0.05$) and was highest at the river edge, with a value of approximately 40 m^2/ha (Fig. 2). As distance from the river increased, the mean basal area decreased, with the value at the outermost limits of the forest being half that found at the river edge.

Cottonwood and black willow were almost completely limited in distribution to the inner bank of the river, where they attained their highest importance. Boxelder was found throughout the riparian forest, but had its greatest mean density and mean basal area at the river edge, decreasing as distance from the river increased (Figs. 3A and 3B). Boxelder accounted for 40% of the total mean importance in transect 1 (Fig. 3C).

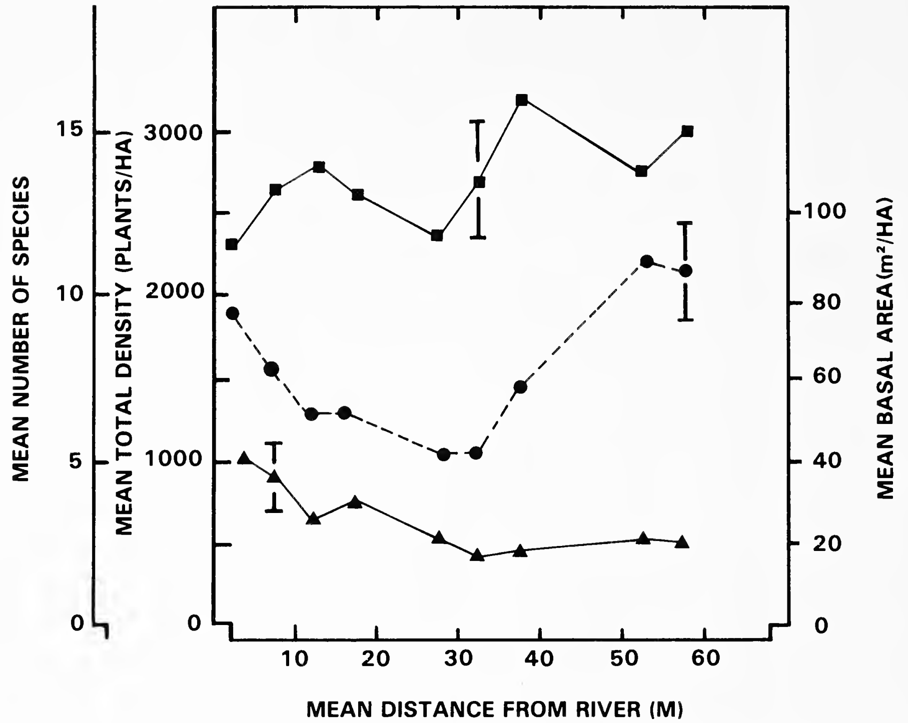

FIGURE 2. Mean number of species (squares), mean total density (circles), and mean total basal area (triangles) as a function of distance from the river for the San Antonio River gallery forest. The bars are one standard error of the mean and representative of the variance for the measured parameter (n = 4).

Gum bumelia, a typical upland species, achieved its greatest density, basal area, and importance 50 to 60 m from the river in the outer bank region of the forest and was rare near the river (Fig. 3). Other species such as desert hackberry, mesquite, live oak (*Quercus virginiana*), and brasil (*Condalia hookeri*), were isolated on the upper edge of the forest and had trends similar to gum bumelia. Several species maintained a fairly uniform distribution throughout the forest, including Texas sugarberry, cedar elm, and American elm. Texas sugarberry had its lowest density, basal area and importance values at the river edge (Fig. 3), but still accounted for 36% of the mean importance throughout the flood plain forest.

DISCUSSION

Many compositional studies of riparian forests have been conducted in Texas (Allen 1974; Nixon and Willett 1974; Marks and Harcombe 1975; Nixon et al. 1977; Van Auken et al. 1979; Ford and Van Auken 1982). However, we are not aware of any investigations concerning the

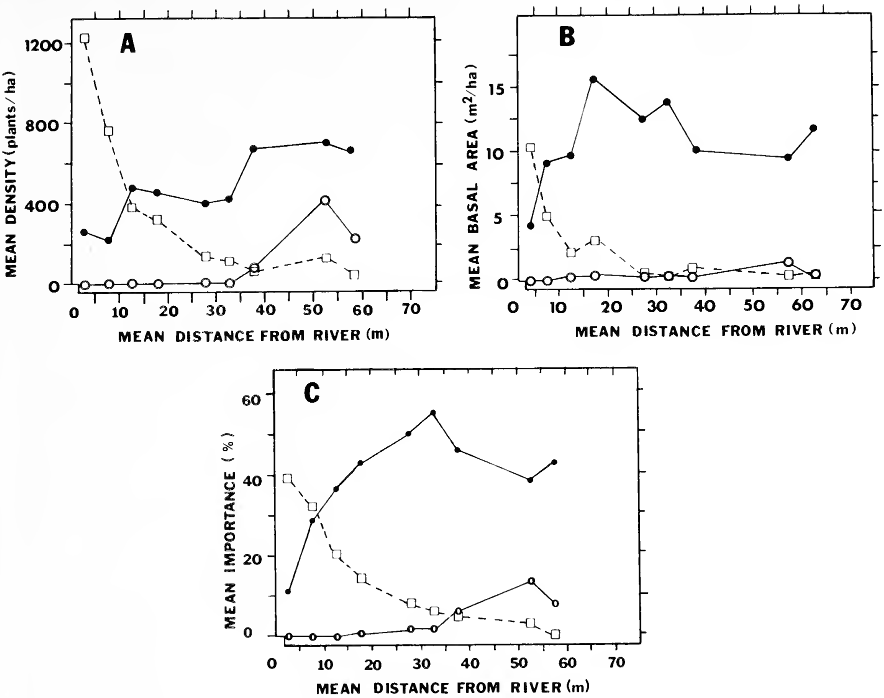

FIGURE 3. Mean total density (A), mean total basal area (B), and mean importance (C) as a function of distance from the San Antonio River for boxelder (squares), Texas sugarberry (filled circles), and gum bumelia (open circles).

riparian forests of the South Texas Plains region. Marks and Harcombe (1975) found many oaks, sycamore (*Platanus occidentalis*), and red maple (*Acer rubrum*) in the river bottoms of east Texas. Nixon et al. (1977) found American hornbeam (*Carpinus caroliniana*), Carolina ash (*Fraxinus caroliniana*), water oak (*Q. nigra*), and red mulberry (*Morus rubra*) on the Neches River in east Texas. Van Auken et al. (1979) reported Mexican juniper (*Juniperus ashei*), cedar elm, sycamore, and Texas persimmon (*Diospyros texana*) as dominants in the creek bottoms in the Edwards Plateau region of Texas. Pecan, Texas sugarberry, bald cypress (*Taxodium distichum*), and cedar elm dominated the riparian forests of the Guadalupe River in the Edwards Plateau (Ford and Van Auken 1982).

The San Antonio River gallery forest is similar in some respects to other riparian forests in Texas, but there are some obvious distinctions. Previously, Texas sugarberry was only reported as a dominant on a few sites in the Trinity River basin (Nixon and Willett 1974) and in some riparian forests in Tennessee and Louisiana (Shelford 1954; Conner and Day 1976). Some major subdominants, found in the present study, such as cedar elm, are similar to those of other Texas riparian forests. However, the major dominants or subdominants in other Texas riparian forests—such as the oaks, pecan, bald cypress, sycamore, and ash—have low importance values in the San Antonio River forest and are replaced by boxelder, cottonwood, and gum bumelia. These changes in forest composition may be due to the east-to-west rainfall gradient seen across the state of Texas, soil differences, anthropogenetic factors, lack of a seed source, flood plain physiography, or frequency and severity of floods in this river drainage.

Many southwest Texas rivers have deep, narrow flood plains (Kochel and Baker 1982); consequently, they have deep, high velocity floods. Oaks and other slow growing trees could be selected against in this particular environment. On the other hand, cottonwood, black willow, boxelder, Texas sugarberry, and chinaberry (*Melia azedarach*) could be selected for, because of rapid growth and their ability to become established during flood intervals. We found that the faster growing species had the larger mean basal areas and importance values in the San Antonio River riparian forest.

Some species were limited in distribution to specific areas within the forest. Cottonwood and black willow were found strictly on the river edge. These two species did not occur in the understory of any species; they seem to become established only in open areas at the river edge (unpubl. data). Desert hackberry, mesquite, live oak, and brasil were only found on the outer bank of this forest.

Mean number of species was highest at the outer edge of the forest (Fig. 2), with many species typical of the South Texas Plains. An increased number of species at the outer edge of a forest has been reported in previous studies (Bell 1974; Ford and Van Auken 1982). This region is really an ecotone between the riparian forest and the surrounding communities. Microclimatic differences, which occur at forest edges (Weaver 1954; Wales 1972), may contribute to increases in the number of species in this area. The increase in total density at the upper and lower forest edge, in the present study, likely was due to similar microclimatic differences. Increased flood frequency along the river edge may produce more tree falls, resulting in more light gaps, thus higher densities. Higher density at the upper forest edge was apparently due to a large number of shrubs and saplings typical of drier upland areas. Smaller size is also indicated by the lower total mean basal area (Fig. 2). Greater basal area at the river edge (Fig. 2) was probably due to increased light above the river and increased moisture availability in this area. Decreases in total mean basal area away from the river could have been caused by decreased soil moisture.

The composition of the San Antonio River gallery forest as well as the distribution of species, density, basal area, and species importance are certainly determined by area climate, flooding, distance from the river, and probably other less obvious factors. A complex gradient is more than likely involved, with one group of species responding to certain environmental factors and another group responding to others. Which of the factors or combinations is the most important for a species complex has not yet been determined.

ACKNOWLEDGMENTS

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COMPARATIVE VEGETATIONAL ANALYSIS OF A DRY BASIN AND A SHALLOW POND WITHIN THE BED OF CATTAIL LAKE, SANTA ANA NATIONAL WILDLIFE REFUGE, TEXAS

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ABSTRACT

We compared the vegetation of a dry basin (dry site) and a shallow pond (wet site) within Cattail Lake, Santa Ana National Wildlife Refuge, Texas. Sixty-three species of angiosperms were present. Nineteen were common to both study sites. A spiny shrub, *Mimosa pigra* var. *berlandieri,* was the dominant species at the dry site. A sedge, *Eleocharis albida,* was dominant in the wet site. Percent plant cover of the dry site was almost twice that recorded for the wet site. Future inundation of the dry lake site will likely result in a vegetational pattern similar to that of the present shallow-water lake site.

INTRODUCTION

In North America, wetlands management has been directed primarily toward providing habitat for wildlife (Lonard et al. 1981). Wetlands in the lower Rio Grande Valley of Texas provide a unique habitat for numerous neotropical vertebrate species that reach the northern limits of their distributions in this area. Many wetlands have disappeared from the lower Rio Grande Valley due to modern agricultural practices and damming of the Rio Grande. Former wetlands are now reverting to more xeric seral stages charactertized by brushland species. Therefore, the management of wetlands in sanctuaries such as the Santa Ana National Wildlife Refuge is of critical importance.

In South Texas, seral development following manipulation of freshwater-marsh water levels has not been well documented. The most relevant work is that of Scifres and Mutz (1975), who studied plant succession on South Texas rangelands following evapotranspiration of standing water left by a tropical storm. The present study compares the vegetation of a dry lake bed, which is rarely inundated, with that of a shallow lake that contains water most of the year and is reflooded after draw-down. It is only one of numerous studies that will be needed before it becomes possible to characterize vegetational changes that

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occur following water-level manipulation of freshwater lakes in South Texas.

The study area was located within the South Texas Plains vegetational area (Gould 1969). Specifically, the Cattail Lake study area was located about 2 km north of the Rio Grande and about 11 km south of Alamo, TX, in the Santa Ana National Wildlife Refuge. The area is characterized by a nearly level topography with an average elevation of about 27 m. Winters are mild and freezes rarely occur. Summers are hot and humid. Annual precipitation averages 56 cm. Slight precipitation peaks occur from November to January and in June and July (Fleetwood 1973).

Geologically, the soils of the study site belong to the Lissie Formation and thus are of Pleistocene origin. They are in the Rio Grande-Matamoros soil association which is taxonomically classed as deep, moderately and slowly permeable soils that typically have a surface layer of brownish gray or grayish brown silt loam or silty clay.

Surface water in the Santa Ana National Wildlife Refuge is contained in three impoundments. One of these is Cattail Lake. It was formed in 1973 by diking a portion of an old resaca, a former channel or oxbow of the Rio Grande (Fleetwood 1973). Before construction in 1953 of Falcon Dam on the Rio Grande, flooding was more frequent and water remained in areas of Cattail Lake that are now dry. The surface area of the potential lake is about 12 ha. Sources of water include precipitation and runoff, periodic flooding from the Rio Grande, and occasional donation of surplus water from the Hidalgo County Water District and water that is pumped from two wells. Presently only a small area of the lake contains water.

Cattail Lake is subdivided by low dikes into 4 shallow basins (Fig. 1). Two of these comprised our study sites. Site A is normally dry and rarely contains water; no water was present during our study. Site B contains water most of the year. During our study, maximum depth of water at site B ranged from 12 to 80 cm.

The objectives of the investigation were (1) to compare the existing flora and vegetational structure of the two study sites and (2) to gain insight into the changes of vegetational structure that result from water-level manipulations in the Rio Grande flood plain of South Texas.

METHODS

The composition and structure of the vegetation of Cattail Lake were studied from October 1979 to March 1980 using the line-intercept technique (Canfield 1941). Four transects were surveyed on each site (Fig. 1). Each transect was sampled only once because prominent seasonal changes in the vegetation were not evident from previous observations

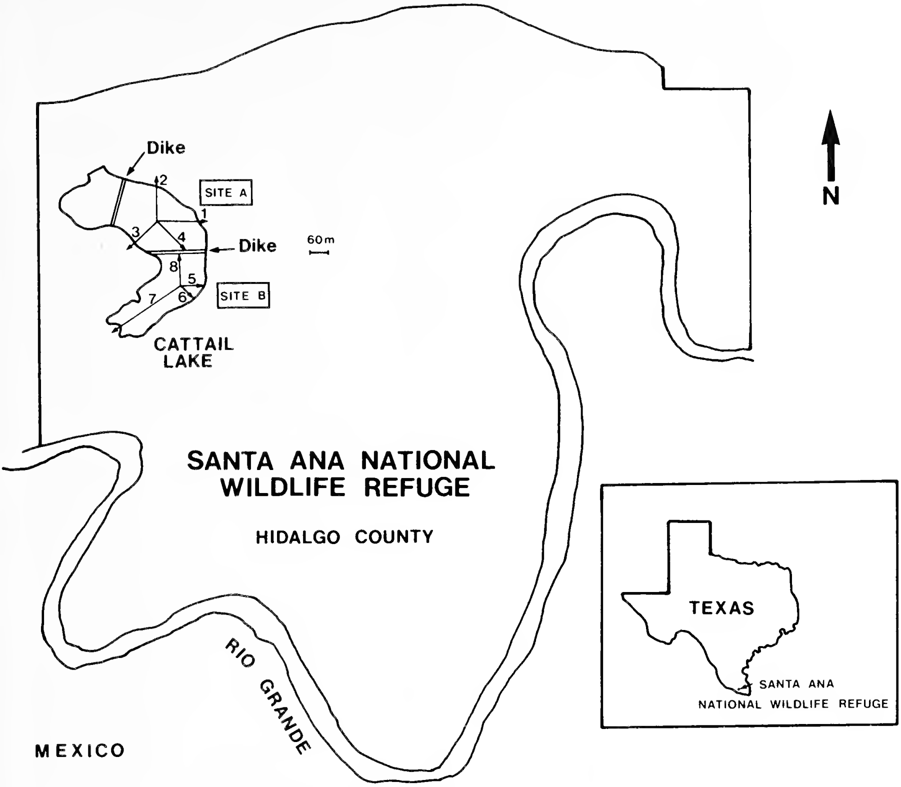

FIGURE 1. Map of Cattail Lake showing the two study sites and the location of transects.

in the study area. Water depths corresponding to vegetation stands were measured at site B. Each transect began at the center of the respective basin and terminated at the margin of the lake. The distance covered by each transect ranged from 38 m to 119 m. Each transect was divided into 1 m intervals. Plant species occuring along every third interval were recorded. Scientific nomenclature followed Correll and Johnston (1970) or Gould (1975).

Coverage was determined for each species by measuring the total distance along the transect "shaded" by individuals of that species. From these data percent cover, relative cover, frequency and relative frequency were calculated. Importance value, as used in this study, was computed by summing relative cover and relative frequency. Dominant and subdominant species were determined from the importance values for each site. The study sites were divided into vegetation zones—zone 1, the lake center; zone 2, the lake margin; and zone 3, the lake bank. These zones then were subdivided into 10 m (site B) or 15 m (site A) lengths. Species contributing 10% or more of the composition of these areas

TABLE 1. Comparison of angiosperms found in a dry basin (site A) and in a shallow pond (site B) within Cattail Lake.

Species	Site A (Dry)	Site B (Wet)
Typhaceae		
Typha domingensis Pers.	X	X
Alismataceae		
Echinodorus rostratus (Nutt.) Engelm.	X	
Gramineae		
Bothriochloa saccharoides (Sw.) Rydb. var. *longipaniculata* (Gould) Gould	X	X
Cynodon dactylon (L.) Pers.	X	X
Dichanthium sericeum A. Camus	X	
Echinochloa crus-pavonis (H.B.K.) Schult. var. *macera* (Wiegand) (Gould)	X	X
Eriochloa punctata (L.) Desv. *ex* Hamilton	X	
Leptochloa fascicularis (Lam.) Gray	X	X
Leptochloa nealleyi Vasey	X	
Neeragrostis reptans (Michx.) Nicora	X	
Panicum maximum Jacq.	X	
Paspalum langei (Fourn.) Nash.	X	X
Paspalum lividum Trin.	X	X
Setaria leucopila (Scribn. & Merr.) K. Schum	X	X
Sporobolus buckleyi Vasey	X	
Cyperaceae		
Cyperus articulatus L.		
Cyperus erythrorhizos Muhl.	X	
Cyperus ochraceus Vahl.		X
Cyperus virens Michx.		X
Eleocharis albida Torr.	X	X
Eleocharis parvula (R. & S.) Link	X	
Scirpus californicus (C. A. Mey.) Steud.		X
Pontederiaceae		
Heteranthera liebmannii (Buch.) Shinners	X	
Salicaceae		
Salix nigra Marsh.		X
Ulmaceae		
Celtis laevigata Willd.	X	
Celtis pallida Torr.		X
Polygonaceae		
Persicaria densiflora (Meisn.) Moldenke	X	
Rumex chrysocarpus Moris.	X	X
Amaranthaceae		
Amaranthus plameri S. Wats.	X	
Phytolaccaceae		
Rivina humilis L.	X	X
Leguminosae		
Acacia smallii Isely	X	X
Desmanthus virgatus (L.) Willd. var. *depressus* (Willd.) Turner	X	

TABLE 1.—(*Continued*)

Species	Site A (Dry)	Site B (Wet)
Leguminosae		
Mimosa pigra L. var. *berlandieri* (Gray) Turner	X	X
Rhynchosia minima (L.) DC.	X	
Sesbania macrocarpa Muhl.	X	X
Euphorbiaceae		
Euphorbia hypericifolia L.	X	
Euphorbia serpens H.B.K.	X	
Sapindaceae		
Cardiospermum halicacabum L.	X	
Serjania brachycarpa Gray	X	
Malvaceae		
Malvastrum americanum (L.) Torr.	X	
Sida spinosa L.	X	
Lythraceae		
Ammannia coccinea Rottb.	X	
Onagraceae		
Oenothera speciosa Nutt.	X	
Primulaceae		
Samolus ebracteatus H.B.K.	X	
Oleaceae		
Fraxinus berlandieriana A. DC.	X	
Asclepiadaceae		
Matelea reticulata (Gray) Woods.	X	
Boraginaceae		
Ehretia anacua (Teran & Berl.) I.M. Johnst.		X
Verbenaceae		
Lippia alba (Mill.) N.E.Br.	X	X
Phyla nodiflora (L.) Greene	X	
Solanaceae		
Solanum nigrum L.		X
Solanum seedling	X	
Acanthaceae		
Ruellia runyonii Tharp & Barkl.	X	
Compositae		
Ambrosia psilostachya DC.	X	X
Aster spinosus Benth.	X	
Aster subulatus Michx. var. *ligulatus* Shinners	X	X
Calyptocarpus vialis Less.	X	
Cirsium texanum Buckl.		X
Eupatorium azureum DC.	X	
Eupatorium incarnatum Walt.	X	
Eupatorium odoratum L.	X	X
Helianthus annuus L.	X	
Parthenium hysterophorous L.	X	
Pluchea purpurascens (Sw.) DC.		X
Unidentified seedlings	X	

based on cover values were determined to characterize the vegetation of these zones.

To compare species richness of the two communities, a species-sample curve was plotted (cumulative number of species in relation to cumulative number of transect intervals) for each site. A relative abundance curve also was prepared using species frequency values to compare the diversity and dominance of species between sites (Brower and Zar 1977).

Species diversity was compared between sites using the Shannon diversity index (Brower and Zar 1977):

$$H' = (N \log N - \Sigma\, n_i \log n_i)/N,$$

where, for each site, n_i = the importance value for the individual species and N = the total number of importance values.

For a measure of community overlap, Sorensen's coefficient, IS_s, was calculated. The formula used was

$$IS_s = 2c/A + B,$$

where c was the number of species shared in common by site A and B, and A + B was the sum of species present in both communities (Mueller-Dombois and Ellenberg 1974). IS_s can range from 0 for communities having no species in common, to 1.0 for communities having identical species.

RESULTS

The angiosperm flora of the two study sites in Cattail Lake comprised 63 species representing 24 families (Table 1). Nineteen species were represented in both communities. Site A, the dry basin, had a total of 55 species representing 12 families. Species representing the families Cyperaceae, Compositae, Gramineae and Typhaceae were present on all eight transects. Only one species, *Typha domingensis,* occurred on all eight transects. *Mimosa pigra* var. *berlandieri* was the dominant species at site A and *Eleocharis albida* was the dominant species at site B (Table 2 and Figs. 2 and 3). Percent cover at site A was almost twice that at site B. In transect 1 (Fig. 1), *Panicum maximum* was confined to the lake bank and *M. pigra* var. *berlandieri* was present in the moist soil at the lake's edge (Fig. 2). Transect 2 (Fig. 1) crossed a small island that was dominated by *Sida spinosa;* stands of *Aster subulatus* var. *ligulatus* occurred on either side of the island (Fig. 2, inset). In transect 3 (Fig. 1) *Oenothera speciosa* was present in the center of the lake bed and *M. pigra* var. *berlandieri* and *Phyla nodiflora* occurred on the lake

TABLE 2. Percent cover, relative cover, relative frequency and importance value[a] for the dominant species in a dry basin (site A) and a shallow pond (site B) within Cattail Lake.

		Percent Cover		Relative Cover		Relative Frequency		Importance Value	
Species	Site:	A	B	A	B	A	B	A	B
Mimosa pigra var. *berlandieri*		7.2	0.5	18.5	1.5	7.4	2.9	25.9	4.4
Oenothera speciosa		3.1		7.9		9.5		17.4	
Typha domingensis		2.7	1.1	7.0	5.5	7.2	7.8	14.2	13.3
Neeragrostis reptans		2.5		6.4		6.7		13.1	
Eleocharis albida		2.4	2.4	6.3	11.7	6.5	20.6	12.8	32.3
Sida spinosa		2.1		5.3		7.2		12.5	
Leptochloa fascicularis		1.3	0.1	3.4	0.3	8.3	1.2	11.7	1.5
Aster subulatus var. *ligulatus*		2.4	0.3	6.0	1.5	4.6	6.1	10.6	7.6
Phyla nodiflora		1.9		4.8		3.5		8.3	
Eleocharis parvula		1.7		4.4		3.2		7.6	
Panicum maximum		2.1		5.4		1.6		7.0	
Bothriochloa saccharoides var. *longipaniculata*		1.4	1.6	3.6	7.9	2.6	3.9	6.2	11.8
Persicaria densiflora		0.4		1.1		3.2		4.3	
Cyndon dactylon		1.2	0.1	3.1	0.2	0.9	0.8	4.0	1.0
Rumex chrysocarpus		0.5	1.1	1.3	5.6	1.9	2.9	3.2	8.5
Paspalum langei		0.2	3.7	0.6	18.5	0.8	3.9	1.4	22.4
Scirpus californicus			1.4		6.8		7.8		14.6
Sesbania macrocarpa		0.2	1.3	0.5	6.6	1.0	7.8	1.5	14.4
Cyperus virens			0.9		4.5		6.9		11.4
Rivina humilis		0.1	1.1	0.4	5.4	0.4	4.9	0.8	10.3
Acacia smallii		0.1	1.5	0.3	7.5	0.7	2.0	1.0	9.5
Others		5.6	4.0	10.9	20.0	17.8	31.4	28.8	51.4
Total Cover		39.1	21.1						

[a] The importance value is the sum of relative cover and relative frequency.

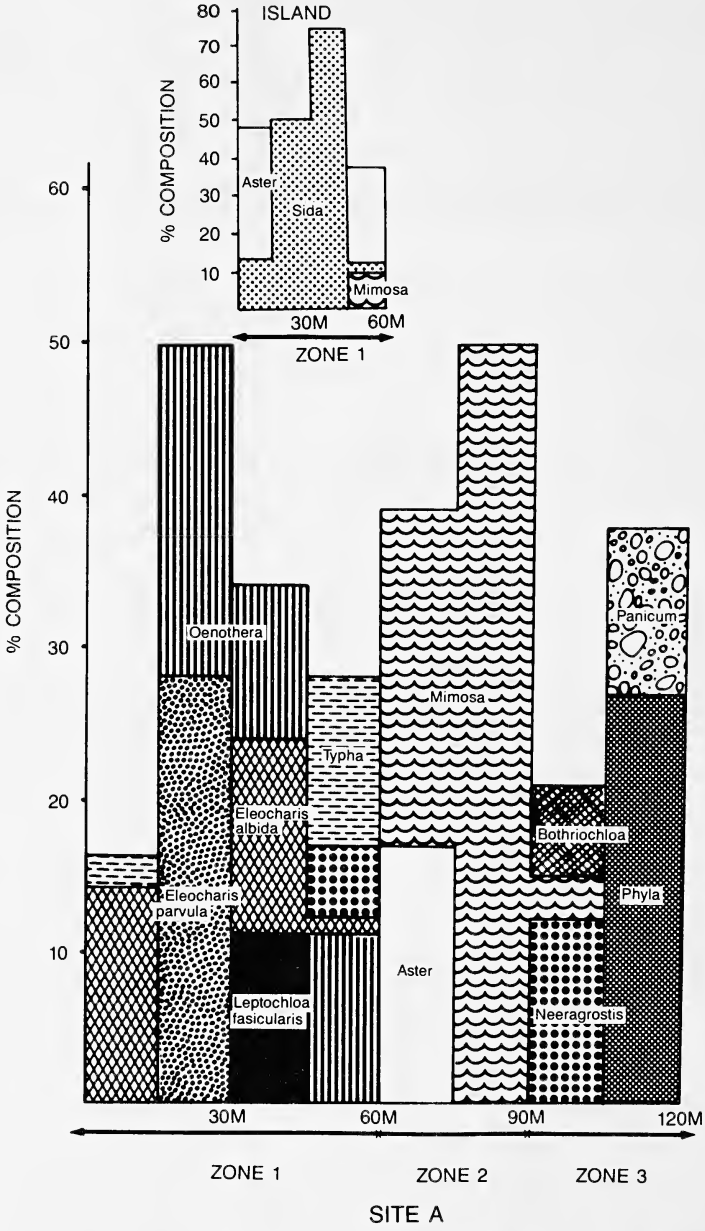

FIGURE 2. The composition of three vegetation zones at Site A based on cover values. Zone 1 = lake center, Zone 2 = lake margin, and Zone 3 = lake bank. The insert represents vegetation zones on a small island found on a segment of Transect 2.

bank (Fig. 2). *Typha domingensis* stands were located primarily at the center of the lake bed (Fig. 2).

Water depths at site B ranged from a few cm to 65 cm. Most of the *T. domingensis* stands occurred at 50 cm depths (Fig. 3). *Eleocharis albida*

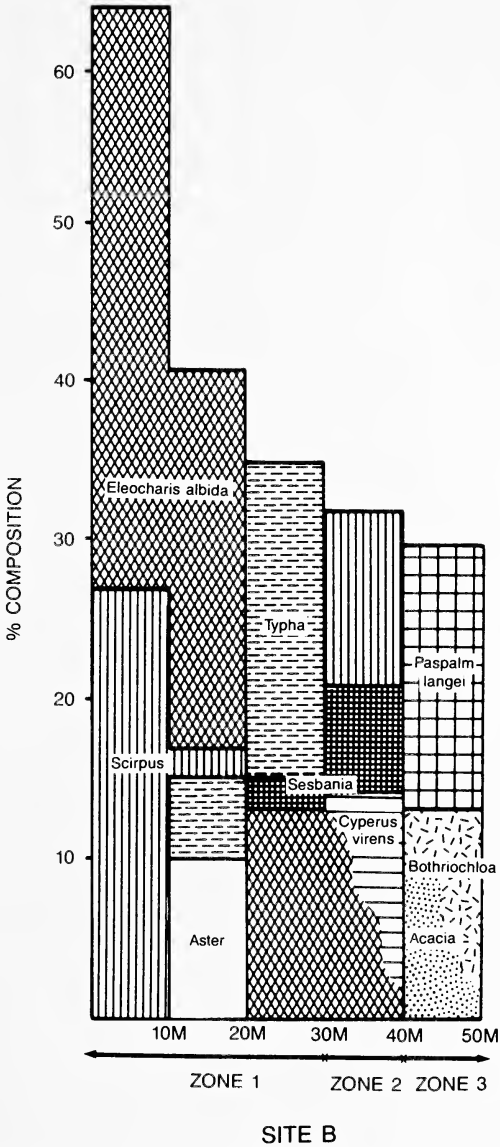

FIGURE 3. The composition of three vegetation zones at Site B based on cover values. Zone 1 = lake center, Zone 2 = lake margin, Zone 3 = lake bank.

populations were found mostly at depths of 30 cm to 40 cm, but some stands occurred in water as shallow as 6 cm. Colonies of *Scirpus californicus* were found at depths of 20 cm to 40 cm (Fig. 3). A few colonies were present in shallow water. Closer to the shoreline on the lake margin, stands of *M. pigra* var. *berlandieri* and *Sesbania macrocarpa* occurred where water depths were about 12 cm (Fig. 3).

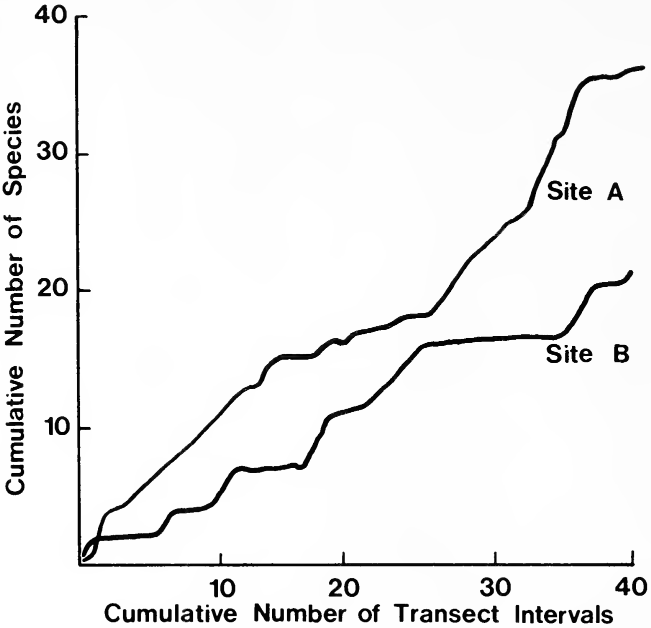

FIGURE 4. Species-sample curves for the two study sites. Cumulative number of species is plotted against cumulative number of transect intervals.

The species-sample curves indicate that site A had greater species richness per unit habitat area than site B (Fig. 4). The relative abundance curves indicate that site A was higher in species diversity and lower in species dominance (Fig. 5).

The Shannon diversity index was H′ = 1.406 for site A and H′ = 1.184 for site B, which indicates that the dry site A had greater species diversity. Sorenson's coefficient was IS_s = 0.45, which indicates that there was not a great deal of similarity between the two communities.

DISCUSSION

The desired results of water level manipulations of Cattail Lake are the establishment and maintenance of plant species that provide food or cover for wetland-dependent species of wildlife. Plant distribution is controlled primarily by the physical factors of the environment. Animal distribution is often determined by the types of food and shelter afforded by vegetation types and vegetative interspersion (Daubenmire 1968; Golet 1973).

Daubenmire (1968) indicated that concentric zones of vegetation are often found around ponds or lakes. Scifres and Mutz (1975) found that the vegetational pattern following extended inundation of a South Texas coastal rangeland was also one of zonation. As free standing

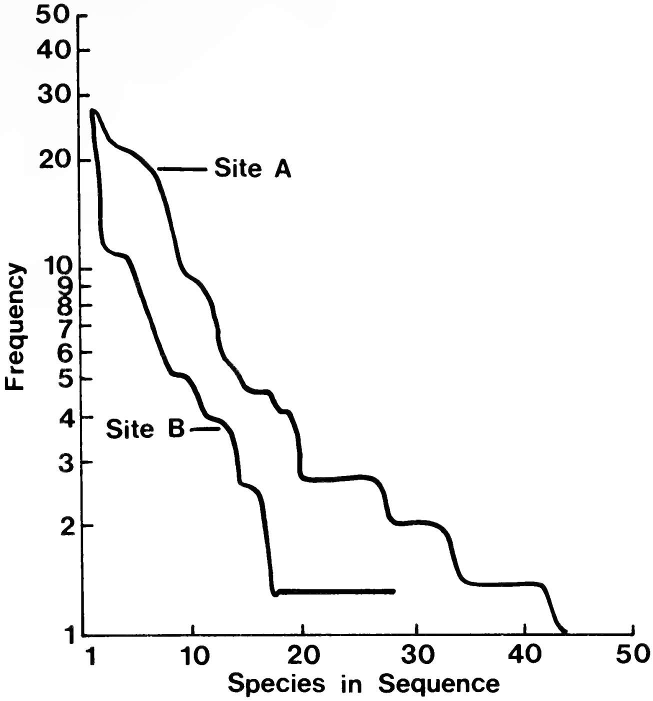

FIGURE 5. Relative abundance curves for the two study sites. Species frequency vs. species rank (in order of decreasing frequency) for species occurring in each site.

water receded, secondary succession resulted in vegetation zones that proceeded from a sedge-bunchgrass stage to a bunchgrass stage and finally to an *Acacia-Prosopis-Setaria* community. Present vegetational communities at our two study sites in Cattail Lake seem to represent seres in a similar succession.

The vegetational pattern and structure at site B, the pond site, may be used as a predictive model for vegetation changes that could occur at site A, the dry site, should it be inundated. Among expected changes are the following. Species diversity likely would be reduced. The site would become dominated by several species of grasses and sedges and the importance of the spiny shrub, *M. pigra* var. *berlandieri*, would be significantly reduced. Importance values of submersed taxa that include *E. albida*, *S. californicus* and *T. domingensis* would increase.

Robel (1962) found that a strong relationship existed between the water level of a Utah marsh and the growth of submersed vegetation. When the water level was increased by 7.6 cm, submersed vegetation increased in the shallow areas and decreased in sites with deeper water. Kadlec (1962) and Harris and Marshall (1963) found that there is a tendency for cover to decrease when water levels are stabilized. The decline in cover frequently is related to water depths in excess of the tolerance of the cover plants. In our study, most of the emergent species at site B were present at depths ranging from 30 cm to 50 cm, although water depths ranged from a few cm to 65 cm.

The primary management objective for Cattail Lake is to provide habitat for the resaca rice rat (*Oryzomus couseii*). Its habitat requirements are not well known, but are likely similar to those reported for *O. palustris,* the northern rice rat (Davis 1974). Northern rice rats utilize emergent marsh plants including grasses and sedges as nesting material, cover and food. Therefore, a water-level manipulation plan should be devised to maintain shallow water levels ranging between 20 cm and 40 cm. Colonies of the sedges, *E. albida* and *S. californicus,* are common within that range of depths.

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TAUTOMERISM OF SOME 1-PHENYL-2-(2-QUINOXALYL) ETHANONES

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ABSTRACT

An analysis of the proton nmr spectra from a series of nine different 1-phenyl-2-(2-quinoxalyl) ethanones clearly indicates that there is an enamine-imine tautomerism. The enamine:imine ratio exhibits a marked dependence on both the solvent and the nature of the substituent in the meta or para position of the phenyl moiety. The equilibrium values correlate with the Hammett substituent constants.

INTRODUCTION

Recently we synthesized some 3- and 4- substituted 1-phenyl-2-(2-quinoxalyl) ethanones as part of our long-term study of heterocyclic ketones (Sund and Callender 1980). Here we report on our examination of the proton nmr spectrum of these ketones for evidence that they may exist in two or more tautomeric forms. We compare our results with those obtained with 2-acetonylquinoxaline, which exists largely in the imine form (Mondelli and Merlini 1966), and substituted quinoxalinones, which exist mainly in the enamine form (Iwanami et al. 1971).

MATERIALS AND METHODS

Proton nmr spectra were determined using the established method of nmr integration of the vinyl and methylene proton signals (Burdett and Rogers 1963). The samples were allowed to equilibrate for at least a day before their spectra were obtained with a Perkin-Elmer R-32 spectrometer. Proton area values were determined as the average of several integrations. No spectra were obtained for the chloro-substituted compounds in DMSO-d_6 because of the very low solubility of these compounds in this solvent. TMS was used as an internal standard in $DCCl_3$ and CCl_4, and all signals were measured relative to it. For convenience the samples which used DMSO-d_6 as a solvent had a sealed capillary tube of TMS inserted in each nmr tube. These signals also were measured relative to the TMS but were shifted downfield approximately 0.5 ppm from the typical values found in the other two series of compounds.

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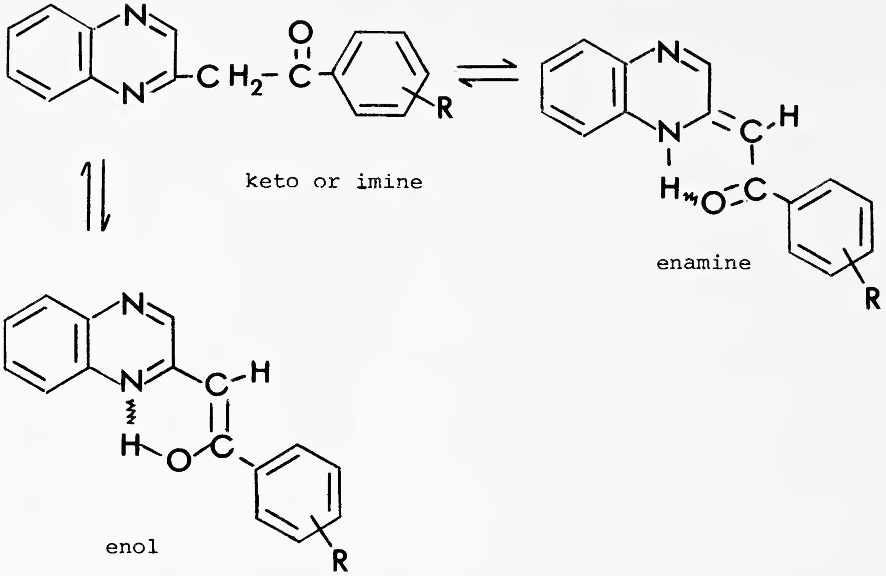

FIGURE 1. Possible tautomers of 1-phenyl-2-(2-quinoxalyl)-ethanones.

RESULTS AND DISCUSSION

Three tautomers of 1-phenyl-2-(2-quinoxalyl) ethanones are possible—the imine or keto form, the enamine form, and the enol form (Fig. 1). The amount of each tautomer present should depend on the polarity of the solvent and the nature of the substituent on the benzene ring. Proton nmr showed that at least two tautomers are present. A singlet at 4.6 ppm indicated the presence of a methylene proton which would be found with the imine or keto tautomer; a singlet at 6.2 ppm indicated the presence of a vinyl proton which would be found with the enamine tautomer or the enol tautomer. Proton nmr does not allow one to make a definite distinction between the enol and the enamine tautomer, but does offer a convenient method for determining the relative quantities of each tautomer present once the structure of each tautomer is known. Recent reports in the literature indicate that benzofusion to the hetero ring increases the probability of imine-enamine tautomerization (Elguero et al. 1976; Iwanami and Inagaki 1976).

We used carbon-13 nmr and model compounds to determine whether an enol-keto or an imine-enamine tautomerism exists. It has been shown that 1-phenyl-2-(2-pyridyl) ethanone undergoes an enol-keto tautomerism (Branch et al. 1963). The carbon-13 nmr of the compound shows the carbonyl function at 196.9 ppm, the enol carbon at 164.1 ppm, and the methine carbon at 94.4 ppm. The other model compound chosen for the study is 1-phenyl-2-(2-quinolyl) ethanone. Recently it

TABLE 1. Ratio (± 0.5) of enamine to imine in various solvents.

Substituent	CCl_4	$DCCl_3$	DMSO-d_6
none	9.9	4.4	3.6
m-CH_3	10.1	5.0	4.1
p-CH_3	9.0	3.5	2.6
m-OCH_3	11.3	6.5	7.3
p-OCH_3	7.1	1.7	1.5
*m*Cl	18.0	9.6	(insol.)
p-Cl	13.6	8.7	(insol.)
m-CF_3	50.0	18.9	9.3
p-CF_3	52.8	23.3	25.1

has been reported that this compound exhibits an imine-enamine type of tautomerism and is predominately in the enamine form (Fukata et al. 1979). The carbon-13 nmr spectrum of the enamine form shows a carbonyl function at 182.5 ppm and the methine carbon at 89.2 ppm. The carbon-13 nmr of 1-phenyl-2-(2-quinoxalyl) ethanone, which is also predominately in the enamine form, shows a carbonyl function at 181.6 ppm and a methine carbon at 91.2 ppm. The keto form shows a carbonyl as a minor peak at 195.9 ppm. Thus, the carbon-13 spectrum of 1-phenyl-2-(2-quinoxalyl) ethanone approximates that of 1-phenyl-2-(2-quinolyl) ethanone in the area of interest and not that of 1-phenyl-2-(2-pyridyl) ethanone. Therefore, it can be stated unequivocally that 1-phenyl-2-(2-quinoxalyl) ethanone and its related ethanones exhibit an imine-enamine tautomerism. Furthermore, 2-acetonylquinoxaline exhibits an imine-enamine tautomerism (Mondelli and Merlini 1966). It would be surprising if 2-acetonylquinoxaline should differ significantly in this regard from 2-phenacylquinoxaline (1-phenyl-2-(2-quinoxalyl) ethanone).

In addition to the parent compound, 1-phenyl-2-(2-quinoxalyl) ethanone, the phenyl moiety was substituted in the meta or para position with methyl, methoxy, chloro, and trifluoromethyl, thus giving a total of nine different compounds. The proton nmr spectrum for the series of compounds was determined in three solvents—carbon tetrachloride, deuteriochloroform, and dimethylsulfoxide-d_6. The proton nmr spectrum typically showed the -CH_2-signal of the imine tautomer at 4.6 ppm and the =CH-signal of the enamine tautomer at 6.2 ppm. The enamine:imine ratios were obtained by integrating the =CH-proton and the -CH_2- protons at 6.2 ppm and 4.6 ppm, respectively, and are shown in Table 1. The log of the equilibrium value was plotted against the Hammett equation substituent constants (Taft 1956) for each compound in the series in each of the three solvents. In each case, a coefficient of linear correlation greater than 0.80 was found (Fig. 2).

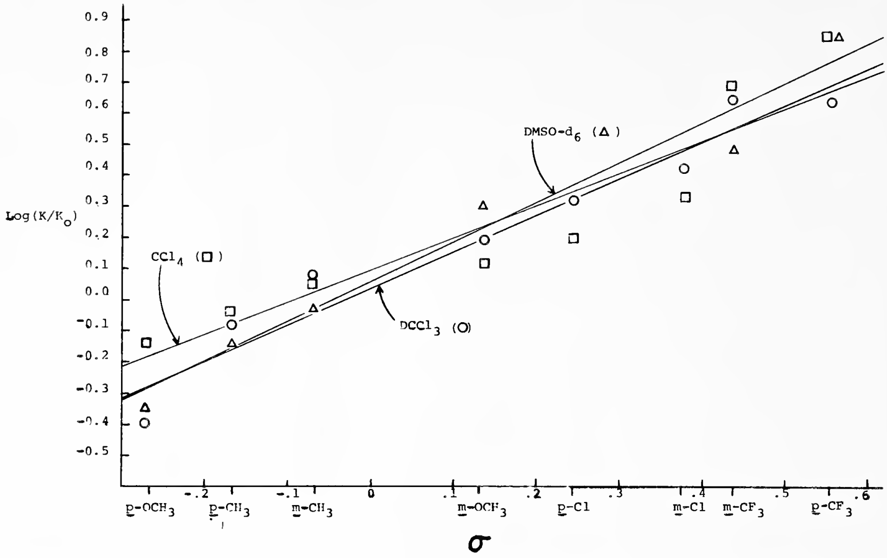

FIGURE 2. Log (K/K_0) in three solvents—CCL_4, $DCCL_3$, and DMSO-d_6—versus Hammett substituent constant (σ). K = enol/keto ratio of phenyl-substituted 1-phenyl-2-(2-quinoxalyl) ethanones, and K_0 = enol/keto ratio of 1-phenyl-2-(2-quinoxalyl) ethanone.

The results obtained are those expected for an enamine-imine tautomerism. The enamine form with a intramolecular hydrogen bond should be susceptible to both solvent and electronic effects. Increasing the polarity of the solvent should favor the imine form because, as the solvents become more polar, they compete better with the hydrogen bond for bonding with the carbonyl oxygen.

The plots of the log of the equilibrium values against the Hammett equation substituent constants indicate that electron-releasing groups decrease the amount of enamine, and electron-withdrawing groups increase the amount of enamine. Electron-withdrawing groups should reduce the electron density at the ring nitrogen, weakening the nitrogen-hydrogen bond, thus facilitating the hydrogen bonding with the carbonyl oxygen. The converse should be true with electron-releasing groups. These are in fact the effects seen.

These results are consistent with those reported by Mondelli and Merlini (1966) for 2-acetonylquinoxaline. It would be expected that the methyl group should have a very small electron-releasing effect, thus favoring the imine, which was found to be the dominant form. Iwanami et al. (1971) report that 3-phenacyl-2(1H)-quinoxalinone exists largely in the enamine form, even more so than the compounds we prepared. It would be expected our compounds should show less enamine formation that the quinoxalinone derivatives because in this case the hetero diazine moiety has lost more of its aromatic character. Thus the enamine should form more readily in the quinoxalinone series.

ACKNOWLEDGMENTS

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HUMAN AND NON-HUMAN SKELETAL REMAINS RECOVERED FROM SORCERER'S CAVE, TERRELL COUNTY, TEXAS

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ABSTRACT

Human skeletal remains have been recovered from a cave passage ca. 143 m below the entrance to Sorcerer's Cave, Terrell County, Texas. Eight fragments representing the mandible, humerus, two ulnae, two femora and a tibia could all represent a single individual who was adult and possibly female. Although no biological affinity could be established for the individual, artifacts of North American Indians were recovered from the cave and around the entrance. Remains of at least 18 species of reptiles, birds and other mammals indigenous to the region also were recovered from the cave.

INTRODUCTION

The analysis of faunal remains from caves is important to biologists and anthropologists for two reasons. The first is that each cave and its fauna, much like an island, represent an isolated and unique ecosystem, and thus can provide a model for the analysis of major problems in ecology. The second reason, which is of more immediate significance to anthropologists and paleontologists, is that caves act as natural traps and protective vaults for faunae that inhabit the surrounding region. Collections from caves can provide us with a comprehensive and usually well preserved sample of remains which may allow the reconstruction of past environments of the region. In Texas, particularly central and west Texas, caves have provided some of the best preserved and largest collections of Pleistocene and Holocene faunal remains (Milstead 1956; Pettus 1956; Mecham 1958; Evans 1961; Meade

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1961; Semken 1961, 1967; Cridlebaugh 1962; Patton 1963; Frank 1964; Dalquest et al. 1969; Lundelius and Slaughter 1971; Roth 1972).

The purpose of this paper is to report on human and non-human remains recovered from Sorcerer's Cave (also known as Adam's Cave and Dryden Cave) near Dryden, Texas. The most extensive description of the cave has been provided by Veni (1980a, b). McNatt (1980b) and Prewitt (1981) provided analyses of archeological materials recovered from the cave. This report will expand upon McNatt's (1980a) report of the osteological remains. The human remains are of particular interest since they represent the deepest human remains yet recovered from any Texas cave, and quite possibly from any cave in the contiguous United States.

GEOGRAPHY, MORPHOLOGY, AND GEOLOGY OF SORCERER'S CAVE

Sorcerer's Cave, near the town of Dryden, Terrell Co., Texas, is located on the Stockton Plateau, a plateau composed primarily of limestone bedrock, dipping slightly to the southeast. The upland flats of the plateau tend to lie on the limestone of the Buda Formation while the shallow stream systems dissecting these upland flats cut through the soft Del Rio Clay and table out in the steam valleys on the Santa Elena Limestone.

The mouth of Sorcerer's Cave, opening onto a small arroyo, cuts through the top of the Santa Elena Limestone, the overlying Del Rio Clay being but a few feet above the mouth opening. Most of the cave penetrates the Santa Elena Formation but the lower levels of the cave may lie within the upper portions of the underlying Sue Peaks Formation.

The cave begins as a sequence of short passages and chambers connected by a series of deep vertical pits which can be divided from top to bottom into three major sections (Fig. 1): (1) the anterior pit system; (2) the chambers; and (3) the river. The overhung entrance passage is 2 m high and extends back 10 m. At the rear of the overhang is the mouth of a 14 m pit. The bottom of this first pit opens into a walkway about 40 m long with a 16-m high ceiling. A side passage from this hall leads to a 5 m pit which opens into a 25 m pit. At the bottom of this 25 m pit, a short crawl leads to a drop of 4 m, followed by yet another pit 22.5 m deep. At the bottom of this fourth pit, approximately 88 m below the cave entrance, a passage opens into a horizontal water passage. Unlike the dry, upper regions of Sorcerer' Cave, the floor of this passage, about 35 m in length, contains a 1-m deep deposit of semiliquid quano overlain by about 0.3 m of clear water.

Beyond this water passage exist two large chambers. The first, named Inner Sanctum, is 50 m long, 7 to 12 m wide and 3 to 7 m high. Its

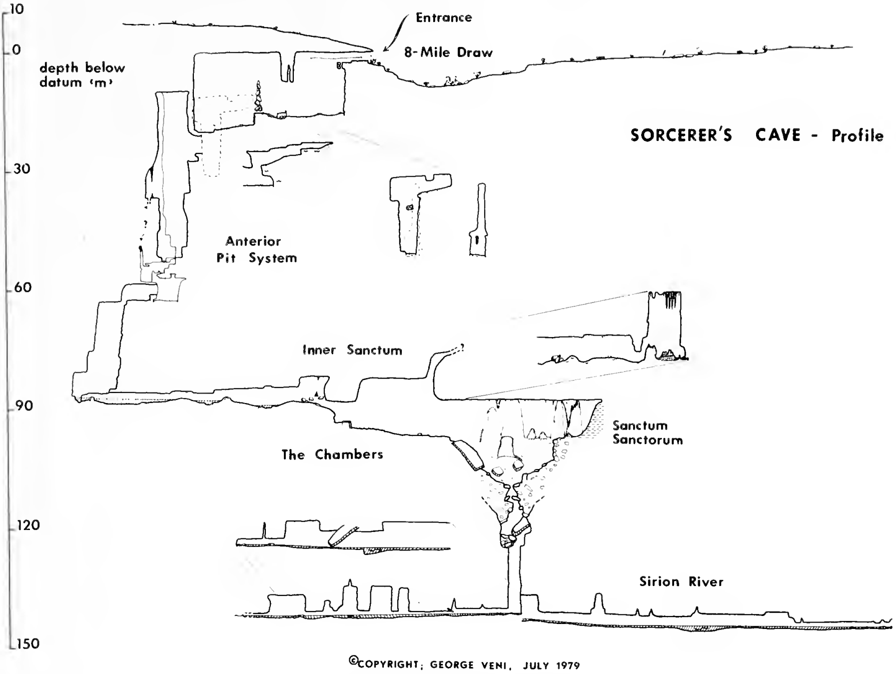

FIGURE 1. Profile drawing of Sorcerer's Cave.

floor is guano-covered and ranges in moisture content from very moist to semi-liquid. The second chamber, named Sanctum Sanctorum, is a larger room measuring 35 m in length, 25 m in width and has a steeply sloping floor strewn with roof fall. Ceiling height of this room ranges from 6 to 25 m above the floor. Within this chamber are 10-m high stalagmites. Located centrally in this room within the breakdown floor is an 18-m deep pit which leads, by a small tributary, into a large, permanent underground river. The tributary leading from this pit to the Sirion River is 53 m long.

The Sirion River, at the bottom of Sorcerer's Cave, runs through passages which are 3.5 m wide and 2 to 10 m high. Water in the river ranged from ankle to chest deep during the periods of exploration. Exploration of the river passage was finally blocked at a depth of 167 m below the entrance to the cave as the passage ceiling descended into 7-m deep water. It was at this level, approximately 143 meters below the entrance, that the human remains were discovered.

HUMAN MATERIAL FROM SORCERER'S CAVE

Eight fragments of human bone have been recovered from the Sirion River, in the deepest part of the cave yet explored. Each specimen is described below in some detail.

FIGURE 2. A. Lateral view of human left mandibular fragment recovered from the Sirion River in Sorcerer's Cave. B. Superior view of same left mandibular fragment. Maximum length of fragment is 92.5 mm.

Mandible (Fig. 2)

The specimen is a badly water-worn right hemimandible. No teeth are present. Several clay-filled alveolar sockets are present. The coronoid process, mandibular condyle, neck, and gonial angle are all absent. Multiple abrasions on the specimen have been smoothed and polished, apparently by water action. The specimen is stained a light brown color. On the specimen's buccal aspect, the alveolar process has been largely eroded away, exposing the alveolar sockets. A mental foramen (plugged with cave-fill) lies just below the socket for the second mandibular premolar (P_4). A large socket for the mandibular canine is exposed anterior to the mental foramen. A pronounced tubercle exists for the attachment of the pterygomandibular raphe approximately 10 mm mesial from the edge of the ascending ramus. A relatively sharp alveolar crest between the pterygomandibular raphe tubercle and the alveolar socket for the last premolar appears to be the result of tooth loss and subsequent alveolar resorption. The angle of the ascending ramus appears to be relatively inclined at approximately 50°. On the lingual aspect of the specimen, the mandibular foramen is partially filled with clay. A marked mylohyoid groove runs anterior-inferiorly from the foramen. Mesially, water-worn superior and inferior mental spines are present as is a single digastric fossa. A weak mylohyoid line is evident in the distal half of the specimen. From the occlusal aspect, the extent of the alveolar resorption occurs posterior to the socket for the canine. The mental prominence and superior and inferior mental spines are obvious as are the alveolar sockets for the two left mandibular incisors. Maximum length of fragment is 99.0 mm; maximum breadth of body of the mandible is 12.0 mm; and, maximum height of the body is 24.5 mm.

The loss of teeth, the degree of alveolar resorption posterior to P_4 and the apparent oblique angle of the ramus suggest the individual was an adult. No obvious indicators of sex are present on the specimen, although the small size of the mental prominence and weak mylohyoid line may indicate female status.

Humerus (Fig. 3A)

The specimen is a right diaphysis missing proximal and distal epiphyses. The external aspect is stained dark brown and water worn. The inferior end of the medullary cavity is clogged with cave fill material (clay, gravel, etc). The specimen has several small postmortem abrasions (all water-worn) on its external surface. The anterior aspect of the specimen presents water-worn remnants of the bicipital groove and a deltoid tuberosity at its proximal end. The distolateral portion displays a partial lateral supracondylar ridge. A nutrient foramen on the inferiomedial surface occurs 83.0 mm above the distal end of the specimen. Distally, both condyles are missing although the proximal margin of the olecranon fossa is evident. Neither humeral head nor greater tuberosity is present.

Maximum length of the fragment is 196.5 mm; maximum breadth of the distal end is 24.5 mm; and, maximum anterioposterior dimension of the diaphysis is 22.0 mm. Although the humerus is incomplete, it compared favorably in size and shape to a complete human humerus which was 29.7 cm long.

While the humerus' polished, water-worn nature makes identification of its osteological landmarks relatively difficult, the gracile appearance of the specimen may indicate female status, and the specimen is apparently from an adult individual. Assuming the reconstructed length is accurate and that the specimen is from an Amerindian female, stature was estimated to be 155 cm, based on the ratios of humerus length to stature prepared by Genoves (1969).

Ulnae (Fig. 3B and C)

The most complete specimen is a right ulna missing the distal end. Considerable water-wear has eroded the radial notch and olecranon process. The distal half of the diaphysis is stained dark brown and is shiny due possibly to water polishing. The medullary cavity is exposed at the distal end of the diaphysis and is partially occluded by cave-fill material. Several apparently postmortem abrasions on the specimen have been smoothed by water polishing. Anteriorly, the distal half of the specimen shows a pronounced medial convexity associated with a slight anterior convexity. The interosseous border, although water-worn, is pronounced. A large tubercle for attachment of the ulnar collateral ligament is present on the medial aspect of the coronoid process, and a marked ridge for attachment of the pronator quadratus muscle occurs on the distal fifth of the specimen. Posteriorly, the distal half of the specimen shows a pronounced medial convexity and posterior concavity. The supinator crest is well developed although water-worn. Cancellous bone is exposed around the radial notch and olecranon process; cave fill (clay) occludes the intertrabecular spaces.

FIGURE 3. Fragments of human limb bones from Sorcerer's Cave. A. Right humerus fragment (196.5 mm maximum length). B. Right ulna fragment (264.5 mm maximum length). C. Left proximal ulna fragment (71.0 mm maximum length). D. Right femur fragment of the diaphysis (92.0 mm maximum length). E. Femur fragment of the diaphysis, side indeterminate (140.0 mm maximum length). F. Left tibia fragment of the diaphysis (182.0 mm maximum length). G. Right fibula fragment of the diaphysis (142.0 mm maximum length).

Maximum specimen length is 264.5 mm; maximum breadth at the coronoid process is 21.0 mm; and, maximum anteroposterior dimension at the coronoid process is 30.5 mm. The ulna is relatively gracile in overall appearance although exceedingly long. The gracility of this specimen suggests female status.

The second specimen is the proximal end of a left ulna including the olecranon process, trochear notch, the coronoid process and the ulnar tuberosity. The shaft is missing immediately below the ulnar tuberosity, and the exposed medullary cavity is occluded by cave-fill material. A number of postmortem abrasions on the specimen have been smoothed by the action of water, and the cortical bone has been completely eroded from most of the surface of the olecranon process. Maximum length of the fragment is 71.0 mm; maximum breadth at the coronoid process is 16.0 mm; and, the maximum anterior/posterior dimension at the coronoid process is 26.0 mm. Because of the amount of erosion of the cortical bone, it is difficult to precisely compare this specimen's original size to the other ulna. It appears, however, that the right ulna is larger, but the differences are not so extreme that the two ulnae could not have come from one individual.

Femora (Fig. 3D and E)

The first specimen is a fragment of the posterioproximal portion of a right diaphysis, with cancellous bone lining the medullary cavity exposed over a wide area. The specimen is stained a dark brown color on its exterior surface although the medullary cavity is largely unstained and is a beige color. The broken edges of the fragment are polished and rounded. Some abrasions exist on the external surface, apparently postmortem in nature, but are well smoothed and polished by water action. Posteriorly, a marked pectineal line runs obliquely from the upper left to lower right portion of the specimen. Immediately lateral of the pectineal line is a portion of the gluteal tuberosity. In addition, a nutrient foramen is present where both pectineal line and gluteal tuberosity meet to form the proximal portion of the lineal aspera. Maximum length is 92.0 mm; maximum breadth (medial-lateral) is 21.0 mm; and, maximum anterioposterior dimension is 29.5 mm. It is difficult to tell if the relative gracility of both pectineal line and gluteal tuberosity is due to (1) postmortem erosion, (2) advanced age of the individual, (3) female status, or (4) a combination of these factors.

The second specimen is a mid-diaphysis fragment distal to the confluence of the pectineal line and gluteal ridge with the linea aspera, and proximal to the area where the medial and lateral supracondylar ridges merge with the linea aspera. No nutrient foramen is visible on this fragment. Based on the structure of the linea aspera it appears to be a fragment of a left femur. This specimen is variably stained light and dark brown and the surface of the cortex is marked by many weathering cracks and abrasions. The broken ends, exhibiting fractures which are 90° to the shaft, indicate these breaks occurred well after the individual died and the bone had lost most of its collagen and water content.

The fragment is 140.0 mm in maximum length, 25.0 mm in minimum medial/lateral diameter, 30.0 mm in minimum dorsal/ventral diameter, and 8.0 mm in minimum cortical thickness. It appears to be from an adult individual of indeterminate sex and stature.

Tibia (Fig. 3F)

The specimen is a very water-worn and polished diaphysis of a left tibia. Missing are both proximal and distal articulating surfaces. The medullary cavity is exposed at both ends and filled with clay and gravel. The proximal opening of the medullary cavity has small pieces of charcoal imbedded within the cave-fill matrix. Only a small portion of the diaphysis is stained dark brown; most of the specimen is colored beige and is very eroded and water polished. Large abrasions are scattered across the external surface, but they have been smoothed, apparently by water action. All broken edges are rounded and smooth. On its lateral aspect, a pronounced nutrient foramen is present. The interosseous border, although badly eroded, is still discernible, particularly where it passes just anterior to the nutrient foramen and inferior to the distal end of the specimen. Several large dents are in the lateral surface of the specimen and are presumably postmortem in nature. In addition, several cracks run parallel to the anterior border of the specimen on the anteriolateral surface. Medially, the surface of the specimen is relatively nondescript except for the large number of cracks and fissures running the length of the diaphysis. Distally, the medial surface begins to flare just proximal to the start of the medial malleolus. Posteriorly, the distal half of the posterior diaphysis is heavily pitted with dents and grooves, all of which have been smoothed and polished by water action. Such an assemblage of abrasions may have been caused by postmortem water action or transport through a cave environment.

Maximum specimen length is 182.0 mm; miniumm specimen breadth is 14.5 mm; and, minimum anterioposterior dimension is 18.5 mm. The relatively small size is perhaps suggestive of female status although gracility was impossible to positively ascertain due to extreme water erosion of the specimen.

Fibula (Fig. 3G)

This specimen appears to be a mid-shaft fragment of a right fibula minus both articular ends. The bone is variably stained and exhibits some postmortem abrasions. The fractures at both ends of the shaft are 90° to the shaft, and smoothed by abrasion of the surface. Structurally, there are few features worth noting. The interosseous, anteriolateral, posteriolateral and posteriomedial borders are present but exhibit no unusual configuration. A nutrient foramen is present midshaft on the fragment. Maximum length of the fragment is 142.0 mm; minimum medial/lateral diameter is 10.0 mm; and, minumum dorsal/ventral diameter is 12.0 mm. Gross inspection of the fragment suggests it was from an adult individual of indeterminate sex and stature.

All of the material was radiographed; this confirmed the adult status of the mandible (no unerupted tooth buds present) and the absence of disease processes or abnormalities in all of the fragments.

In summary, several comments can be made about the total sample of human skeletal material. The common gracility of the specimens and their proximity to one another in the cave suggest that these bones all came from the same individual. All specimens indicate adult status, and the gracility of the material suggests either that the individual was a female, a quite gracile male, or an old adult in which bone resorption associated with age gave the impression of gracility. Reconstructed humerus length suggests that the individual may have been approximately 160 cm ± 4.16 cm in stature. Racial affinity was not determinable. We chose to use a stature formula for North American Indians because of the recovery of American Indian artifacts in the cave.

Age of the specimen is unknown. Radiocarbon dating of the bone would be of little value because of the contamination with groundwater and probably bat guano. The only date for any material from the cave, 890 A.D., was obtained from a wooden mortar by Prewitt (1981). The mortar found by an amateur spelunker was reported to have been secreted within a vertical pit 30 m below the entrance passage. There is no known association between the mortar and skeletal material reported here; the mortar does, however, provide one date for human use of the cave.

NON-HUMAN MATERIAL FROM SORCERER'S CAVE

Table 1 lists the minimum number of individuals of the 25 vertebrate taxa recovered from the three major sections of Sorcerer's Cave. The material representing the 24 non-human taxa is described and briefly discussed below. The classification of nondomesticated mammals follows Schmidly (1977).

Reptilia

Live specimens of the whipsnake, *Masticophis* sp., have been observed in the cave (Veni 1980a), and the skeleton and skin of a *Masti-*

TABLE 1. Faunal remains recovered from Sorcerer's Cave, indicating minimum number of individuals from the series of vertical pits in the anterior portion of the cave (0-80 m), the series of horizontal chambers in the middle portion of the cave (80-120 m), and from the Sirion River at the bottom of the cave (120-167).

Taxon	0-80 M	80-120 M	120-167 M	?
REPTILIA				
Squamata				
Lacertilia family indet.	-	-	1	-
Crotalidae cf. *Crotalus*	-	-	1	-
Colubridae cf. *Masticophis*	1	-	-	-
MAMMALIA				
Artiodactyla				
Capra hircus	13	-	-	-
Ovis aries	1	-	-	1
Odocoileus sp.	-	-	-	1
Carnivora				
Canis sp.	1	-	1	-
Canis cf. *C. latrans*	-	-	1	-
Felis rufus	1	-	2	-
Felis cf. *F. concolor*	-	1	-	-
Mephitis sp.	1	-	-	-
Conepatus mesoleucus	2	-	-	-
Lagomorpha				
Lepus cf. *L. californicus*	-	-	2	-
Sylvilagus sp.	1	1	1	-
Sylvilagus audubonii	2	-	3	-
Rodentia				
Rodentia family indet.	-	-	1	-
Spermophilus sp.	-	-	1	-
Spermophilus variegatus	23	-	1	-
Neotoma sp.	2	-	-	-
Neotoma cf. *N. micropus*	-	-	1	-
Sigmodon hispidus	2	-	2	-
Perognathus sp.		-	-	-
Chiroptera				
Chiroptera family indet.	-	-	1	-
Myotis velifer	29	-	-	-
Mormoops megalophylla	-	20	-	-
Primates				
Homo sapiens	-	-	1	-
AVES				
Falconiformes				
Cathartes aura	3	-	-	-

cophis sp. killed by cavers in 1978 was recovered from the anterior portion of the cave. From the Sirion River, we recovered vertebrae of a species of *Crotalis* and vertebral elements of a lizard of indeterminate species.

Aves

The only bird remains recovered from the cave consist of three mummies of the turkey buzzard, *Cathartes aura.* All three specimens were found in the first pit.

Mammalia

ARTIODACTYLA: Three species from this order are represented in the collection. Domestic sheep and goats, *Ovis aries* and *Capra hircus,* are represented by partially mummified carcasses, complete skeletons, partial skeletons, and individual skeletal elements. These remains were recovered from the base of the first pit and in the hall leading from the pit (see Fig. 1). Most of the contributors appear to have fallen into the pit, but some of the isolated skeletal elements seem charred; these charred elements may represent human food refuse thrown into the pit by users of the entrance overhang. A third artiodactyl, *Odocoileus* sp., is represented in the collection by a single antler fragment collected in the Sirion River.

CARNIVORA: The mountain lion, *Felis* cf. *F. concolor,* is represented by a left femur, right tibia and fibula, and right and left innominate bones. This material was collected beneath the roof fall in Sactum Sanctorum (see Fig. 1) and appears to represent a single animal. The innominate fragments show signs of weathering and may have been transported by water, at least for a short distance. The partial remains of at least three specimens of bobcat, *Felis rufus,* were recovered: a partial skull, two cervical vertebrae, and two femora from one of the pits in the anterior portion of the cave; and two skulls, two left and right humeri, one innominate, one femur, one tibia, one astragalus, and one thoracic vertebra from the Sirion River. In addition to these specimens, two cervical vertebrae of a smaller felid also were recovered from the Sirion River, but it could not be determined if these represented a different species or a small specimen of *Felis rufus.* The remains of a canid were recovered from the anterior portion of the cave, but we could not determine whether they represented a coyote or a domestic dog. From the Sirion River a right deciduous upper fourth premolar of an indeterminate species of canid was recovered as well as a left femur from an indeterminate canid genus. This femur is remarkable because it displays a compound fracture which was in the process of mending at the time of the animal's death. The small size of the femur rules out the possibility of its being either *Canis latrans* or *Urocyon cinereoargenteus.* One almost complete skeleton of the hog-nosed skunk, *Conepatus mesoleucus,* was recovered from the anterior pit system of the cave. A single mandible of the striped skunk, *Mephitis* sp., was discovered at the base of the first pit.

LAGOMORPHA: The remains of at least three specimens of *Sylvilagus* sp., and five specimens of *Sylvilagus audubonii* have been recovered from Sorcerer's Cave. A mandible and right femur fragment of *Sylvilagus* sp. were recovered from the anteriormost pit; an almost complete skeleton was found in another area of the anterior portion of the cave. Nine bones identifiable as *Sylvilagus audubonii* were recovered from the Sirion River. These included three left femora, two maxillary fragments, a right humerus, a left mandible, a right mandible and a left tibia. Also recovered from the Sirion River were a right tibia and two left mandibles which were assignable to *Lepus californicus.*

RODENTIA: The remains of the rock squirrel, *Spermophilus variegatus,* were the most abundant rodent material recovered. Twelve mummified carcasses of this species were found in several of the anterior pits and crevices, and isolated fragments were found in other locations in the anterior portion of the cave. From the Sirion River a left ulna, left femur, right tibia, and an occipital fragment of *Spermophilus variegatus* were recovered. Also recovered from the Sirion River was a left humerus of an undetermined species of *Spermophilus.* In addition to these bones of known provenience, two specimens of unrecorded provenience were collected. *Sigmodon hispidus* remains are represented in the cave fauna by a complete mummy and a secondary maxillary fragment from the bottom of the anteriormost pit, and by a right femur recovered from the Sirion River. Mandibular fragments of three different specimens of a wood rat, *Neotoma,* were found in the anterior portion of the cave. All three mandibles are similar in size to the mandibles of *Neotoma albigula.* Recovered from the Sirion River was a left femur from an indeterminate species of *Neotoma,* and the left femur from *Neotoma* cf. *N. micropus.* A cranium of a pocket mouse, *Perognathus* sp., was recovered from the anteriormost pit. Finally, a mineralized humerus and an unmineralized vertebra were assignable to the order Rodentia, but not to a specific family.

CHIROPTERA: Sorcerer's Cave houses a colony of approximately 5,000 bats consisting primarily of the cave bat, *Myotis velifer.* Their primary roosting sites, 20 m above the floor of the Sanctum Sanctorum, is the deepest bat roost yet recorded for Texas, 88 m below the entrance of the cave (Veni 1980a). Bats also roost occasionally in other areas near Sanctum Sanctorum, and in August 1980, a few were seen at the top of Poltergeist Pit (see Fig. 1).

Dead specimens of *M. velifer* were found usually below the primary roost site in the Sanctum Sanctorum. In August 1980, however, hundreds of specimens of this bat were found dead in the upper portion of the cave, chiefly between the floor of the anteriormost pit and the floor of Poltergeist Pit. At the same time, four dead specimens of the ghost-faced bat, *Mormoops megalophylla,* were found in the passage leading from the first pit. This is the first record of the latter species being present in Terrell County, Texas. Metapodials of bats of indeterminate species were collected from the Sirion River.

DISCUSSION

One of the first questions to be raised concerns the antiquity of the faunal remains. While none of the remains have been radiocarbon dated, most appear not to be mineralized, and thus are presumed to be of recent origin. In addition to the recent material there are some fossilized boney remains. Two heavily mineralized long bones of rodent origin and one heavily mineralized bone from a large mammal have been recovered from the Sirion River. Additionally, skeletal elements of a mountain lion were recovered from beneath the roof fall in Sanctum Sanctorum. Large stalagmites have since formed on top of the breakdown, proving the antiquity of the roof fall and the lion found beneath it. While these findings do not give us much of a picture of the fossilized fauna which probably exists in the cave, they do attest to the fact that the cave has potential as a paleontological resource.

Other questions which can be addressed concern how relatively varied and abundant is the vertebrate fauna from Sorcerer's Cave. Harris (1971), in his review of mammals associated with caves, listed 27 species of mammals reported to occupy or utilize Texas caves. The Sorcerer Cave sample of at least 18 indigenous species (Table 1) is indeed quite diverse when compared to Harris' faunal list. While this comparison provides an indication of species diversity from Sorcerer's Cave, it is more difficult to assess the relative abundance of the various taxa since the collection was gathered from the surface by Logan McNatt under difficult circumstances. The relatively large number of *Capra hircus, Spermophilus variegatus, Myotis velifer,* and *Mormoops megalophylla* does suggest that the cave has served as the place of death for large numbers of some species. Additionally, the dry conditions within some areas of the cave have been very conducive to bone preservation and in some cases mummification of complete carcasses. This suggests that future, more systematic collecting and controlled excavation in selected areas will greatly increase the faunal sample recovered from the cave.

This preliminary faunal sample also provides indications of how the boney remains have accumulated within the cave. Lundelius and Slaughter (1971) note that there are basically five ways in which bone may come to rest within a cave environment: (1) The cave may serve as a natural trap for certain species which fall or become lodged within its confines; (2) boney elements, or even complete carcasses of animals, may become washed into the cave; (3) some species may live and naturally die within the cave; (4) other species, or their bones, may be brought back to the lairs of predators occupying the cave; or, (5) the bones may be introduced to the cave by man for other than dietary reasons. In examining the faunal remains from Sorcerer's Cave, we infer that several of these factors have acted to accumulate bone within the cave.

Certainly, the vertical shafts in the anterior portion of the cave have acted as a trap for several of the species mentioned above. According to local residents of the area, heavy rains during the early 1960s caused domestic sheep and goats to seek the shelter of the cave entrance. Animals shoved to the rear of the overhang fell into the first pit where over a dozen carcasses have been recovered. Examination of some of the mummified carcasses gave no evidence to suggest predators had killed them. Three mummified carcasses of *Cathartes aura* have also been found at the bottom of the first pit, and the condition of the remains suggests that these birds also died of starvation or dehydration while trapped within the cave, rather than having been brought to the cave by predators. The relatively abundant remains of *Spermophilus variegatus,* although commonly associated with cave entrances, suggest that members of this species also may have been trapped in the cave.

It is possible, or even probable, that not all species recovered were trapped within the cave by unusual happenstance. One of the more striking features of the fauna recovered from the cave is the relatively high frequency of carnivores present in the sample. This undoubtedly is simply a reflection that most, if not all, of these predators, like *Spermophilus variegatus,* lived in or near the cave, and therefore were more likely to die within its confines.

A third way that boney remains of some of the species may have come to rest within Sorcerer's Cave is by water transportation—from some unknown source via the Sirion River, or by being washed down through the known series of shafts and chambers. The antler fragment from the deer, the femur from the mountain lion, and the human remains all show evidence of being water-worn. For the many bones recovered from the bed of the Sirion River, it is irrefutable that they have been moved by water for at least a short distance along the river bed. Water transportation down through the tortuous vertical passages is more difficult to envision, however. One of the authors (G.V.), based upon his observation of the cave deposits, hypothesizes two distinct and separate periods of deposition and transportation for the material entering the cave through these passages. The earlier phase of deposition and water transportation occurred during a wetter period (possibly 10,000 years ago) when the arroyo had a higher floor near the entrance of the cave. During this time, more water, which had easier access to the cave, transported materials down through the cave system. The later phase would have occurred after the climate became drier and the floor of the arroyo had dropped below the cave entrance. During this more recent time there has been little opportunity for sediments or bones to have been washed down through the pits. If this reconstruction of the depositional history of the cave is correct, then older boney material could have washed into this portion of the cave, but more recent material probably did not.

How the remains of the rabbit, the pack rat, and the cotton rat came to rest within the cave is harder to explain. All three species are represented only by fragmentary remains—the rabbit by a maxillary fragment, and the two rodents each by a single mandibular fragment. Such fragmentary remains could have been carried in either by predators or, during wetter times, by water. The fragmentary nature of the remains, however, closely resembles refuse from known predator dens personally examined by one of the authors (D.G.S.).

How the human bones reached the depths of Sorcerer's Cave is perhaps the most intriguing and difficult question raised by our findings. The one line of evidence bearing on this issue is the condition of the bone. All of the material is (1) fragmented, (2) shows marked evidence of being water transported, and (3) was dispersed along the Sirion River. This suggestes to us that material was transported postmortem into the cave. While the material could have been washed down through the multiple pits and finally reached the Sirion River, it seems more plausible that the material was transported, relatively intact, by the river from an as yet unexplored region of the cave, into those portions which have been explored. How the remains came to be deposited within the cave in the first place might be explained by the fact that prehistoric Indians in southwest Texas and northern Mexico often utilized caves as burial sites (Martinez del Rio 1953; Collins 1970; Skinner et al. 1980).

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HYSTEROCERAS HYATT [CRETACEOUS (ALBIAN) AMMONOID] IN TEXAS AND THE ANGOLA CONNECTION

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ABSTRACT

Three species of *Hysteroceras* from Trans-Pecos Texas—*H. varicosum* (Sowerby), *H.* sp. cf. *H. orbignyi* (Spath), and *H.* (?) n. sp.—support the correlation of the zones of *Adkinsites bravoensis* (Böse) and *Boeseites romeri* (Hass) with the middle part of the *Mortoniceras inflatum* zone of Europe and its *H. varicosum* and *H. orbignyi* subzones.

Hysteroceras varicosum and *H. orbignyi* also occur in Venezuela, Angola, Europe, and Madagascar. *Boeseites romeri* (Haas) and other elements of this Angolan fauna, however, have been reported only from Texas and Angola [although *B. maroimensis* (White) from Brazil is a close relative]; this faunal relationship indicates the first direct migration of southern African ammonites to the western North Atlantic. Given that the oceanic basin of the South Atlantic was not opened until long after the Late Albian, the ammonites of the *Boeseites romeri* fauna probably migrated through a shallow, epeiric sea during the high stand of sealevel in the early to middle part of the Late Albian, before the opening of a truly oceanic connection between the North and South Atlantic.

INTRODUCTION

The small genus of ammonites, *Hysteroceras,* which is so typical in some of the lower beds of the Upper Albian (Cretaceous System), has not been reported previously as *Hysteroceras* from North America. Böse (1923) illustrated what is probably a species of the genus on his plate 11, figures 45-51. He identified it as *Brancoceras* aff. *varicosum* (Sowerby), although his specimens appear to be more closely related to *H. orbignyi* (Spath), with the ribs markedly swinging orad on the venter where they meet and form chevrons with the ribs of the opposite flank.

The specimens of *Hysteroceras* reported herein were collected by Bill St. John in 1964 and by Jeremiah McCarthy in 1952. They represent the middle part of the Upper Albian and are from the zones of *Adkinsites bravoensis* (Böse), below, and *Boeseites romeri* (Haas), above. These zones are equivalent to the middle part of the zone of *Mortoniceras inflatum* of Europe (Kennedy et al. 1980), which has the subzones of *Hysteroceras orbignyi* (Spath), below, and *H. varicosum* (Sowerby), above (Table 1).

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Table 1. Comparison of European and Texan zones for the late Albian.

*TEXAS	EUROPE**		SUBSTAGE
ZONE	SUBZONE	ZONE	
Drakeoceras drakei	Mortoniceras perinflatum	Stoliczkaia dispar	LATE ALBIAN
	Stoliczkaia blancheti		
Mortoniceras wintoni	Mortoniceras altonense	Mortoniceras inflatum	
Drakeoceras lasswitzi			
Pervinquieria equidistans	Callihoplites aurites		
Eopachydiscus brazoensis			
Craginites serratescens	Hysteroceras varicosum		
Boeseites romeri	Hysteroceras orbignyi		
Adkinsites bravoensis			
Manuaniceras powelli	Dipoloceras cristatum		K. Young, 1984

*Modified from Young 1967, 1979
**From Kennedy, Hancock, and Christensen 1980

The specimens from the Black Gap Area (St. John 1965; Fig. 1) are from the upper 2m of the Sue Peaks Formation, which is thinner at this locality than in most areas. The specimens from Cienega Creek (McCarthy 1953; Fig. 2), Presidio County, are from the middle part of the Benevides Formation, reported as Sue Peaks Formation by Dietrich (1965).

Additional material of *Hysteroceras* is in the Texas Memorial Museum (Austin, Texas) in the small collection of pyritized micromorphs from the Sierra Mojada, western Coahuila, Mexico. This collection was sent to W. S. Adkins in the summer of 1933 by F. L. Wingfield, at that time the resident mining engineer of Cia. Minera de Peñoles, S. A.; Wingfield was then living at Esmeralda, one of the towns associated with the large mining district at Sierra Mojada. This collection of *Hysteroceras* has not been studied because the stratigraphy has not been determined and the stratigraphic section has not been measured or studied.

PALEONTOLOGY

Phylum Mollusca
Class Cephalopoda
Superfamily Acanthoceraceae Hyatt 1900
Family Brancoceridae Spath 1933
Genus *Hysteroceras* Hyatt 1900

Hysteroceras varicosum (Sowerby 1824)

H. varicosum is the type species of the genus. Spath's (1934) synonomy is adopted here. Neither Haas (1942) nor van Hoepen (1944) was aware of each other's work at the time of publication; therefore, a complete and competent synonomy awaits a restudy of the Angolan material.

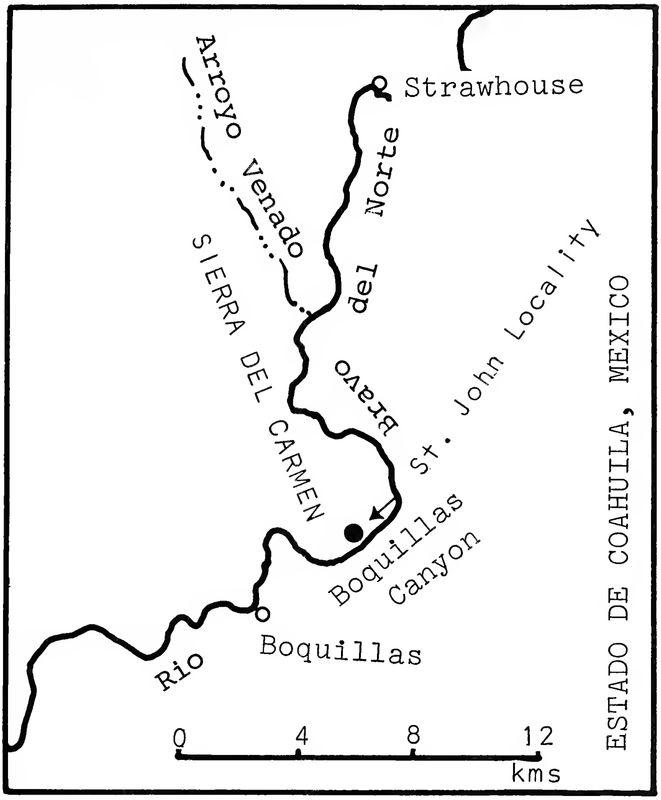

FIGURE 1. Locality collected by Bill St. John on the northwest side of Boquillas Canyon, Brewster County, Texas. The geology is mapped in Maxwell et al. (1967).

The specimen illustrated by A-D and P in Figure 3 is from about 30 m below the top of the Benevides Formation, 12 m below the lowest ocurrence of *Boesites,* and from the zone of *Adkinsites bravoensis* (Böse), Cienega Creek, Presidio County, Texas. WSA-3592 (Fig. 3, J and K) was collected by J. D. De Jong; it differs from *Hysteroceras orbignyi* Spath) in Renz (1982) in the absence of a keel on the adult and in its less dense ribbing. Specimens illustrated by Q-V in Figure 3 are from the upper 2 m of the Sue Peaks Formation, zone of *Boeseites romeri* (Haas), west end of Boquillas Canyon, Big Bend National Park, Brewster County, Texas.

Hysteroceras orbignyi (Spath 1922)

The specimen illustrated by L-O in Figure 3 is from Barbacoas, Estado de Lara, Venezuela. It was collected by J. D. De Jong. *Hysteroceras orbignyi* (Spath) has also been identified by Barker ("Cretaceous ammonites from western Venezuela" with 59 plates, unpublished and

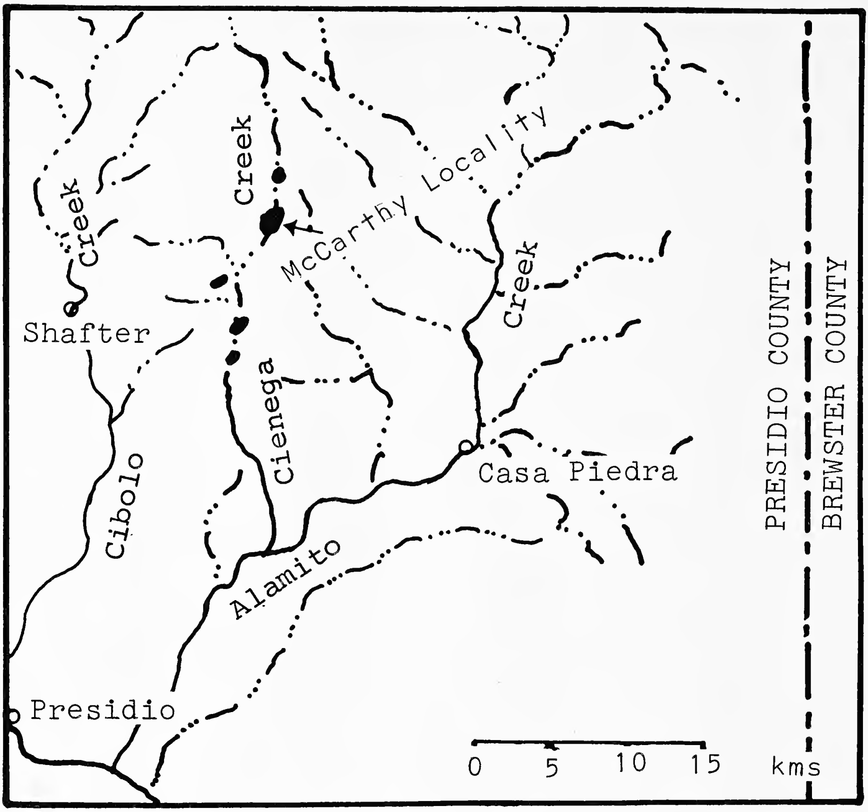

FIGURE 2. Locality collected by J. F. McCarthy along Cienega Creek, Presidio County, Texas. The areas in black are outcrops of the Benevides Formation on Cienega Creek.

undated) in collections (also by J. D. De Jong) from outcrops along the Chejende-Miton road, Chejende Area, Estado Trujillo, Venezuela. Renz (1982) discussed the stratigraphy and geography of these deposits.

The Venezuelan specimen illustrated was chosen to show the ventral chevrons formed by the meeting or sometimes joining of oradly projected ribs, so diagnostic of this species. The keel is weaker than on other, smaller specimens in the sample and is weaker than on those illustrated by Renz (1982). In the designation of species of this genus some authors have made much of the number and distribution of intercalated and primary ribs. However, this feature is extremely variable in both *H. varicosum* (Sowerby) and *H. orbignyi* (Spath) and can vary even between opposite flanks of the same specimen (Fig. 3, Q and V).

Hysteroceras sp. cf. *H. orbignyi* (Spath 1922)

The specimen illustrated by W-Z in Figure 3 is from the west end of Boquillas Canyon, Big Bend National Park, Brewster County, Texas,

A-D, J, K, P-V—*Hysteroceras varicosum* (Sowerby 1824). A-D, P:UT-1289, from about 30 m below the top of the Benevides Formation and 12 m below the lowest occurrence of *Boeseites,* Cienega Creek, Presidio Co., TX.; collected by J. F. McCarthy from bed 1 of section 4 of McCarthy (1953). J, K: WSA-3592, Adkins Collection; from Barbacoas, Venezuela, collected by J. G. De Jong. Q-V:UT-6260-B, from the upper 2 m of the Sue Peaks Formation, west end of Boquillas Canyon, Big Bend National Park, Brewster Co., TX; collected by Bill St. John in 1964. A-C, Q, U, V × 1.5; D, P, R-T × 0.75.

E-I—*Hysteroceras* (?) n. sp. UT-6261, from the upper 2 m of the Sue Peaks Formation, west end of Boquillas Canyon, Big Bend National Park, Brewster Co., TX; collected by Bill St. John in 1964. E, F × 0.75; G-I × 1.5.

L-O—*Hysteroceras orbignyi* (Spath 1922). WSA-3592, W. S. Adkins Collection; from Barbacoas, Venezuela, collected by J. G. De Jong. × 0.75.

W-Z—*Hysteroceras* sp. cf. *H. orbigyni* (Spath 1922). UT-6260-A, from the upper 2 m of the Sue Peaks Formation, west end of Boquillas Canyon, Big Bend National Park, Brewster Co., TX; collected by Bill St. John in 1964. W, X × 0.75; Y, Z × 1.5

FIGURE 3. *Hysteroceras* spp. from Texas and Venezuela.

and was collected by Bill St. John. It is from the *Boeseites romeri* (Haas) zone, upper 2 m of the Sue Peaks Formation.

This specimen (Fig. 3, W-Z) shows, at least in one view, ribs projected forward onto the venter. Otherwise, it does not seem greatly different from specimens of *H. varicosum* on the same figure. It is crushed, and the venter is not well preserved. It is questionably related to *H. orbignyi* (Spath) because of the ribs oradly projected onto the venter, but it must be remembered that many workers have confused *H. orbignyi* (Spath) and *H. varicosum* (Sowerby), even though much better preserved material than this was available for study.

Hysteroceras (?) sp.

The specimen illustrated by E-I in Figure 3 is from the upper 2 m of the Sue Peaks Formation, zone of *Boeseites romeri* (Haas), west end of Boquillas Canyon, Big Bend National Park, Brewster County, Texas. It was collected by Bill St. John.

Hysteroceras (?) sp. (Fig. 3, E-I) has a smooth ventral area, which is not typical of *Hysteroceras* or of other genera associated with the zone of *Mortoniceras inflatum*. On each flank ribs alternate, primary and secondary, ending at the slight swelling on the ventrolateral shoulder. Ribs do not extend onto a smooth, only slightly arched venter. Ribs are paired from flank to flank, and there are probably 17 to 20 ribs per whorl. With only one specimen of about one-half whorl, no attempt at assignment has been made.

DISCUSSION

The Boeseites *fauna*

The *Boeseites* fauna (Young 1968) is known only from Trans-Pecos Texas, adjacent northeastern Chihuahua, Mexico, and Angola (Haas 1942; Young 1968; Kennedy and Cooper 1975). The following species are from Hanha, Angola (Haas 1942), and Texas and Chihuahua (Young 1968).

Boeseites romeri (Haas) [= *Pervinquieria romeri* Haas 1942]
Boeseites perarmatus (Haas) [= *P. perarmata* Haas 1942]
Boeseites barbouri (Haas) [= *P. barbouri* Haas 1942]
Boeseites proteus (Haas) [= *P. proteus* Haas 1941]
Boeseites howelli (Haas) [= *P. howelli* Haas 1942]
Prohysteroceras sp. cfr. *P. hanhaense* Haas 1942
Elobiceras (?) sp.

Hysteroceras varicosum (Sowerby), *H.* sp. cf. orbignyi (Spath), and *Hysteroceras* (?) sp. occur in the *Boeseites romeri* zone, Sue Peaks Formation, in the Black Gap area of Brewster County. *H. varicosum* occurs a few tens of meters below the first occurrence of *Boeseites* on Cienega Creek, Hudspeth County, Trans-Pecos Texas.

There are some geographic anomalies that cannot be explained, as yet. The extensive middle Upper Albian fauna in Zululand, South Africa (van Hoepen 1931-1951), contains many forms of *Hysteroceras,* including *H. varicosum* and *H. orbignyi,* but no species of *Boeseites.* A single species of *Boeseites* [*Ammonites maroimensis* (White 1887)] has been recorded from Brazil, which by modern models was attached to Nigeria at that time (Fig. 4). However, middle Late Albian deposits in Venezuela with *Hysteroceras orbignyi* (Spath) do not contain *Boeseites* (Renz 1968, 1982) but do contain *Venezoliceras karsteni* (Stieler 1920) (Renz 1982), which is related to *Venezoliceras umsinenense* [= *Lophoceras umsinenese* van Hoepen (1931)]. *Venezoliceras umsinenense* also occurs with species of *Hysteroceras,* including *H. orbignyi* and *H. varicosum,* but species of *Boeseites* are absent from Zululand.

It is obvious that van Hoepen (1931, 1941, 1942, 1944, 1946, 1951, but especially 1941, pp. 87-90) collected from a considerable section of rocks of the early part of the Late Albian. Although Haas (1942, pp. 138-141) went to considerable effort to demonstrate that the specimens of the Vernay collection all came from the same, single "horizon," I have not been convinced. The supposed occurrence together of certain genera not found together in other parts of the world (such genera as *Elobiceras, Dipoloceras, Neokentroceras, Hysteroceras,* and *Pervinquieria)* may indicate either stratigraphic condensation or separate occurrences in different strata. Haas knew that the collections came from different toes of talus slopes (as collectors stepped off of the boat at intervals to pick up the loose fossils).

It is possible that the *Boeseites* level in the Zululand area is represented by that part of the section which van Hoepen (1946) stated was covered. This would explain the absence of such forms in van Hoepen's publications, but not their absence in Venezuela or Colombia.

The Opening of the South Atlantic

Many authors have discussed the opening of the South Atlantic to the North Atlantic (Beurlen 1961; Reyment 1969, 1980; Reyment and Tait 1972; Sclater et al. 1977; Van Andel et al. 1977; Förster 1978; and others.) This opening of the Atlantic between Nigeria and Brazil has been discussed from several different bases, which are best summarized by Reyment (1980). The general conclusion is that a truly oceanic connection (underlain by oceanic crust) between the South and North Atlantics did not develop until the Turonian, and at least not until long after the Late Albian. Some of Förster's (1978) proposed marine

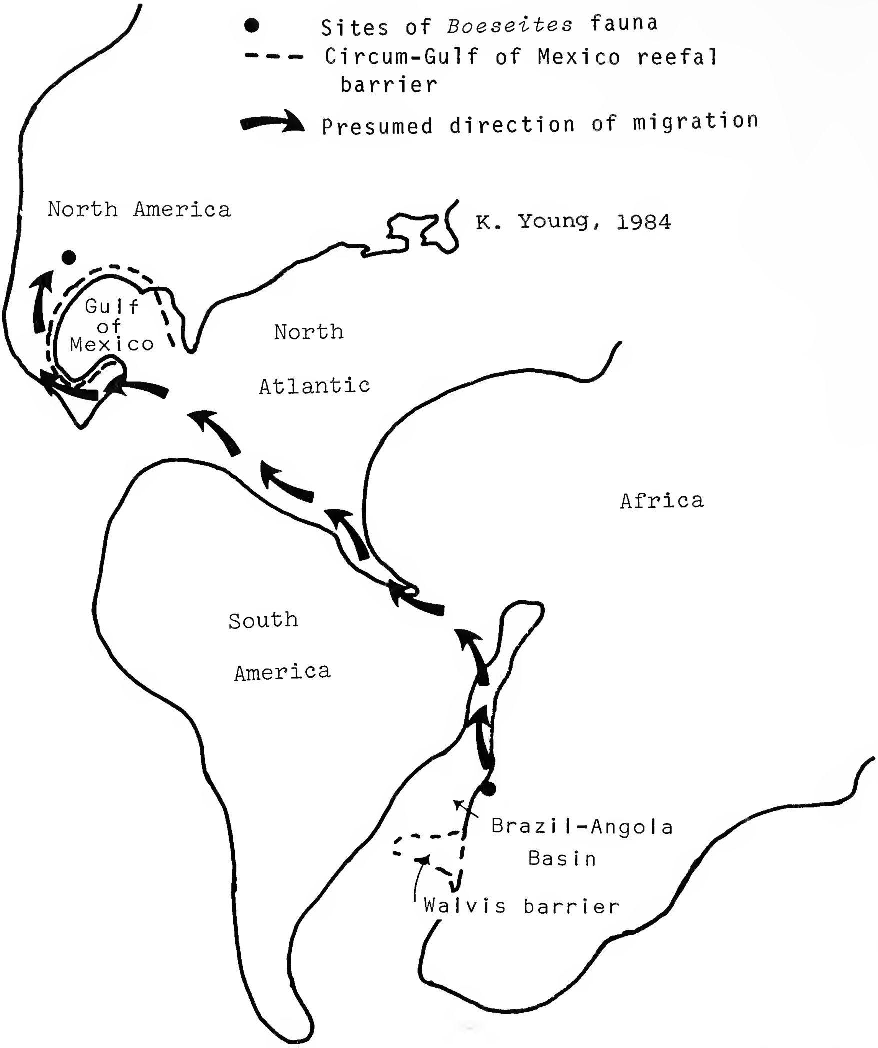

FIGURE 4. Proposed route of migration of the *Boeseites* fauna from Angola to Texas.

connections in the Albian have been explained in other ways (Reyment 1969, 1980; Kennedy and Cooper 1975; Reyment and Mörner 1977).

The Late Albian Transgression

With continential crust continuous from Nigeria to Brazil until the Turonian, processes other than continential separation are necessary to explain the distribution of the *Boeseites* fauna. Kennedy and Cooper (1975) have suggested an extensional sag. Whether this would have occurred as early as Late Albian or not is uncertain.

The transgression that began in the late Medial Albian and culminated in the Late Albian (Reyment and Mörner 1977; Förster 1978; Reyment 1980) seems adequate to explain the distribution of *Boeseites*. Perhaps the widespread distribution of *Manuaniceras manuanense* (Spath) and its relatives during the late Medial Albian indicates that Reyment et al. (1976) are correct in claiming that the late Medial Albian was the beginning of the maximum transgression of the Late Albian, but Kennedy and Cooper (1975) emphasize the differences between the manuanicerine faunas of these different areas and emphasize that they could have been distributed through the Tethys. The *Boeseites* fauna, on the other hand, is not known to occur in the Tethys. The *Boeseites* fauna seems to have migrated across the shallow Brazilian shelf during the Upper Albian zone of *Mortoniceras inflatum*, which was the culmination of the transgression that started in the late Medial Albian (Fig. 4).

CONCLUSIONS

The *Boeseites* fauna is known only from Angola in Africa and from northern Mexico and Texas in the Americas, except for one species, *Boeseites maroimensis* (White), in eastern Brazil. Such a restricted distribution means that this fauna crossed the Brazilian Shelf during a widespread, high stand of sealevel in the Late Albian.

At times of high stands of sealevel major oceans do not have to be present to accommodate short-lived migrations. The migration of the *Boeseites* fauna and the genus *Hysteroceras* into northern Mexico and Trans-Pecos Texas probably dates the beginning of the maximum stage of the Late Albian transgressive cycle, when migration occurred across the narrow Brazilian Shelf. It also indicates that faunas were not continuously replenished from South Africa during the Albian, but migrated only once. Therefore the *Boeseites romeri* zone in southwestern North America marks an important zone of short duraton that is correlatable and is not encumbered by the usual arguments of rapid or slow transgression, regression, punctuational or phyletic theories of evolution, or changes in facies.

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DIVERSITY IN FOX SQUIRREL SPATIAL RELATIONSHIPS AND ACTIVITY RHYTHMS

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ABSTRACT

Radiotelemetry was used to study changes in distances between individuals, home-range parameters and activity rhythms during the breeding, post-breeding, nursing and dispersal cycles for 3 adults and 1 juvenile in a fox squirrel (*Sciurus niger*) population. Mean linear distance between a previously mated pair (363 and 365) increased significantly ($P < 0.01$) during the post-breeding period, as compared to the breeding period. Both members of the mated pair maintained nearly the same average distance from a non-breeding male (366), but average distance was about 25 m less during the breeding period. The mean distance (17 m) maintained by female 363 from her single male offspring during the nursing period was significantly ($P < 0.01$) less than that (115 m) maintained during the dispersal period. Home-range increases of over 1.7 ha, changes in primary nest-site locations and changes in the position of the calculated activity centers were observed. Correspondence in daily activity rhythms between the mated pair during the breeding period and between the 2 males during the post-breeding period was detected.

INTRODUCTION

Past studies of the spatial requirements of fox squirrels (*Sciurus niger*) have dealt primarily with home-range shape or size (Allen 1943; Donohoe and Beal 1972; Adams 1976). Bernard (1972) suggested a form of territorial spacing in fox squirrels consistent with their dominance hierarchies. Hicks (1949) reported on fox squirrel activity in relation to changing weather patterns. Donohoe and Beal (1972) determined cumulative activity rhythms for adult fox squirrels but provided no comparative analysis of individual rhythms. Havera and Nixon (1978) studied the interactions, spacing and habitat utilization of adult female fox squirrels during their winter breeding season. The social organization of gray squirrels (Thompson 1977; Connolly 1979) seems better known than that of fox squirrels.

This study was designed to determine if differences in inter-animal distance could be detected for fox squirrel pairs during the breeding, post-breeding, nursing and dispersal cycle. Daily activity rhythms and the home-range parameters of size, center of activity, nest-site location and degree of home-range overlap were determined and compared

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among study periods. Finally, data were analyzed in terms of applications to future home-range studies.

METHODS

The squirrels used in this study were part of a population residing within an 8 ha residential section of the town of Seward, Nebraska. The arboreal habitat consisted of widely spaced American elm (*Ulmus americana*), pin oak (*Quercus palustris*), a single cottonwood (*Populus deltoides*), and scattered evergreens (*Juniperus* sp. and *Pinus* sp.). Human disturbance and contact with the squirrel population were observed to be minimal.

Research design was based on the assumption that territorial interactions and changes in spatial relationships, home ranges and activity rhythms could be detected by comparing relative locations of individual squirrels during a breeding, post-breeding, nursing and dispersal cycle. Fox squirrels breed semiannually, during January and June, with dispersal periods occurring approximately 135 days later (Allen 1943; Nixon and McClain 1968; Jordan 1971).

Four squirrels were fitted with collar-type radio transmitters (144-159 MHz) and located with an AVM model 12 receiver. Spatial positions (fix-points) were recorded on an aerial photograph of the study area scaled to 1 inch = 100 feet. A cumulative record of all fix-points for all squirrels was produced on a x-y grid overlaid on the aerial photograph.

Linear distance relationships were determined for 3 adult fox squirrels—a mated pair (female 363 and male 365) and a nonbreeding male (366). The x and y coordinates (fix points) of each squirrel were obtained each daylight hour for 22 days in January (breeding period) and again, for 31 days, beginning 17 March 1975 (post-breeding period). Female 363 was nursing male 305 by the beginning of the second period; therefore, the same 31 days were also considered the nursing period. Dispersal data were taken for 20 days beginning 15 May 1975 when male 305 was about 12 weeks old. In all, data were collected over 934 field hours.

Linear distances, $D = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$, calculated between simultaneous fixes on each pair of squirrels were compared among squirrel pairs and between periods. Data sets were tested using the Mann-Whitney U-test (Freund 1973).

During the breeding and post-breeding periods, the location (outside and inside the nest) and activity (feeding, napping, chasing) of each squirrel were recorded hourly between dawn and dusk. It was assumed that if intraspecific spatial relationships included agonistic or defensive behavior, these would be observed during these periods of study. Home ranges were described in terms of size, position of the calculated center

TABLE 1. Linear distances between members of 3 fox squirrel pairs during breeding and post-breeding periods. Squirrels 363 and 365 comprised a mated pair.

Squirrel Pair	Distance (m) between Animals during Breeding Period $\bar{X} \pm$ S.D. (N)	Post-Breeding Period $\bar{X} \pm$ S.D. (N)	Z score[a]
363/365 (F/M)	34 ± 46 (168)[b]	85 ± 71 (188)	9.20
363/366 (F/M)	123 ± 74 (168)	96 ± 65 (288)	−8.03
365/366 (M/M)	117 ± 69 (161)	86 ± 93 (186)[c]	−3.70

[a] Mann-Whitney U-test, $P < 0.01$
[b] 92 observations in 0 distance category.
[c] 52 observations in 0 distance category.

of activity (Cahoun and Casby 1958), the primary nest site and degree of home-range overlap (Jorgenson 1968).

RESULTS AND DISCUSSION

Comparison of mean inter-animal distance for all three pairs of adult squirrels (Table 1) between breeding and post-breeding periods indicated a mean increase of 51 m between female 363 and male 365, a mean decrease of 31 m between male 365 and male 366 and a mean decrease of 27 m between female 363 and male 366. All differences were significant at $P < 0.01$ (Mann-Whitney U test).

During the breeding period, male 365 was observed driving off other males, including male 366, and nesting with female 363 each night. Male 366 nested alone, about 90 m from the mated pair. During the post-breeding period, the two males nested together while the female nested alone in new nest site about 85 m from the two males.

The reproductive behavior of male 365 and female 363 did not include the mating chases between an estrus female and a group of socially ranked males described by Moore (1968). The latter female mated simultaneously with several males rather than just one as observed in my study.

Male 365 copulated with female 363 on 22 and 23 January 1975. One offspring, male 305, resulted from this mating. The distance ($\bar{X} = 17 \pm 27$ m; $N = 285$) maintained by female 363 from juvenile male 305 during the nursing period was significantly ($P < 0.01$) less than the distance ($\bar{X} = 115 \pm 82$ m; $N = 132$) maintained during the dispersal period. There were 188 observations in the 0-distance category during the nursing period.

Certain descriptive aspects of the dispersal process could be determined during the 20-day duration of this portion of the study. Dispersal appeared to begin when female 363 left the nursing nest with juvenile male 305. Both moved to an old leaf nest about 20 m from the original nest. Both squirrels usually traveled, fed, and nested together for the succeeding 3 days. After the 3-day period, juvenile male 305 was observed alone and no longer nested with female 363. He nested for 2 nights in his nursery nest, then moved to a tree hole about 20 m away for the next 2 nights and finally built a platform-type leaf nest 187 m from his birthplace. Male 305 exemplified the dispersal behavior described in Calhoun's (1963) summary of home range. During the next 5 days, 2 agonistic encounters between female 363 and male 305 were observed. Both encounters involved loud squeals from male 305 ending when he retreated over 100 m. Since May 1975, male 305 has not been observed nor has he been reported as a road kill.

The home range of male 365 increased from 1.0 to 2.4 ha, and male 366's home range increased from 0.4 to 2.1 ha between the breeding and post-breeding periods. The seasonal availability of new food resources probably contributed to the areal increase. However, certain intraspecific spatial changes were indicated in the home-range data. The distance between the calculated home-range centers (HRC) of males 365 and 366 decreased by 54 m during the post-breeding period. There was a 44 m change in the position of the HRC of male 365 toward the HRC of male 366. Calhoun (1963) indicated that as distance between HRC's of squirrels decrease, the probability of interactions between population members increase. He further indicated that distance maintenance between HRC's is an active process sustained by the signs and signals of population members. The HRC of female 363 was located 26 m farther from the HRC of male 365 and 27 m closer to the HRC of male 366 during the post-breeding period. The overlap area in the home ranges of the 2 males increased from 0.1 ha to 0.9 ha during the post-breeding period. According to Jorgenson's (1968) computational method, this increase in overlap should have increased these 2 squirrels' probability of interaction to certainty, compared to a $P = 0.21$ during the breeding period.

The home-range size of female 363 decreased from 0.8 ha during the breeding period to 0.4 ha during the post-breeding period while male 305 was nursing. It increased to 0.7 ha when male 305 was 12 weeks old and increased again to 1.5 ha during the dispersal period. During this time there was also a distance increase of 77 m between the HRC's of female 363 and male 305. In August 1975 female 363 was nursing another litter of 4 sired by a different male. At this time, her home range was 0.9 ha, but she demonstrated the same ($P > 0.05$, Mann-Whitney comparison) fix-point pattern as during the dispersal period in May 1975.

The daily activity rhythms (Fig. 1) of male 365 and female 363 during the breeding period were approximately the same, with peaks occurring between 0900 and 1500 Hours. This was the general activity

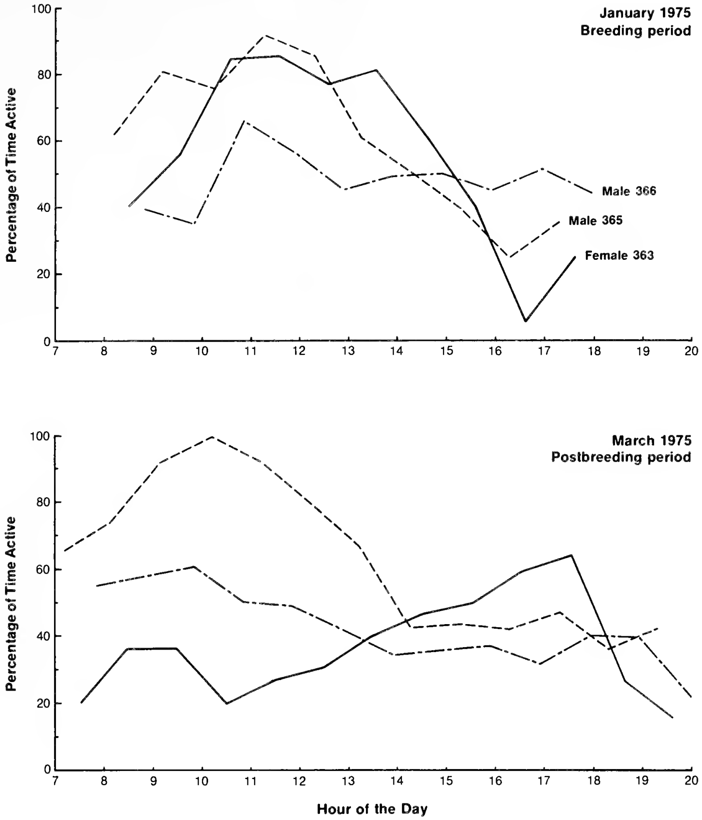

FIGURE 1. Hourly frequencies of activity for three adult fox squirrels (*Sciurus niger*) during a breeding and post-breeding period.

period reported by Donohoe and Beal (1972). The mated pair usually fed and traveled together during the breeding period. Activity of male 366 was spread evenly across all daylight hours. The relatively even distribution of activity of male 366 may have been due to his unique behavior of spending 3-day periods in the nest followed by day-long feeding periods ending when he returned to the nest at night.

During the post-breeding period the activity rhythms of male 365 and female 363 were no longer comparable in distribution and amplitude; rather, similarity in the activity rhythms appeared between the 2 males, whose greatest activity occurred between 0700 and 1400 Hours. Male 366 continued to spend 3-4 day periods in his nest with a total of 67% of total time spent nesting which was more than the total time (64%) spent in the nest by nursing female 363. Attention to her litter caused decreased amplitude in her activity cycle, which occurred between 1400 and 1900 Hours when the 2 males were usually in their nests.

CONCLUSION

This is the first reported study of spatial relationships between members of a fox squirrel population. Development of a territorial model based on similar procedures is feasible. However, a larger sample of individuals will be required to develop a discriminant function expressing the degree of territorial response one member of the population displays toward another. Obtaining longer time series of data from the same squirrels is not practical because of negative trap response, death, or dispersal. In the present case, males 366 and male 365 were reported as road kills in spring 1976 and after February 1976 female 363 was no longer found in the area.

This study indicated that home-range size estimates were influenced by reproductive behavior, season, and the time of day when data were gathered. For example the determination of home-range size for female 363 during the nursing period only or a lack of consideration for the entire daily activity rhythm when one is gathering data could lead to biased conclusions on home range.

Changes in the position of nest sites, calculated HRC and the degree of home-range overlap were quantified during the tenure of this study. The role of population members in effecting these changes needs further study. The inclusion of these considerations would be consistent with the suggestion of Sanderson (1966) that home-range data be made applicable to ecological studies on a species.

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PREVENTING NUTRIA DAMAGE TO SEISMIC CABLES WITH CHEMICAL AND PHYSICAL DETERRENTS

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ABSTRACT

Laboratory and field tests assessed the effectiveness of chemical repellents and metallic armor in preventing nutria (*Myocaster coypus*) damage to seismic cables. Chemical repellents currently registered by the Environmental Protection Agency were ineffective. However, internally armored wire, "Terncoat", proved impervious to gnawing by nutria.

INTRODUCTION

Nutria destroy seismic cables left overnight on the ground in the lowlands of Texas and Louisiana (Gunn 1980). The damage, which results from gnawing, varies from minor cuts in the cable jacket to severing of major cables. The objective of this study was to test chemical repellents and internally armored cable under laboratory and field conditions to determine effective methods of reducing nutria damage.

Most efforts to control nutria have been limited to removal methods, including killing and trapping (Talbert 1962; Evans 1970; Schitoskey et al. 1972; Kuhn and Peloquin 1974). Large-scale poisoning has been tested (Kuhn and Peloquin 1974), and a program of zinc-phosphide poisoning has been recommended as the best method of nutria control (Evans 1970). None of these methods, however, is acceptable in the cable-damage situation because nutria control must cover a large spatial area which may not be under the control of seismic companies.

Chemical repellents would seem to offer an attractive solution to the problem of cable gnawing by nutria. These non-lethal substances can be added to the jacket of the cable, and they have proven effective in repelling rodents in other situations. At least 32 chemicals exhibit broad-spectrum repellency to vertebrates; however, none of these is known to effectively repel nutria (Evans 1970). Moreover, the Federal Insecticide, Fungicide, and Rodenticide Act of 1957 amended by the

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Environmental Protection Agency (EPA) in 1972, has severely restricted the use of chemical repellents.

Physical deterrents include impenetrable covers for cables. A new type of cable amoring, called E-service armored wire, or "Terncoat", was developed by Bell Laboratories to protect wire against damage by pocket gophers and squirrels. Terncoat is 0.003 or 0.005 mm type 304 stainless steel that is helically wrapped around the wire and covered with a vinyl-plastic jacket, yielding a reasonably flexible cable with minimal extra weight. Relative to chemical repellents, this product presents fewer problems (such as toxicity, cost, and EPA registration).

METHODS AND MATERIALS

Laboratory Testing

Ten nutria were live-trapped at the J. D. Murphree Wildlife Management Area (WMA), Port Arthur, Texas, and brought to Texas A&M University for laboratory tests. Our test design followed Stolurow (1948) with some modification to facilitate the use of cable as a barrier and the use of nutria as the test species.

The nutria were housed and tested in standard dog runs that measured 91.5 × 183 × 244 cm. Runs were divided into 2 compartments of approximately equal size by a partition made of 2.5-cm mesh stainless-steel wire in a 91.5 cm × 91.5 cm frame. One compartment, called the den area, provided shelter and contained an automatic watering apparatus. The other compartment was the feeding area and had the cage entrance. Access between the compartments was through a 15-cm square hole, large enough to permit passage by nutria but small enough to allow blockage with a single segment of cable.

Body-weight reduction was used to create a relatively uniform motivation to feed. Once the nutria were habituated to the cage system, each animal was weighed daily during the experiment. Water was available *ad libitum* throughout the experiment. Food was available *ad libitum* until weight reduction began, at which time precise amounts of each part of the diet were presented at each feeding. The amount of food given each animal was that required to reduce the body weight to about 80% of its mean value under *ad libitum* feeding.

Once body weight was reduced and stabilized, each nutria was trained to gnaw through a cable barrier to obtain food. Training began with easily penetrable materials, such as paper towels and masking tape. The strength of the barrier gradually was increased to that of the actual cable as each nutria became more adept at chewing through the barrier. Testing began when all the animals had been trained to gnaw through a wire barrier and were at approximately the same level of ability.

Three trials with each animal, spaced a minimum of 2 h apart, were conducted daily. The reward for completion of the task for the 1st and 2nd trails was 0.1 each of the individual's food ration. The reward for the final trial was the remaining 0.8 of the food ration. A maximum trial period was 1 h. If at the end of 1 h the animal had not severed the barrier, both barrier and food were removed; after a period of 30 min, the food allocation was presented without a barrier.

After weight reduction and training, only 6 of the original 10 animals could be used for testing. Two females were pregnant, one individual was immature, and a 4th nutria had to be sacrificed because both of its upper incisors were broken.

Tests were conducted on untreated control cables, chemically treated cables, and internally armored cables. The following 5 chemicals, each reported to exhibit good repellency in some type of animal-damage control situation and each currently or recently registered with the EPA, were chosen for testing: tri-N-butyltin chloride (Bio-Met 12), a derivative of Bio-Met 12, tetramethylthriuram disulfide (Gustafson 42S), 3,5-dimethyl-4-(methylthio) phenyl methylcarbamate (Mesurol), and tert-butylsulfenyldimethyl dithiocarbamate (R-55). Testing of repellents was conducted using 2-conducter geophone string cable, Geospace model GS92883 (Geospace, P.O. Box 36374, Houston, TX 77036). The only physical deterrent tested was internally armored E-service armored wire (commonly called Terncoat) provided by the Western Electric Company (P.O. Box 20046, Greensboro, NC 27420). Bio-Met 12 and its derivative were tested in the form made available by the manufacturer. R-55 and Gustafson 42S were tested after dilution to 10% in a solution of associated inert compounds and Rhoplex AC-33, a binder manufactured by the Rhom and Haas Company (Philadelphia, PA). Mesurol was tested in a similar manner, except it was diluted to 1%. All chemical coatings were applied by dipping the wire or cable in the prepared solution followed by air-drying for 48 hours.

Testing followed a randomized-block design, with each animal comprising a block. Eight replications of the six treatments and the control (56 tests) were run on each animal, yielding a total of 48 trials of the control and each treatment. The following variables were recorded during each test: *failure time* = the amount of time between the animal's first exposure to the cable and electrical-continuity failure of the cable (continuity failure was defined as the first major deflection of an electrical resistance meter from the normal reading); *penetration time* = the time between the first exposure to the cable and actual severing of the cable, permitting passage of the nutria into the feeding compartment; *attack time* = the amount of time the animal actually spent in apparent attempts to get through the barrier, including all actions such as pushing, pulling, gnawing, licking, and any other investigation of the cable itself; and *exposure time* = the amount of time that the animal was exposed to the barrier, maximally 1 h. All times were measured in minutes and seconds using a stop watch. Data were analyzed using the Means and General Linear Model procedures of the Statistical Analysis System (Helwig and Council 1979).

Field Test

A field test was conducted at J. D. Murphree WMA, Port Arthur, Texas. Three sites—designated as the Island, Compartment 1, and Compartment 2—were selected for their high density of nutria and ease of access. Each site was prebaited with carrots, sweet potatoes, lettuce, and apples for 3 nights prior to laying the test cables.

Cable treatments were the same as in the laboratory test except the Bio-Met 12 derivative was deleted from the field test because its brittleness rendered it unusable on flexible cables. Thus, four chemical repellents, the armored cable, and the control cable were tested.

After the 3rd night of prebaiting, six 30.5 m sections of cable—one per treatment—were placed 6.1 m apart on the ground at each test site. The three arrays were oriented so the animals would be likely to cross the cables. The sequence of the cables was determined by a random number table. All cables were loosely stretched and secured at both ends to wooden poles sunk into the marsh mat. The cables were left 3 successive days and nights without baiting and then checked for gnawing damage. Weathering characteristics and ease of handling also were noted for each cable.

Following the initial test, each site was rebaited and the cables were left out an additional 7 nights. Then all cables were returned to the laboratory for inspection. Cables were visually checked for gnawing or chewing and the number of bites was determined with a magnifying lens and a dissecting microscope. Cables also were checked for electrical continuity. Weathering of the chemical coatings and the handling characteristics of the cables were noted.

RESULTS

Laboratory Tests

All 6 test animals (3 males, 3 females) rapidly reached and then maintained the desired level of reduced weight. Each animal exhibited a consistent method of gnawing at the test cable, although some individual variation was noted with respect to the direction in which the cable was attacked (Gunn 1980). Attack always occurred at the lowest accessible point on the cable.

The physical barrier (Terncoat) was not penetrated during the experiment (Table 1). The chemical treatments and the control did not differ significantly ($P > 0.05$) in vulnerability to nutria damage. Thus, Terncoat emerged as the only effective deterrent among those tested.

The data on Terncoat were deleted from further analysis because only 2 of the 4 variables were present in the data set and 1 of the 2 remaining variables, exposure time, was fixed at 60 min. There were no significant effects ($P > 0.05$) due to treatment or the interaction between treatment and animal or exposure (Table 2). Significant effects (P ¼0.05) were observed due to animal, exposure, and the interaction between animal and exposure. There was no significant difference between the control and any of the chemicals tested.

Field Test

The results of the field tests did not completely corroborate those of the laboratory tests. At the end of the first 3 nights of field testing, there were signs of damage only to the Terncoat cables. Terncoat had been attacked at the Island and Compartment 1, exposing the stainless steel jacket in a few places. The chemical coatings were beginning to loosen and bubble-up off the cable surface. All cables maintained good flexibility, but the chemical coatings were obviously not useable in wet areas for extended periods.

After 7 additional nights of exposure, the following results were obtained: (1) The control cable (with no chemical or physical repellent) was never attacked; (2) the cable covered with Bio-Met 12 was never attacked; (3) the cables covered with the 3 chemical alternatives that used Rhoplex AC-33 were all attacked and caused to fail at 1 or more of the test sites; (4) Terncoat was the most heavily attacked alternative, but was never caused to fail; and (5) minimal attack (2 bites in 2 cases) of unarmored cable caused failure of the wire to carry the proper current.

The chemically treated cables posed considerable problems at the conclusion of the field test because of the loosening of the coating during exposure. Terncoat could be picked up fairly easily as long as the "roll cast" of the cable was followed during rolling. The control cable displayed excellent handling characteristics throughout the experiment.

DISCUSSION

Results of the laboratory tests indicated that Terncoat is the best deterrent tested and the only treatment that prevented nutria damage to seismic cable. Chemical repellents effective in repelling other rodents had little or no effect on nutria. Adverse reactions to chemical

Table 1. Mean values of time (min:sec) variables measured in the laboratory experiment to evaluate armoring (Terncoat) and 5 chemical treatments as potential deterrents of cable-gnawing in nutria.

Animal	Variable	Terncoat	Bio-Met 12 derivative	R-55	TMTD	Bio-Met 12	Mesurol	Control
1	Failure Time		0:05.6	0:05.0	0:07.9	0:04.6	0:08.6	0:06.6
	Penetration Time		0:21.9	0:23.0	0:35.0	0:21.3	0:33.4	0:23.8
	Exposure Time	60:00.0	0:22.5	0:23.0	0:35.6	0:21.5	0:33.4	0:23.8
	Attack Time	9:22.1	0:21.9	0:23.0	0:35.0	0:21.3	0:33.4	0:23.8
2	Failure Time		0:03.4	0:03.5	0:02.9	0:03.9	0:04.0	0:03.3
	Penetration Time		0:07.0	0:06.0	0:06.3	0:07.8	0:07.1	0:06.8
	Exposure Time	60:00.0	0:07.0	0:06.0	0:06.3	0:07.8	0:08.1	0:06.8
	Attack Time	12:40.0	0:07.0	0:06.0	0:06.3	0:07.8	0:08.1	0:06.8
3	Failure Time		0:02.8	0:02.9	0:03.1	0:03.4	0:03.9	0:03.5
	Penetration Time		0:08.0	0:08.9	0:09.3	0:08.4	0:09.1	0:10.1
	Exposure Time	60:00.0	0:08.0	0:08.9	0:09.3	0:08.4	0:09.1	0:10.1
	Attack Time	10:32.1	0:08.0	0:08.9	0:09.3	0:08.4	0:09.1	0:10.1
4	Failure Time		0:01.9	0:02.3	0:02.6	0:02.3	0:02.0	0:02.5
	Penetration Time		0:01.1	0:11.1	0:11.9	0:13.6	0:11.4	0:11.0
	Exposure Time	60:00.0	0:10.1	0:11.1	0:11.9	0:13.6	0:11.4	0:11.0
	Attack Time	5:39.4	0:10.1	0:11.1	0:11.9	0:13.6	0:11.4	0:11.0
5	Failure Time		0:04.6	0:04.4	0:05.1	0:04.6	0:04.1	0:04.3
	Penetration Time		0:07.4	0:10.0	0:08.8	0:09.0	0:08.0	0:07.8
	Exposure Time	60:00.0	0:08.4	0:10.0	0:08.0	0:09.0	0:08.0	0:07.8
	Attack Time	26:20.6	0:08.4	0:10.0	0:08.8	0:09.0	0:08.0	0:07.8
6	Failure Time		0:13.5	0:13.9	0:11.0	0:21.5	0:14.9	0:11.9
	Penetration Time		0:32.4	0:31.1	0:24.4	0:40.0	0:37.6	0:22.6
	Exposure Time	60:00.0	0:32.4	0:31.1	0:24.4	0:40.0	0:37.6	0:22.6
	Attack Time	10:38.5	0:32.4	0:31.1	0:24.4	0:40.0	0:37.6	0:22.6

TABLE 2. Analysis of variance in 4 time variables for all 6 animals used in the laboratory test (Table 1). The degrees of freedom for each variable are in parentheses preceding the F value. The Terncoat treatment was excluded from the analysis.

Source of Variation	F Value (all animals)
Failure Time	
Animal	(5) 37.47**
Treatment	(5) 0.68
Exposure	(7) 4.75**
Animal-Treatment Interaction	(25) 0.92
Treatment-Exposure Interaction	(35) 0.82
Animal-Exposure Interation	(35) 1.86*
Penetration Time	
Animal	(5) 38.63**
Treatment	(5) 0.83
Exposure	(7) 6.74**
Animal-Treatment Interaction	(25) 0.88
Treatment-Exposure Interaction	(35) 0.94
Animal-Exposure Interaction	(35) 3.32**
Attack Time	
Animal	(5) 38.61**
Treatment	(5) 0.79
Exposure	(7) 6.85**
Animal-Treatment Interaction	(25) 0.88
Treatment-Exposure Interaction	(35) 0.93
Animal-Exposure Interaction	(35) 3.34**
Exposure Time	
Animal	(5) 38.63**
Treatment	(5) 0.83
Exposure	(7) 6.74**
Animal-Treatment Interaction	(25) 0.88
Treatment-Exposure Interaction	(35) 0.94
Animal-Exposure Interaction	(35) 3.34**

*significant at $P \leq 0.0005$
**significant at $P \leq 0.0001$

treatments were evident in only 4 of the 240 individual tests, and never prevented penetration of the cable. This probably can be accounted for by the unusual characteristics of the nutria's mouth. As with all rodents, nutria have a diastema between the incisors and molar teeth in both the upper and lower jaws. In nutria considerable modification of this region is evident in association with its aquatic habits. The entrance to the buccal cavity is reduced by skin and fur so that the animal may use its incisors for gnawing, grasping, and holding items while submerged or swimming. The entrance into the mouth cavity is about 3 cm in diameter in an average adult and is easily blocked by the tongue. Therefore, chemoreception occurs only when items are passed back into this region or licked by the animal. Thus, nutria can gnaw through a wire and never taste any component, rendering chemical repellents ineffective.

The field test shows that none of the chemical coatings, in the form tested, was acceptable for use in wet environments. All of the chemical coatings were loosened and/or partially dissolved by prolonged exposure to moisture. Neither the control nor Bio-Met 12 were attacked. This could indicate that the other 3 chemicals, or the adhesive used, are attractants, but this seems highly improbable because all of the chemicals have been shown to have good mammal repellency (EPA 1973).

In the field, Terncoat was attacked more often than the other alternatives. This could be due to its slightly larger size or the chemical make up of the cable jacket. Connolly and Landstrom (1969) and Cogelia et al. (1976) have shown there is a size class of wire which is more susceptible to pocket gopher damage. Lizell et al. (1958) have shown that a polyvinyl chloride (PVC) cable jacket is more highly susceptible to attack and possibly acts as an attractant to gnawing rodents. Because Terncoat is only 0.1 mm larger in diameter than the control cable, the PVC cable jacket itself offers the more plausible explanation.

One obvious point is that any form of biting can cause the cable to fail. This is clearly shown by the failure of Gustafson 425 and R-55 in Compartment 2. In both cases only 2 bites resulted in a drastic change in the measured current carried. Therefore, even minor damage can not be tolerated in geophysical cables. The only treatment that prevented damage to the cable in both testing situations was the Terncoat armor.

MANAGEMENT IMPLICATIONS

It appears that chemical repellents are of no use in controlling nutria damage to seismic cables. Control of nutria damage must, therefore, be limited to physical or lethal means. Terncoat offers potential control of cable damage caused by nutria and other wildlife. There are several modifications of the Terncoat system which could be used in almost any cable application. Variables in the coiling can allow for maximum protection, maximum flexibility, or minimum weight gain dependent on the requirements of the cable. This type of protective system would alleviate cable damage by most pests with the fewest legal problems, highest safety level, and shortest time to implementation.

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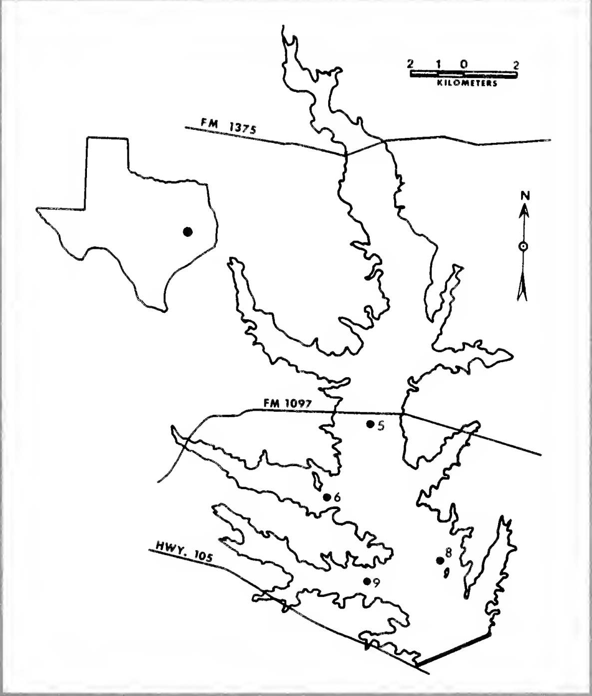

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PHYTOPLANKTON COMMUNITY STRUCTURE AND DYNAMICS IN LAKE CONROE, TEXAS[1]

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and WILLIAM J. CLARK

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ABSTRACT

The phytoplankton community in Lake Conroe, Texas, was sampled bimonthly from January 1980 to December 1981, to establish a baseline data set prior to implementation of an aquatic weed-control program. Collections were made at four limnetic stations using a five-meter integrated tube sampler.

Mean densities of phytoplankters peaked at 13,070/ml in August 1980 and 23,720/ml in August 1981. Cyanophyta comprised over 75% of the total density in collections made during the summer peaks in both years; *Raphidiopsis* alone accounted for approximately 60% of these total densities. Chlorophyta/Cryptophyta densities peaked in October 1980 (1,440/ml) and in November 1981 (1,080/ml), although their greatest relative abundance occurred during the winter and spring months when total phytoplankton densities were less than 1,000/ml. Peak diatom densities occurred in June 1980 (1,650/ml) and August 1981 (2,180/ml). During the high density season (June-July through October), mean densities of Cyanophyta, Chlorophyta/Cryptophyta, and diatoms were significantly greater in 1981 than in 1980. We believe that a rapid rise in water level due to heavy spring rains in 1981 was in large part responsible for the increased mean densities observed during the high density season in 1981, compared with 1980.

INTRODUCTION

Lake Conroe is a 8,100 ha impoundment on the West Fork of the San Jacinto River in Walker and Montgomery counties, Texas. After the reservoir's impoundment in 1973, there was a rapid invasion of submersed and floating macrophytes, particularly the exotic *Hydrilla verticillata* (Menn 1977; Martyn and Snell 1982). In January 1980, collection of phytoplankton data began as one part of the pretreatment evaluation for an extensive macrophyte control program using the grass carp (*Ctenopharyngodon idella*).

Some researchers have reported that aquatic plants out-compete phytoplankton for nutrients (e.g. Hasler and Jones 1949; Fitzgerald 1969; Boyd 1971), and that removal of aquatic macrophytes by grass

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carp leads to increased phytoplankton production (Miley et al. 1979; Opuszynski 1979). However, other studies have detected either no change or a decrease in phytoplankton standing crop following removal of vegetation by grass carp (Rottman and Anderson 1976; Terrell 1976; Hestand and Carter 1978; Lembi et al. 1978; Mitzner 1980). One explanation for the lack of increase in phytoplankton standing crop following vegetation removal by grass carp is that the nutrients formerly bound-up in the macrophytes are now part of the grass carp biomass and are still unavailable to the phytoplankton (Canfield et al. 1983).

Most of the aforementioned studies were conducted in ponds and small lakes. Lake Conroe presented an opportunity to examine the response of phytoplankton to large-scale macrophyte control in a larger body of water. The objectives of our study were to 1) identify the dominant phytoplankton forms in Lake Conroe, and 2) assess pretreatment temporal and spatial variations in the abundance and diversity of the phytoplankton community.

STUDY AREA

Aquatic vegetation in Lake Conroe began to reach nuisance levels in 1976 (Menn 1977). Aerial surveys utilizing infrared photography indicated 33.9% of the lake (2,690 ha) was infested with submersed vegetation in June 1980; by July 1981 the level of infestation rose to 45.5% of the lake (3,650 ha). Hydrilla comprised 80% or more of the total infestation throughout this study period and grew at depths as great as 7 m. An in-depth analysis of the distribution of aquatic vegetation in Lake Conroe is presented by Martyn and Snell (1982).

Some general physical-chemical parameters of the lake during the course of this study were as follows: mean depth 6.2 m, maximum depth 22.9 m, secchi disc depth 0.9-2.0 m, pH 7.0-8.7 with a two year mean of 7.9, total PO_4 means 0.2 mg/liter in winter and 0.07 mg/liter in summer epilimnion, NO_3 means 0.5 mg/liter in winter and 0.2 mg/liter in summer epilimnion, hardness 52-74 mg/liter, total alkalinity 35-70 mg/liter, specific conductance 180-330 μmho. Calculated hydraulic retention times varied from 45 to 354 days. The lake stratified from mid-May through late September and the hypolimnion became anoxic by mid-summer.

The southern half of the lake has extensive recreational and housing developments along the shoreline, while the northern half of the lake lies within the Sam Houston National Forest.

Locations of the phytoplankton sampling stations are given in Figure 1. Station numbers correspond to four of the ten stations that are sampled monthly for water quality parameters by the San Jacinto

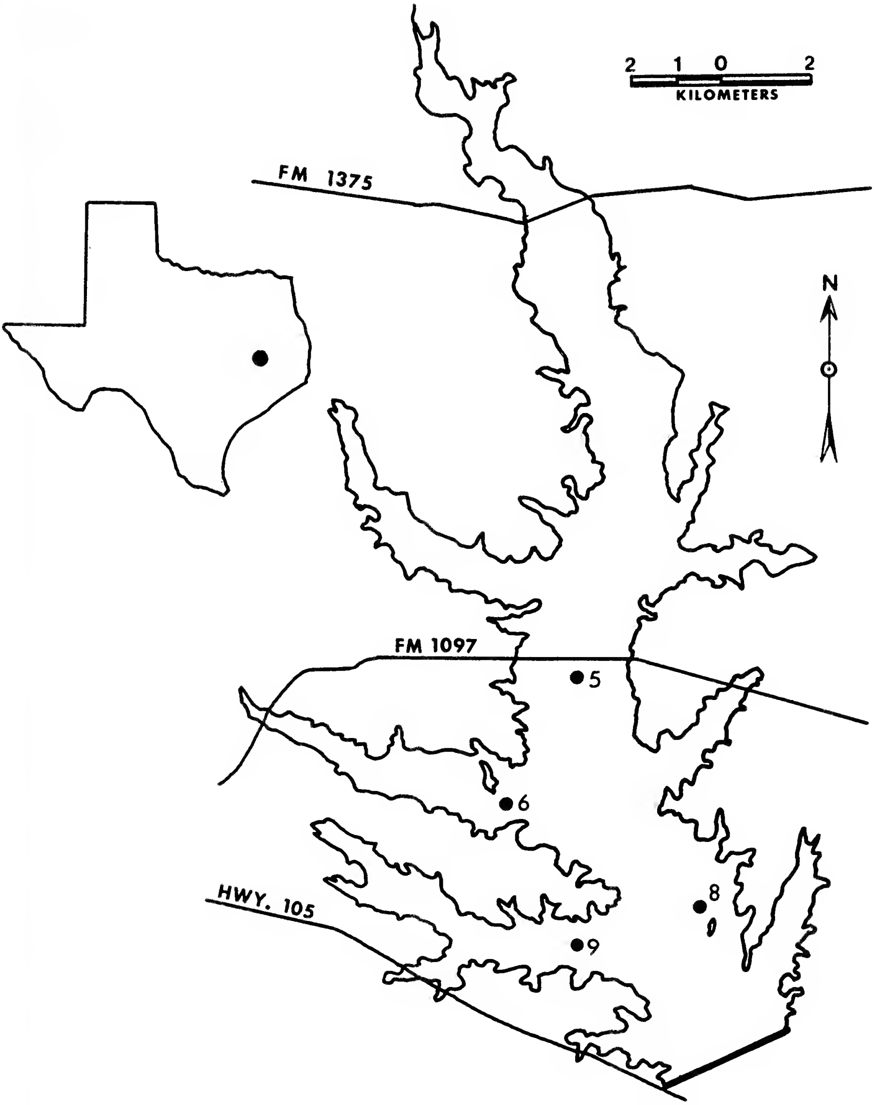

FIGURE 1. Map of Lake Conroe, TX, showing phytoplankton sampling stations.

River Authority for the city of Houston. Average depths at each sampling station over the course of this study were as follows: Sta. 5, 9.7 m; Sta. 6, 9.1 m; Sta. 8, 14.1 m; Sta. 9, 11.2 m.

MATERIALS AND METHODS

Samples were collected approximately twice monthly from January 1980 through December 1981 using a 5-m-long integrated tube sampler. All samples were preserved in the field using Lugol's solution.

In the laboratory, one aliquot from each sample was settled, and plankters were enumerated on an inverted microscope at 400x magnification. Plankton were identified and counted in randomly selected strips until the count of the most abundant form approximated 100 (Lind 1974). Counting units were either individual cell, colony, or filament. Chains of *Melosira* and *Diatoma* were recorded as occurrences, rather than as individual cells (see Table 1). The primary key used in identification was Prescott (1978). Representative samples from our collections will be sent to experts for identification and verification.

Triplicate samples were taken in February, June and August 1980, and in November 1981, to evaluate within-station variability. To determine if transformation of the data was required prior to statistical analyses, a set of ten replicates was taken at station 5 in July 1981. The chi-square analysis of the sample mean-variance relationship indicated a Poisson (random) model (Elliot 1977). Therefore, density data were subjected to square-root transformations prior to analysis.

Data were analyzed via multiple regression techniques using the Statistical Analysis System's General Linear Model procedure for a two-way ANOVA for unbalanced data (Helwig and Council 1979). Analyses of station, season, and year differences were performed for each taxonomic division and for the total counts. A Duncan's Multiple Range test was performed on all significant main effect means (station and season). A probability level of 0.05 was used in all tests of significance.

For the statistical analyses, each year was subdivided into two seasons characterized by low and high total density. The seasonal divisions were determined by examining trends in the data set (see RESULTS section). Data collected during periods of transition between high and low density seasons were not analyzed in the ANOVA procedures.

An additional station located at the FM 1375 bridge crossing was sampled throughout this study; however, unidentified flocculents in those samples over a 9 month period prevented phytoplankton enumeration. Consistently higher turbidities in this shallow water, more riverine section of the reservoir also added to the difficulties encountered in processing samples. Consequently, only data from the four limnetic stations were used in the statistical analyses and description of lake-wide trends.

TABLE 1. Phytoplankton taxa collected at four limnetic stations in Lake Conroe, TX, 1980-1981, and how enumerated (C = cell, CO = colony, F = filament, and CH = chain).

Division Chlorophyta
- *Ankistrodesmus* (C)
- *Bohlinia* (CO)
- *Botryococcus* (CO)
- *Carteria* (C)
- *Chlamydomonas* (C)
- *Chlorangiella* (C)
- *Chlorogonium* (C)
- *Chodatella* (C)
- *Closteriopsis* (C)
- *Closterium* (C)
- *Coelastrum* (CO)
- *Cosmarium* (C)
- *Crucigenia* (CO)
- *Dictyosphaerium* (CO)
- *Euastrum* (C)
- *Eudorina* (CO)
- *Gloeocystis* (CO)
- *Golenkinia* (C)
- *Gonium* (CO)
- *Kirchneriella* (CO)
- *Micractinium* (CO)
- *Oocystis* (CO)
- *Pandorina* (CO)
- *Pediastrum* (CO)
- *Platydorina* (CO)
- *Pleodorina* (CO)
- *Pyramimonas* (C)
- *Scenedesmus* (CO)
- *Selenastrum* (CO)
- *Sphaerellopsis* (C)
- *Sphaerocystis* (CO)
- *Staurastrum* (C)
- *Tetradesmus* (CO)
- *Tetraedron* (C)
- *Tetraspora* (CO)
- *Tetrastrum* (CO)
- *Treubaria* (C)
- *Volvox* (CO)

Division Euglenophyta
- *Euglena* (C)
- *Lepocinclis* (C)
- *Phacus* (C)
- *Trachelomonas* (C)

Division Pyrrophyta
- *Ceratium* (C)
- *Glenodinium* (C)
- *Gymnodinium* (C)
- *Peridinium* (C)

Division Cryptophyta
- *Chroomonas* (C)
- *Rhodomonas* (C)
- *Cryptomonas* (C)

Division Chrysophyta
- *Achnanthes* (C)
- *Asterionella* (CO)
- *Cocconeis* (C)
- *Diatoma* (CH)
- *Melosira* (CH)
- *Navicula* (C)
- *Synedra* (C)

Division Cyanophyta
- *Anabaena* (F)
- *Anabaenopsis* (F)
- *Anacystis* (CO)
- *Aphanizomenon* (F)
- *Aphanothece* (CO)
- *Chamaesiphon* (C)
- *Chroococcus* (CO)
- *Coelospaerium* (CO)
- *Gloeocapsa* (CO)
- *Gloeothece* (CO)
- *Oscillatoria* (F)
- *Raphidiopsis* (C)
- *Stichosiphon* (C)
- *Spirulina* (F)

Phylum Protozoa
- *Codonella* (C)
- *Difflugia* (C)
- Vorticellidae

RESULTS

A total of 73 phytoplankton genera were identified (Table 1). Numerous unidentified forms also were enumerated. Keys to species for Texas phytoplankton do not exist. Unidentified organisms were classified by division if possible; otherwise, they were classified as unknown. Because unidentified flagellates were often a dominant component of the counts and because individuals could not be distinguished as being from the Division Chlorophyta or the Division Cryptophyta, these two divisions were combined for analyses.

The low density periods (defined as those dates with average densities of phytoplankters less than 1,000/ml) were January through May 1980 and December 1980 through April 1981, plus December 1981. High density periods (when average total densities exceeded 5,000/ml) were June through October 1980 and July through October 1981.

Analysis of variance for the triplicate samples indicated no significant differences among samples within stations for any of the four sampling dates.

During low density periods, there were no significant differences among stations for any division or the total count in either year. During high density periods, there was only one instance of a significant difference among stations (Division Pyrrophyta, 1980). Therefore, station samples were pooled for statistical analysis.

Highest mean densities occurred on 26 August 1980 (13,070/ml) and 11 August 1981 (23,440/ml) (Fig. 2). Although the duration of the summer blooms and dates of peak abundance were similar, the mean densities during the high density period in 1981 were significantly greater than in 1980. The 1981 bloom was coincident with a rapid rise in water level caused by heavy rainfall following drought conditions in 1980 (Fig. 2).

The dynamics of the cyanophyte *Raphidiopsis* largely accounted for the gross trends in seasonal abundance and absolute density of the phytoplankton community during this study (Fig. 2). During the high density periods, *Raphidiopsis* often comprised over 60% of the total number of plankters enumerated, while during the low density periods it was virtually absent from the samples. Although the density of cyanophytes during the bloom in 1981 was significantly greater than in the bloom of 1980, the relative abundance of cyanophytes remained consistent between years (Fig. 3). Other cyanophytes commonly occurring and occasionally abundant during the high density periods were *Oscillatoria*, *Aphanizomenon*, *Anabaena*, and *Anabaena* A (enumerated separately from the other *Anabaena* species). In 1980, *Oscillatoria* had a density greater than 1,000/ml in at least one sample,

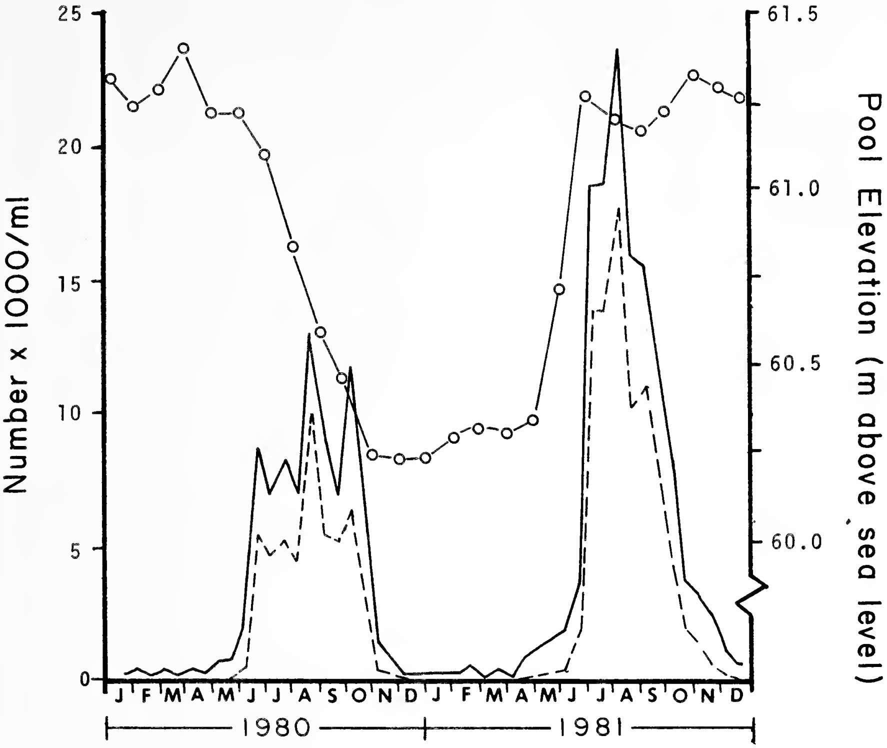

FIGURE 2. Total phytoplankton density (——) and density of *Raphidiopsis* (-----) averaged over four limnetic stations (5,6,8, and 9), and pool elevation (--o--) in Lake Conroe, TX, during 1980 and 1981.

while in 1981, *Oscillatoria*, *Anabaena*, and *Anabaena* A each had densities greater than 1,000/ml in at least one sample.

Mean densities during the low density periods ranged from 300/ml to 880/ml in 1980 and 360/ml to 970/ml in 1981. During these periods, Chlorophyta/Cryptophyta were dominant, with *Ankistrodesmus* comprising the majority of the identifiable forms. Mean densities were not significantly different between years during the low density periods.

Although Chlorophyta/Cryptophyta dominated during the low density periods, their annual pulses began during the summer cyanophyte blooms. Peak densities occurred 9 October 1980 (1,440/ml) and 20 November 1981 (1,080/ml); mean densities during the high density period were significantly greater in 1981 than in 1980 (Fig. 4). During the high density period of both years, the majority of the Chlorophyta/Cryptophyta were unidentified flagellates.

Diatoms generally were placed either in the Order Centrales or the Order Pennales with no further attempt at identification. The most frequently observed and identified taxa were *Melosira*, *Diatoma*,

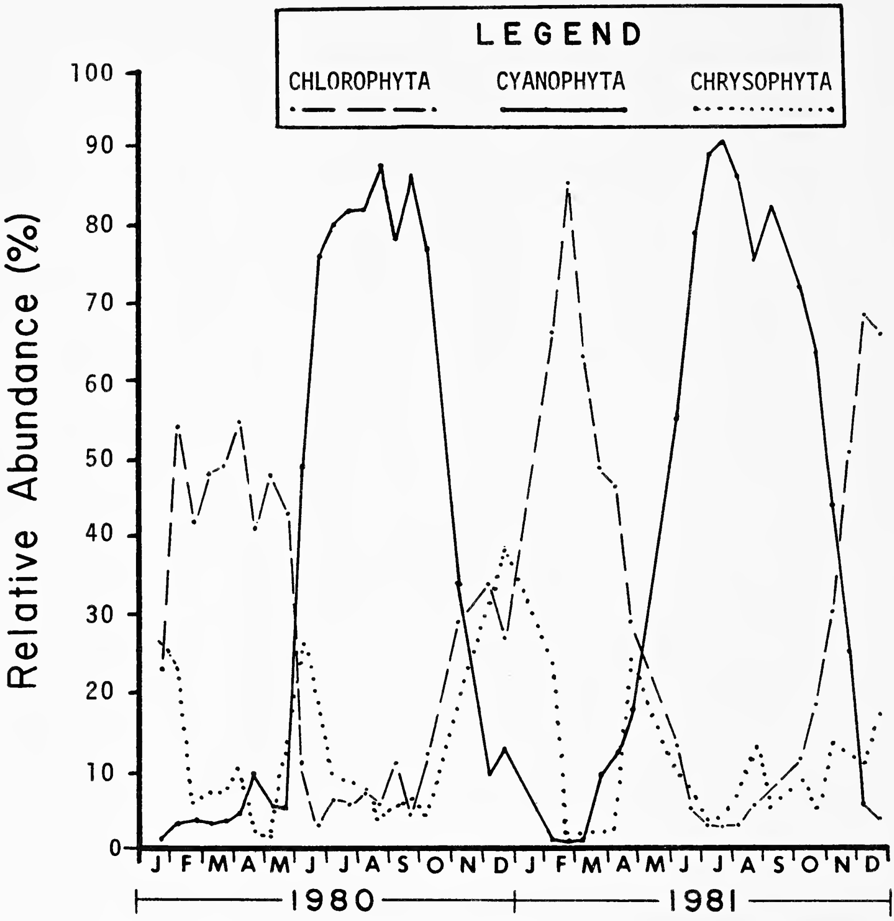

FIGURE 3. Relative abundance of the three dominant algal groupings (Chlorophyta/Cryptophyta, Cyanophyta, and diatoms) from four limnetic stations (5,6,8, and 9) in Lake Conroe, TX, during 1980 and 1981.

Synedra, and *Achnanthes*. Peak diatom densities occurred 30 June 1980 (1,650/ml) and 27 August 1981 (2,180/ml) (Fig. 5). The density of diatoms during the high density period was significantly greater in 1981 than in 1980. The main contributor to the 1980 peak was *Synedra* (79% of all diatoms), while *Achnanthes* was the most abundant form in 1981 (89% of all diatoms). Peak relative abundance of diatoms occurred in December 1980 (39%) and April 1981 (25%).

The divisions Euglenophyta, Pyrrophyta, and the phylum Protozoa were only minor contributors to phytoplankton community density during this study. None of these groups ever had a mean density in excess of 100/ml or a relative abundance greater than 10%.

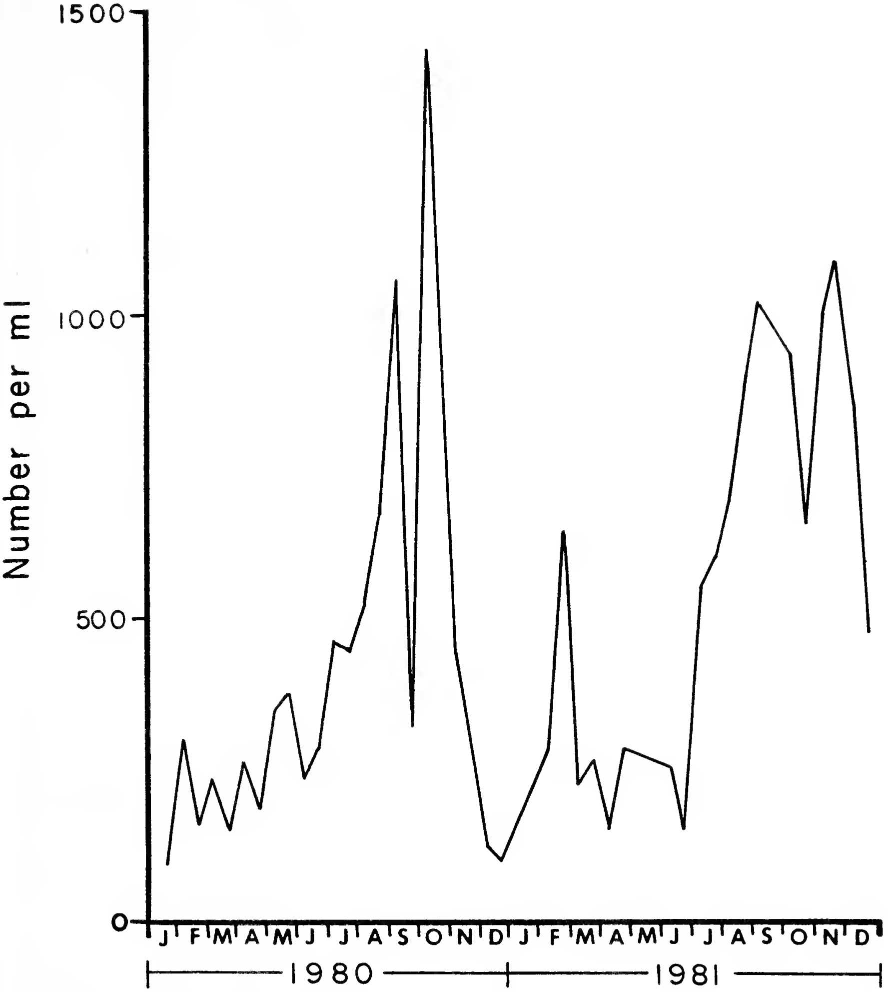

FIGURE 4. Density of Chlorophyta/Cryptophyta averaged over four limnetic stations (5,6,8, and 9) in Lake Conroe, TX, during 1980 and 1981.

DISCUSSION

The timing and duration of Lake Conroe's annual phytoplankton blooms, as well as the date on which densities peaked, were largely consistent between 1980 and 1981. The cyanophyte *Raphidiopsis* was the dominant form during both annual blooms of the community. The Cyanophyta, Chlorophyta/Cryptophyta, and the diatoms demonstrated seasonal trends in relative abundance during 1980 that were similar to trends in 1981. The Chlorophyta/Cryptophyta dominated each year during low density and transition periods, but reached highest absolute densities in the fall as the cyanophyte blooms declined. The

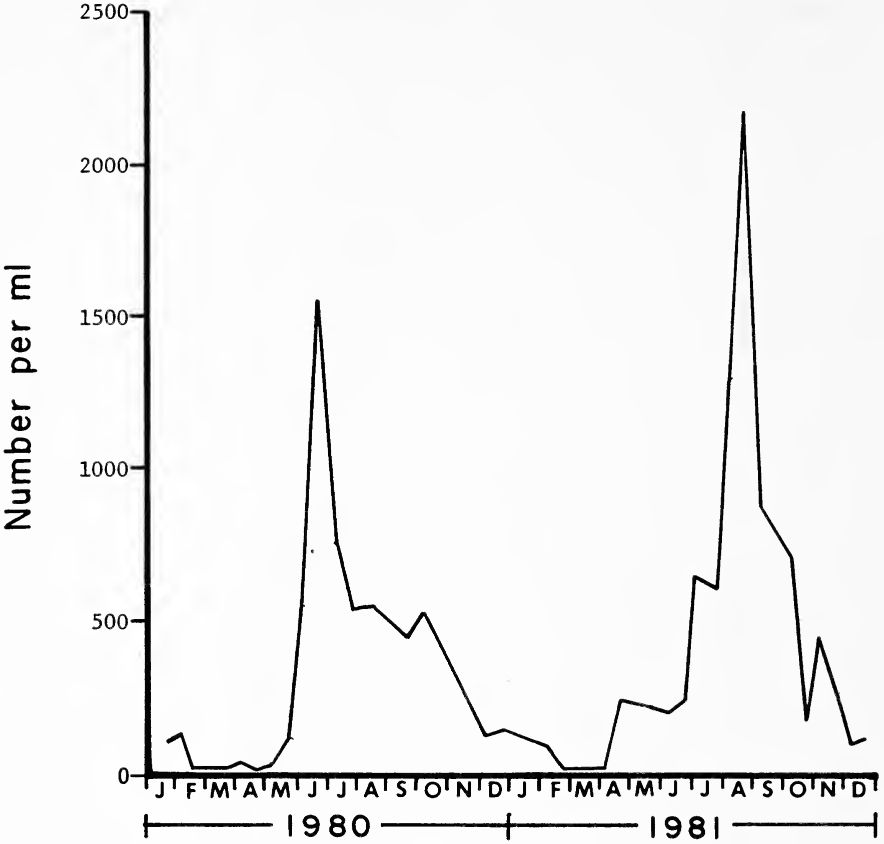

FIGURE 5. Density of diatoms averaged over limnetic stations (5,6,8, and 9) in Lake Conroe, TX, during 1980 and 1981.

diatoms exhibited one major bloom each year during the summer months, with each bloom characterized by a definite and short-lived peak, followed by a gradual decline through the fall and winter months.

A literature search yielded few journal articles containing phytoplankton data for eastern Texas reservoirs (Harris and Silvey 1940; Cheatum et al. 1942; Patterson 1942; Silvey and Harris 1942). Most of these articles concerned impoundments in the Dallas/Fort Worth area, all pre-dated 1945, and all recorded net plankton information, i.e. zooplankton plus large phytoplankton collected by straining water through bolting cloth. Although direct comparisons of total numbers are not possible, the authors did make some specific comments regarding various phytoplankton categories and genera. Harris and Silvey (1940) reported summer minima, due largely to decreases in diatoms and bluegreens, particularly *Melosira* and *Lyngbya*, in Lake

Bridgeport, Eagle Mountain Lake, Lake Dallas, and Lake Worth. In Lake Bridgeport, phytoplankton had its highest populations during late winter and early spring, with blooms of *Melosira* and *Aphanizomenon.* Lake Dallas was dominated in late winter by *Melosira,* followed by an early spring increase of greens, peaking in March. In a later publication, Silvey and Harris (1942) stated that, during a 1936-1941 sampling period in Lake Dallas, algal blooms shifted from the middle of summer to late winter and early spring, due primarily to *Melosira.* Patterson (1942) reported that in White Rock Lake diatoms out-numbered all other plankton during her one-year study. They peaked in April with an average of 1,740/liter with *Melosira* the major component. Cheatum et al. (1942) studied Ellis Lake, approximately 100 miles east of Dallas, for 3 years. The most prominent algal forms were desmids, which peaked in May 1941 (3,780/liter). A more recent study of Eagle Mountain Lake by the EPA (Morris et al. 1979) showed a continuance of the late winter/early spring maxima (March 3,060 individuals/ml; May 3,330/ml) and summer minima (August 980/ml). During March, the dominant forms were *Stephanodiscus astraea* (19.8% of total), *Chroomonas acuta* (18.7%) and an unidentified flagellate (11.0%). In May, the dominant forms were chlorophytan filament #1 (27.0%) and *Nitzschia* #1 (27.0%).

The United States Geological Survey's Water Resources Data for Lake Conroe (USGS 1980,1981) show August/September as the time of peak phytoplankton abundance, and dominance by bluegreens (92% or more). These data, like ours, indicated that phytoplankton densities were higher in 1981 than 1980. Their mean August/September counts for Lake Conroe were much higher than ours for both years.

The USGS information for Lake Livingston (USGS 1980,1981), based on 2 sampling dates per year, also shows August/September as the time of peak phytoplankton abundance, and shows dominance by bluegreens (88% or more). The dominant forms were *Lyngbya, Oscillatoria,* and *Agmenellum* (*Merismopedia*). However, Lake Livingston had a decrease in phytoplankton numbers from 1980 to 1981.

In 1974, the EPA collected quarterly (March, May, August and November) samples from numerous impoundments across the United States. Included in this survey were Lake Livingston and Lake Houston. In Lake Livingston, the maximum phytoplankton density (32,600 individuals/ml) was recorded in August. Numerically, bluegreens accounted for 74.4% and diatoms, 23.9% of the total. The most prominent forms were *Dactylococcopsis* (24.0% of total), *Cyclotella* (20.3%), *Oscillatoria* (15.8%), *Merismopedia* (11.7%) and *Raphidiopsis* (11.3%). Minimum densities occurred in November (1,090/ml). Lake Houston, which is downstream of Lake Conroe on the San Jacinto

River, exhibited its maximum phytoplankton abundance in March (5,820/ml). Diatoms were the dominant group (53.3%), followed by bluegreens (19.9%). The dominant algal forms were *Melosira* (37.4%) and *Cyclotella* (10.3%). Although geographically close and under the same basic environmental conditions, the three reservoirs show considerable individuality.

The principal difference in the phytoplankton community in Lake Conroe, Texas, between years was that high densities of the major divisions were significantly greater in 1981 than in 1980. Whereas the major divisions bloomed in 1980 during a time of stable, and then declining water levels, the 1981 blooms developed following a rapid increase in water levels due to late-spring rainfall. We feel that nutrients brought in by the large influx of runoff water in 1981 were responsible in part for the positive response of the phytoplankton community, though this remains speculation until additional data, particularly on water chemistry, are analyzed.

Environmental factors unrelated to removal of aquatic vegetation were responsible for a significant increase in phytoplankton density in Lake Conroe from 1980 to 1981. Therefore, close scrutiny of post-treatment data will be necessary to distinguish relationships between phytoplankton dynamics and aquatic vegetation removal from variations caused by physical-chemical changes unrelated to vegetation removal.

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ZOOPLANKTON COMMUNITY STRUCTURE AND DYNAMICS IN LAKE CONROE, TEXAS[1]

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ABSTRACT

Zooplankton were collected approximately twice monthly at five stations in Lake Conroe, Texas, from January 1980 through December 1981, using vertical hauls with a Wisconsin plankton net (153 μm mesh). Organisms from five one-milliliter subsamples of each concentrated sample were identified and enumerated using a Sedgewick Rafter cell. The resulting species list included 6 protozoans, 20 rotifers, 18 cladocerans, 6 copepods and 15 miscellaneous taxa.

The highest mean zooplankter densities (127-130/liter) occurred during January and February, with *Bosmina*, *Asplanchna* and *Conochilus* the dominant forms. From May through November, mean densities were generally less than 20/liter, with *Conochiloides* the dominant organism. Other abundant organisms during these two years were *Polyarthra*, *Ceriodaphnia*, cyclopoid copepods and copepod nauplii.

INTRODUCTION

Lake Conroe is a 8,097 ha reservoir on the West Fork of the San Jacinto River in Walker and Montgomery counties, Texas. This paper examines the structure and dynamics of the reservoir's limnetic zooplankton community prior to stocking of grass carp (*Ctenopharyngodon idella*) for control of an exotic macrophyte, *Hydrilla verticillata.* Since most other grass carp studies have been conducted in small impoundments, Lake Conroe provides a unique opportunity to evaluate response of the limnetic zooplankton community in a larger reservoir to large-scale biological control of macrophytes. General limnological data are given in Bettoli et al. (1985).

The primary objectives of our two-year baseline study were to identify the major taxa of zooplankton and to quantify their abundance and distribution, both spatially and temporally, within the lake. Although we know of no other studies of the limnetic zooplankton in Lake Conroe , such studies have been conducted on other impoundments in East Texas (Smith 1971; Allard 1974; Rogers

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1976; McCullough et al. 1977). We shall compare the zooplankton community of Lake Conroe to the communities found in these other reservoirs.

MATERIALS AND METHODS

Zooplankton samples were collected approximately twice monthly from January 1980 through December 1981 at the five stations in Lake Conroe described by Bettoli et al. (1985), using a Wisconsin plankton net (153 μm mesh). Single vertical tows of 5 m were taken at stations 5,6,8 and 9 in the downstream half of the reservoir; a 3-m tow was taken at station 1 near the upper end of the reservoir. The samples were preserved in approximately 10% formalin.

In the laboratory, five one-milliliter aliquots from each concentrated sample were enumerated in a Sedgewick Rafter cell using a compound microscope at 100x magnification. Counts were converted to number per liter. Zooplankton were identified using the taxonomic keys in Pennak (1978). To facilitate enumeration, copepods were grouped as calanoid, cyclopoid or nauplii; selected specimens were sent to Dr. H.C. Yeatman for identification.

Triplicate samples were collected periodically from each station (February, June and August 1980 and November 1981). Differences among samples within stations were never significant ($P > 0.05$) relative to within sample variability (subsampling error), as determined by one-way analysis of variance (ANOVA). At one station, triplicate vertical hauls of the plankton net were compared to triplicate samples taken using a large capacity piston pump which (1) collected a depth-integrated sample and (2) took water at a rate which would minimize avoidance by zooplankters. Density estimates for the more abundant organisms did not differ significantly between net and pump samples, as evidenced by 95% confidence intervals.

Chi-square analysis of the sample mean-variance relationship (Elliott 1977) of zooplankton densities in a set of ten replicate samples collected at one station indicated that the statistical distribution of density estimates approximated the Poisson (random) model; therefore, density data were converted prior to all statistical analyses using a square-root transformation.

For statistical analyses, each year was divided into two seasons characterized by high and low zooplankton densities. The criteria used to divide each year are detailed in Table 1.

Statistical analyses were done to determine (1) station differences within seasons, within years and between years, (2) differences between seasons, (3) differences between years and (4) season-by-station interaction. Data were analyzed by multiple regression techniques

TABLE 1. Criteria for determining the seasons of high and low zooplankton density, and their corresponding dates during 1980/81, in Lake Conroe, Texas.

Season	Dates	Mean No./liter
High 1980	31 Jan-16 Jun; Dec	>15
Low 1980	30 Jun-13 Nov	<10
High 1981	13 Feb-23 Apr	>40
Low 1981	16 Jun-16 Dec	<20

using the Statistical Analysis System (SAS) General Linear Model (GLM), which performs two-way ANOVA for unbalanced data (Helwig and Council 1979). Analyses were performed for each major taxonomic group (protozoa, rotifers, cladocerans, copepods and miscellaneous) and for total zooplankton. Duncan's Multiple Range test was performed on all significant (α = 0.05) main-effect means (season and station).

The minimum sensitivity (densities calculated under the assumption that only one organism was seen in the 5 sub-samples) of our sampling procedure varied, depending upon concentrate volume and tow length. For the 5-m tows (stations 5,6,8 and 9), the minimum sensitivity ranged from 0.11-0.45/liter with a mean of 0.35/liter; whereas, the 3-m tows (station 1) had a minimum sensitivity range of 0.27-0.72/liter with a mean of 0.58/liter.

RESULTS AND DISCUSSION

Annual Densities and Community Structure

The limnetic zooplankton collected in Lake Conroe during 1980/81 consisted of 6 protozoans, 20 rotifers, 18 cladocerans, 6 copepods and 15 miscellaneous taxa (Table 2). Rotifers predominated, and cladocerans were the next most abundant organisms. Copepods were present at consistently low densities; protozoans and miscellaneous organisms occurred infrequently (Fig. 1). The most abundant taxa during the two-year study period were *Conochilus*, *Bosmina*, *Asplanchna*, *Conochiloides*, cyclopoid copepods, copepod nauplii, *Ceriodaphnia* and *Polyarthra* (Table 3).

Highest mean densities occurred from January to June 1980 and from December 1980 to May 1981 (Fig. 2). Annual mean maxima occurred on 31 January 1980 (126.8/liter) and 27 February 1981 (129.9/liter). On these dates, rotifers and cladocerans predominated (Table 4); the most abundant taxa were *Bosmina*, *Conochilus*, *Asplanchna*, cyclopoid copepods and *Synchaeta* (Table 5). Mean zooplankton densities reached relative minima during early August in both years: 0.8/liter in 1980 and 2.1/liter in 1981.

TABLE 2. Checklist of zooplankton found in Lake Conroe, Texas, January 1980 through December 1981. R, C, and A indicate whether the organism was considered rare (<10 observations), common (>10 but <50 observations) or abundant (>50 observations). There were 198 observations (dates X stations). Nomenclature follows Pennak (1978).

- Protozoa
  - *Arcella* R
  - *Centropyxis* C
  - *Difflugia/Codonella* R
  - *Stentor?* R
  - Ciliate protozoan R
  - Vorticellidae C

- Rotatoria
  - *Polyarthra* A
  - *Hexarthra* R
  - *Filinia* R
  - *Keratella* C
  - *Asplanchna* A
  - *Anuraeopsis* R
  - *Ploesoma* R
  - *Trichocerca* C
  - *Testudinella* R
  - *Platyias patulus* R
  - *Platyias quadicornis* R
  - *Brachionus* spp. C
    - *B. angularis*
    - *B. calyciflorus*
  - *Colurella* R
  - *Lepadella* R
  - *Monostyla* R
  - *Euchlanis?* R
  - *Synchaeta* C
  - *Conochilus* A
  - *Conochiloides* A

- Cladocera
  - *Sida* R
  - *Diaphanosoma brachyurum* C
  - *Daphnia* spp. C
    - *D. pulex*
    - *D. longispina*
  - *Ceriodaphnia* spp. A
    - *C. reticulata*
    - *C. lacustris*
  - *Bosmina longirostris* A
  - *Ilyocryptus* R
  - *Euryalona occidentalis* R
  - *Camptocercus* R
  - *Kurzia latissma* R
  - *Alona* spp. R
    - *A. rectangula*
    - *A. guttata*
  - *Alonella* spp. C
    - *A. karua*
  - *Pleuroxus hamulatus* R
  - *Pleuroxus striatus* R
  - *Pleuroxus denticulatus* R
  - *Chydorus* spp. C

- Copepods
  - Calanoid C
    - *Diaptomus siciloides*
  - Cyclopoid A
    - *Cyclops (Acanthocyclops) vernalis* form *brevispinosus*
    - *Mesocyclops edas*
    - *Macrocyclops albidus*
    - *Tropocyclops prasinus mexicanus*
    - *Cyclops (Diacyclops)bicuspidatus thomasi*
  - Nauplii A

Elsewhere in eastern Texas, the zooplankton communities of Sam Rayburn Reservoir (Allard 1974), Murvaul and Striker Creek Reservoirs (Rogers 1976) and Livingston Reservoir (McCullough et al. 1977) were dominated by rotifers and copepods, while Wilkes Creek Reservoir (Smith 1971) was dominated by copepods. Annual mean maxima of zooplankton densities in Livingston Reservoir (156.95/liter and 157.42/liter) and Sam Rayburn Reservoir (120/liter) were similar to those

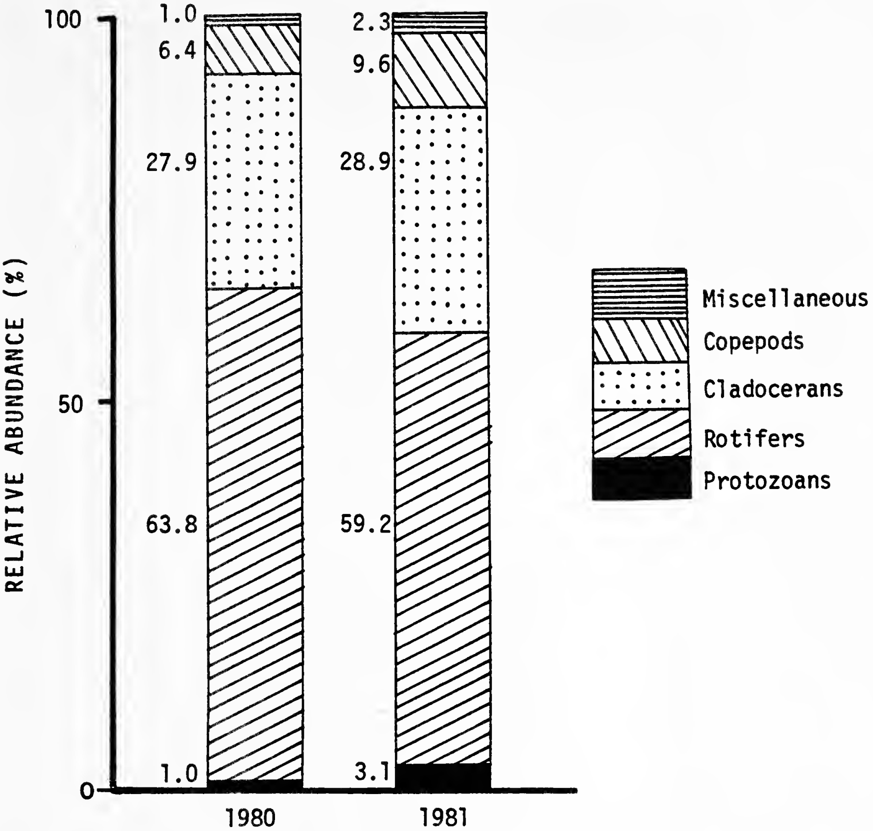

FIGURE 1. Percent composition by major category and year for the zooplankton in Lake Conroe, Texas.

found in Lake Conroe in 1980 and 1981; the Livingston Reservoir maxima, however, occurred in June and April, while the Sam Rayburn Reservoir maximum occurred, like Lake Conroe's, in February. Wilkes Creek Reservoir, like Lake Conroe, had its maximum densities in February and its minimum densities in August. However, unlike Lake Conroe, copepods dominated during the annual zooplankton maxima in Sam Rayburn and Wilkes Creek reservoirs.

The annual mean standing crop of zooplankton in Lake Conroe was 26.2/liter in 1980 and 30.5/liter in 1981. Annual mean standing crops reported for other Texas impoundments were 60.0/liter, Livingston Reservoir (McCullough et al. 1977); 56/liter, Sam Rayburn Reservoir (Allard 1974); 29.6/liter, Murvaul Reservoir; and 22.3/liter, Striker Creek Reservoir (Rogers 1976).

TABLE 3. Single station maximum densities (SSMD), maximum mean density for all stations (MMD), and annual mean densities (all stations and dates; AMD) for the major taxa. Station numbers and months of occurrence are in parentheses. All values are reported in number per liter. There were 107 samples collected in 1980 and 91 in 1981.

	1980			1981		
	SSMD	MMD	AMD	SSMD	MMD	AMD
Asplanchna	62.9 (S9,3)	24.2 (1)	5.2	39.1 (S9,3)	15.9 (2)	4.7
Conochilus	381.1 (S1,12)	81.1 (12)	8.2	87.2 (S1,2)	42.6 (2)	8.4
Conochiloides	85.4 (S9,6)	35.3 (6)	2.3	9.4 (S1,10)	4.9 (10)	1.1
Polyarthra	2.0 (S5,11)	0.9 (3)	0.2	3.2 (S1,11)	2.1 (4)	0.5
Bosmina	169.4 (S9,3)	45.3 (3)	6.3	54.8 (S8,2)	24.5 (2)	4.9
Ceriodaphnia	4.0 (S1,12)	2.0 (1)	0.2	37.4 (S1,2)	8.5 (2)	1.3
Cyclopoid adults	25.9 (S9,1)	12.9 (1)	1.0	25.9 (S1,3)	11.1 (2)	2.1
Copepod nauplii	8.1 (S9,3)	2.1 (3)	0.3	5.9 (S9,10)	3.3 (10)	0.7

Seasonal Variation

Results of the ANOVA indicated, except for the miscellaneous category in 1981, that our seasonal density groupings were valid for both years. Low density seasons were not significantly different between years for any group or totals. A comparison of high-density seasons showed that 1981 densities were significantly higher than 1980 densities for all groups and totals. For total density, significant season-by-station interaction was evident in 1980, but not in 1981. Although all stations had higher total densities during the high-density seasons than during the low-density seasons, the magnitude of the increase

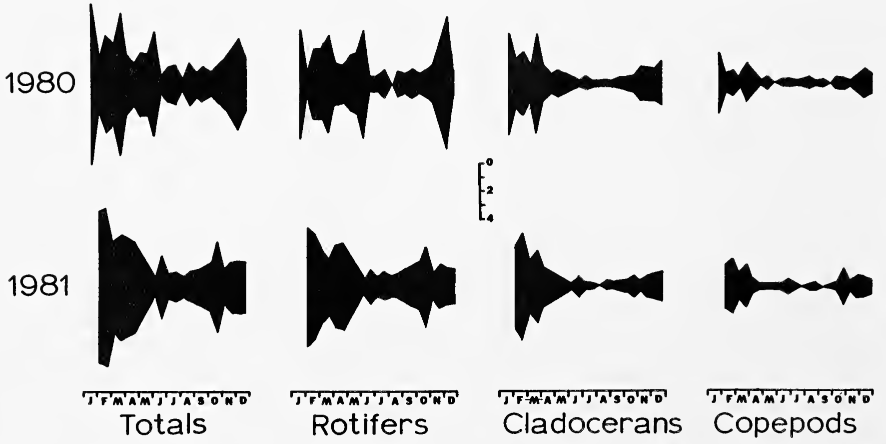

FIGURE 2. Seasonal variation in total density for major groups of zooplankton in Lake Conroe, Texas, during 1980 and 1981. Vertical width of envelope, in scale units, represents the sqaure root of average density in number/liter.

TABLE 4. Mean densities and relative abundances for the major categories of zooplankton forms during periods of density maxima in 1980/81 in Lake Conroe, Texas.

	31 January 1980		27 February 1981	
	no./ liter	% of total	no./ liter	% of total
Protozoans	0.2	0.2	4.9	4.4
Rotifers	56.6	44.6	54.6	45.9
Cladocerans	52.1	41.1	56.8	39.5
Copepods	17.8	14.0	13.6	10.2
Miscellaneous	0.1	0.1	0.0	0.0
	126.8	100.0	129.9	100.0

varied greatly among stations (from 151% at station 1 to 1,454% at station 9).

An examination of differences in total densities among stations within years indicated that stations 9 and 1 had significantly higher densities than station 5 in 1980, while station 1 had significantly higher densities than the rest of the stations in 1981. There were no significant differences between stations within seasons, except for the low-density season of 1981, when station 1 had significantly higher total densities than the other stations.

The observed seasonal variation in densities of the major taxa in Lake Conroe is detailed by group in the following sections. Where appropriate, information pertinent to those organisms classed as abundant (Table 2) will be presented first, followed by those classed as common.

Protozoans. With the exception of Vorticellidae and *Centropyxis*, protozoans were rarely observed and, when present, generally contributed less than 10% of the total. The highest average densities occurred on 14 July during 1980 (3.6/liter) and on 30 June during 1981

TABLE 5. The mean densities (all stations) and relative abundances of the major zooplankton in Lake Conroe, Texas, during annual maxima.

	31 January 1980		27 February 1981	
	no./ liter	% of total	no./ liter	% of total
Bosmina	41.3	32.6	27.2	20.9
Conochilus	24.2	19.1	28.5	21.9
Asplanchna	24.4	19.2	13.7	10.5
Cyclopoid copepods	9.7	7.6	11.1	8.5
Synchaeta	0.0	0.0	12.1	9.3
	99.6	78.5	92.6	71.1

(5.4 liter). The dominant protozoan in 1980 was *Centropyxis* (0.0-4.3/liter at individual stations), while colonial Vorticellidae (0.0-16.3/liter at individual stations) dominated in 1981. These two taxa, plus *Difflugia/Codonella,* were found at least once at each of the five stations. Total protozoan densities never differed significantly among stations.

Rotifers. Rotifers were ubiquitous, occurring in approximately 96% of the samples. Three quarters of the time they comprised 50% or more of each station's count (Fig. 2). They were especially dominant during the low-density seasons, when they frequently composed 90-100% of each station's total count. The highest average densities of rotifers occurred in December 1980 (84.1/liter) and February 1981 (68.2/liter). The early 1980 peak occurred in January (56.5/liter; Fig. 2). The highest density observed at a single station was 390.0/liter at station 1 in December 1980. This peak was primarily due to *Conochilus.*

The most abundant rotifers were *Asplanchna, Conochilus, Conochiloides* and *Polyarthra* (Table 3). *Asplanchna* and *Conochilus* were dominant during the high-density seasons, while *Conochiloides* was the most abundant organism during the low-density seasons. *Polyarthra* occurred at low densities year-round. Increases in the density of *Conochiloides* generally followed decreases in the density of *Conochilus.* Rogers (1976) reported a similar sequence of density fluctuations for these two genera in Striker and Murvaul reservoirs in East Texas.

Keratella, Trichocerca, Brachionus and *Synchaeta* were common rotifers and had individual station maxima of 2.0, 5.2, 7.8 and 16.4 per liter, respectively. However, densities of *Keratella, Trichocerca,* and *Brachionus* were generally less than one per liter.

The dominant rotifers reported for the other East Texas reservoirs are *Brachionus, Polyarthra, Keratella, Conochiloides, Conochilus, Kellicottia* and *Platyias* (Allard 1974; Rogers 1976; McCullough et al. 1977). Of these taxa, *Conochilus, Conochiloides* and *Polyarthra* were also dominants in Lake Conroe, but *Asplanchna,* another Lake Conroe dominant, has not been listed previously as a prominent form in East Texas impoundments.

Significant among-station differences in rotifer density occurred during the high-density season of 1980, when station 9 had significantly higher densities than stations 6,5 or 1. Significant season-by-station interactions were evident in both 1980 and 1981. During both years, station 1 had the highest rotifer densities among all stations during the low-density seasons, but it had the lowest rotifer densities among all stations during the high-density seasons. From the low to the high density seasons in 1980, rotifer densities increased at stations 5,6,8 and 9, but decreased at station 1 (Fig. 3).

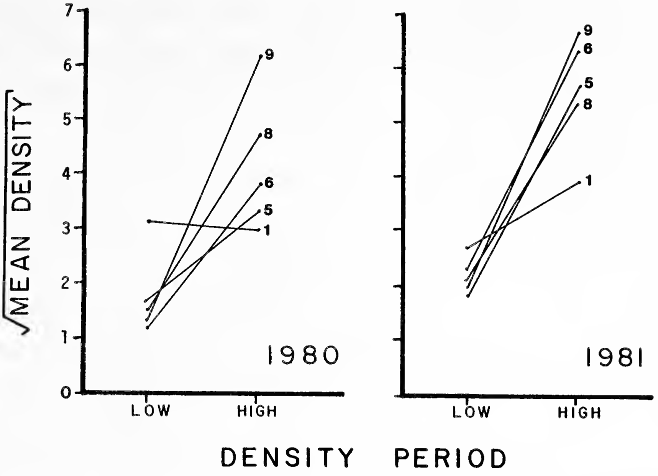

FIGURE 3. Square root of mean density of total zooplankton for low and high density periods plotted to demonstrate season-by-station interactions.

Cladocerans. Highest average densities of Cladocera occurred in January 1980 (52.1/liter) and February 1981 (56.8/liter) (Fig. 2). Their relative abundance was generally greater than 20% but less than 50%. *Bosmina longirostris* was the most abundant cladoceran and usually comprised at least half of the individual cladoceran totals. Mean densities of *Bosmina* were greatest in March 1980 (45.3/liter) and February 1981 (27.2/liter) (Table 3); its densities were less than one per liter from June through mid-October during both years. *Bosmina* was found most frequently at station 9 and least frequently at station 5. *Ceriodaphnia,* the only other abundant cladoceran, was present January through April 1980 and February through April 1981. It occurred most frequently at station 1.

The common cladocerans were *Daphnia, Chydorus, Diaphanosoma* and *Alonella,* in decreasing order of abundance. Mean density of *Daphnia* peaked at 8.3/liter in 1980 (January) and at 3.7/liter in 1981 (February). *Chydorus* had an annual mean maximum of 3.1/liter in 1981 (February), but was recorded only once in 1980 (0.4/liter, June). *Diaphanosoma* and *Alonella* had mean densities of less than one per liter during both years.

The highest total annual number per liter of *Ceriodaphnia, Chydorus, Diaphanosoma* and *Alonella* occurred at station 1 both years. Station 1 was located in the river channel immediately adjacent to dense beds of vegetation. *Ceriodaphnia, Diaphanosoma* and chydorids were found in very high densities within the weed beds in Lake Conroe (Campbell et al. 1985); therefore, frequent occurrence of these taxa at station 1 was probably indicative of the close proximity of vegetation. Furthermore, in 1981, total cladoceran densities at stations 9,1 and 6 were significantly higher than those at station 5. These higher densities may also be attributable to the close proximity of vegetation.

Cladocerans were not significant components of the zooplankton communities in Sam Rayburn Reservoir (Allard 1974), Murvaul and Striker Creek Reservoirs (Rogers 1977) or Livingston Reservoir (McCullough et al. 1977); in these reservoirs, as in Lake Conroe, *Bosmina* was the most abundant cladoceran.

Copepods. Copepods occurred year-round at consistently low densities. They were most abundant during the high-density seasons, with highest mean densities of 17.8/liter in January 1980 and 13.6/liter in February 1981 (Fig. 2). Relative abundance of copepods was usually less than 15%. Cyclopoid copepods and nauplii were the dominant forms (Table 3) and were observed primarily January through April 1980 and December 1980 through April 1981. Calanoid copepods, represented by *Diaptomus,* occurred January through April both years. The calanoids had highest mean densities of 4.6/liter in 1980 (January) and 0.3/liter in 1981 (February and March). Total densities of copepods never differed significantly among stations.

Miscellaneous. Most of the organisms classed as "miscellaneous" were not true plankters, but benthic or periphytic organisms. Two tychoplankters (organisms spending part of their life cycle in the plankton) included in this category were the phantom midge *Chaoborus* and the parasitic copepod *Argulus.* The most frequently encountered non-planktonic organisms were unidentified eggs, ostracods, chironomid larvae and nematodes. Other contributors were flatworms, oligochaetes, amphipods, bryozoans, spiders, water mites, damselfly and dragonfly nymphs and unidentified insects.

CONCLUSION

The limnetic zooplankton community in Lake Conroe, Texas, during 1980 and 1981 was dominated by rotifers and cladocerans, particularly the rotifers *Asplanchna, Conochilus, Conochiloides* and the cladoceran *Bosmina.* Mean densities peaked in January and February and reached minima in August. Annual mean zooplankton standing crops were 26.2/liter in 1980 and 30.5/liter in 1981.

Other East Texas reservoirs are dominated by rotifers and copepods or copepods alone. Although *Conochilus* and *Conochiloides* have been listed as dominant forms in these other reservoirs, *Asplanchna* has not. The timing of the maximum and minimum zooplankton densities in Lake Conroe did not coincide in all instances with those found in other East Texas reservoirs, but the annual standing crops of Lake

Conroe were within the range of those in other reservoirs. The most significant difference between Lake Conroe and other East Texas reservoirs is the low density of copepods in Lake Conroe.

The major taxa, annual trends, station differences and season-by-station interactions remained fairly constant between years in Lake Conroe during the two-year pre-treatment study; however, total zooplankton densities in 1981 were significantly higher than those in 1980. These patterns of temporal and spatial variability, along with the annual quantitative differences, should be carefully considered in future determinations of what impacts the use of grass carp for the biological control of macrophytes will have had on the limnetic zooplankton community of Lake Conroe. The accumulated evidence of four additional years of data and analyses of physical-chemical and other pertinent parameters should provide some interesting insights into the structure and dynamics of the Lake Conroe limnetic zooplankton community, and its reaction to large-scale ecosystem modification.

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SPATIAL VARIABILITY AND COMMUNITY STRUCTURE OF LITTORAL MICROCRUSTACEA IN LAKE CONROE, TEXAS[1]

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ABSTRACT

Microcrustaceans living in and near beds of the plant *Hydrilla verticillata* in Lake Conroe, Texas, were sampled on six dates during 1980 and 1981 by pumping water into buckets and pouring measured amounts through a Wisconsin net. Mean densities of microcrustaceans were high during all seasons, usually exceeding 290/liter. The community was dominated by Cladocera, with 22 species, mostly from the family Chydoridae. Vertical and horizontal variations in density occurred in relation to hydrilla beds.

INTRODUCTION

The littoral regions of lakes are inhabited by microcrustacean fauna distinctly different qualitatively and quantitatively from that found in the limnetic zone (Pennak 1966). Limnetic zooplankton detect the elevation of the horizon and orient in such a way that horizontal movement takes them away from the shore; littoral microcrustacea orient oppositely, and thus remain in the littoral zone (Siebeck 1980).

Submerged plants increase the structural complexity of the littoral habitat and provide a variety of microhabitats for small invertebrates. Certain species of Cladocera in the families Macrothricidae and Chydoridae have adapted structures and behaviors for living on the surfaces of plants and other submerged substrates (Fryer 1968, 1974) and will remain on the surface of plants even when disturbed (Campbell et al. 1982). Other species of littoral microcrustaceans are normally associated with surfaces but readily enter the water to swim (Whiteside 1974; Meyers 1980). Organisms such as *Ceriodaphnia* (Cladocera: Daphnidae) inhabit mainly the open spaces between and adjacent to submerged plants (Meyers 1980). The recently proposed

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terms "epon" (upon surfaces) and "peron" (around surfaces) are appropriate in this context to categorize organisms that are tightly and loosely associated with surfaces (Clark 1981).

Conventional methods for sampling in the littoral zone simultaneously collect organisms from all of the aforementioned microhabitats, and some workers have used the ambiguous term "littoral zooplankton" to describe collections made with these techniques. To avoid ambiguity, we herein refer to the sampled population as "littoral microcrustacea," which includes both littoral epon and peron.

Food supplies for littoral microcrustacea may be virtually unlimited in lakes having abundant aquatic plants, which provide a source of organic detritus and surfaces for attachment of small eponic algae. Dense mats of submerged plants may also restrict the movements of some fishes that would normally prey upon the microcrustaceans. However, littoral planktivorous fishes such as silversides (Antherinidae), which may be abundant in areas adjacent to plant beds, may feed to some extent upon plant-associated organisms (Morris 1982). The combined effects of abundant food and low levels of fish predation permit development of dense populations of littoral microcrustacea. Our purpose here is to report on the density and community structure of the littoral microcrustacean populations found in the extensive hydrilla beds of Lake Conroe (Martyn and Snell 1982) during 1980 and 1981.

METHODS AND MATERIALS

A detailed description of Lake Conroe is contained in Bettoli et al. (1985). On six days from June 1980 to November 1981, we collected samples at 13 different locations in the littoral regions of the reservoir (Fig. 1). Stations 6 through 13 in this report correspond to stations 1 through 8 in Morris (1982). The number of stations per sampling period varied from one to seven. Dense beds of submerged plants dominated by hydrilla occurred at all stations and occupied 33-45% of the surface area of the reservoir during the study.

Water was normally collected from within the plant beds at locations where the water was 2-3 m deep using a large capacity piston pump (Fagot 1975). The end of the intake hose was raised or lowered at a constant rate through the water column (from surface to within 0.5-1 m of bottom) amid weeds as a bucket calibrated to contain 15 liters was filled. Collected water was then poured through a 153 μm mesh Wisconsin net to concentrate the organisms. Two or three replicate samples were collected at each station.

Entire samples were examined and enumerated under a dissecting microscope when samples contained fewer than about 300 organisms.

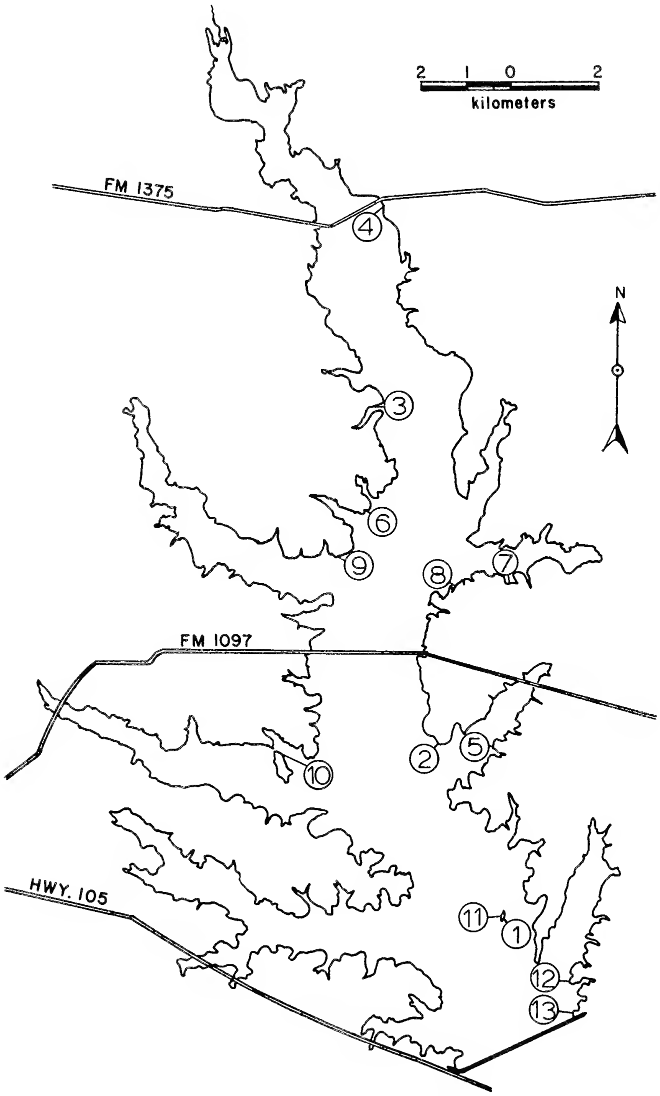

FIGURE 1. Map of Lake Conroe showing locations of stations for collecting littoral microcrustacea.

For dense samples, consecutive 1 ml aliquots were enumerated in a Sedgewick Rafter chamber under a compound microscope until at least 100 organisms had been counted. Numbers of organisms in the sample or subsamples were used to calculate average densities of microcrustaceans for each station.

TABLE 1. Total density (number/liter) of organisms in water collected from within plant beds of hydrilla in Lake Conroe during 1980-1981. The numbers in parentheses are the station numbers.

	16 June 1980	11 Oct. 1980	13 Mar. 1981	30 June 1981	13 Aug. 1981	23 Nov. 1981
	238(1)	1728(4)	498(1)	1922(6)	15(7)	336(1)
	507(2)		314(2)	179(7)	118(8)	317(2)
	139(3)		596(5)	78(9)	130(10)	362(5)
				220(10)	1760(11)	
				150(11)	1634(12)	
				348(12)		
				269(13)		
Mean	294.7		469.3	452.3	731.4	338.3
Standard Deviation	190.4		143.2	653.8	883.7	22.6
Coefficient of Variation	64.6%		30.5%	144.6%	120.8%	6.7%

RESULTS AND DISCUSSION

Density and Community Structure

Average total density of organisms (including non-microcrustaceans) exceeded 290/liter for all sampling dates, although individual stations produced densities as low as 15/liter on some dates (Table 1). Total densities of organisms in the weed beds averaged at least one order of magnitude higher than densities of limnetic zooplankton measured at limnetic stations during the same time periods (Cichra et al. 1985). We think that the great variation in total population density evident among stations during June and August 1981 was mainly due to differences in the density of vegetation among the stations. On the June 1980, March 1981 and November 1981 sampling dates, samples were collected from stations which appeared to have nearly equal densities of submerged plants (visual determination), and the resulting estimates of animal population density were less variable. The single estimate for October 1980 at station 4 was based upon samples collected by filling a bucket at the surface in the dense hydrilla mat and is probably not comparable to samples taken with the pump, which took a sample of water integrated through the entire water column.

The microcrustacean community included 27 species of Cladocera and Copepoda (Table 2), with the family Chydoridae represented by 14 species. Average densities by station and date for the major cladoceran species are shown in Figure 2; densities for ostracods, cyclopoid and calanoid copepods, *Hyalella azteca* (Amphipoda) and non-microcrustacean organisms are shown in Figure 3.

Cladocera dominated the community numerically, especially *Camptocercus* sp. and *Chydorus brevilabris* (Chydoridae), *Ceriodaphnia* spp.

TABLE 2. Checklist of Cladocera and Copepoda found in beds of hydrilla in Lake Conroe during 1980-1981. Cladocerans followed by letters in parentheses also were found in the extensive study of limnetic zooplankton by Cichra et al. (1985) reported elsewhere in this issue. The letters indicate categories of frequency of occurrence in 198 *limnetic* samples: A = abundant, >50 ; C = common, >10 but <50 ; R = rare, 1-10. (Copepods were not evaluated for frequency of occurrence in the limnetic samples.)

Cladocera Family Bosminidae
  Bosmina longirostris (A)
 Family Chydoridae
  Alona guttata
  Alona karua
  Alona quadrangularis } (R)
  Alona setulosa
  Alonella excisa
  Alonella hamulata(C)
  Anchistropus minor
  Camptocercus sp.(R)
  Chydorus brevilabris(C)
  Dunhevedia crassa
  Euryalona occidentalis(R)
  Leydigia acanthocercoides
  Pleuroxus denticulatus(R)
  Pseudochydorus globosus

Cladocera (continued)
 Family Daphnidae
  Ceriodaphnia spp.(A)
  Simocephalus serrulatus
 Family Macrothricidae
  Ilyocryptus spinifer(R)
  Macrothrix laticornis
 Family Sididae
  Diaphanosoma brachyurum(C)
  Latonopsis occidentalis
  Sida crystallina(R)
Copepoda
 Cyclopoida
  Cyclops (*Acanthocyclops*) *vernalis*
   (form *brevispinosus*)
  Eucyclops agilis
  Macrocyclops albidus
  Mesocyclops edax
 Calanoida
  Diaptomus dorsalis

(Daphnidae), and *Diaphanosoma brachyurum* (Sididae). Ostracods and cyclopoid copepods were also consistently important components of the community. The calanoid copepod *Diaptomus dorsalis* occurred abundantly only at station 10 during June 1981. Co-occurrence of *D. dorsalis* with same-sized *Diaptomus siciloides* of the limnetic zooplankton (Cichra et al. 1985) is unusual (pers. comm. from Dr. H.C. Yeatman, P.O. Box 356, Sewanee, TN). However, *D. dorsalis* (considered a brackish water species) appeared to be restricted to the littoral zone in Lake Conroe. Consequently, the spatial distributions of these closely related species probably did not overlap. *Bosmina longirostris* also occurred frequently in samples from limnetic stations; it was the dominant cladoceran in the limnetic zooplankton (Cichra et al. 1985). *B. longirostris* is a weak swimmer (Zaret and Kerfoot 1980), and its occurrence in the littoral zone in Lake Conroe may have been due to its inability to resist currents carrying it toward shore areas.

Non-microcrustaceans which occurred regularly in moderate densities included rotifers, the oligochaete *Stylaria lacustris* and small chironomid larvae. Water mites (Hydracarina) were collected on every sampling date, but were never abundant.

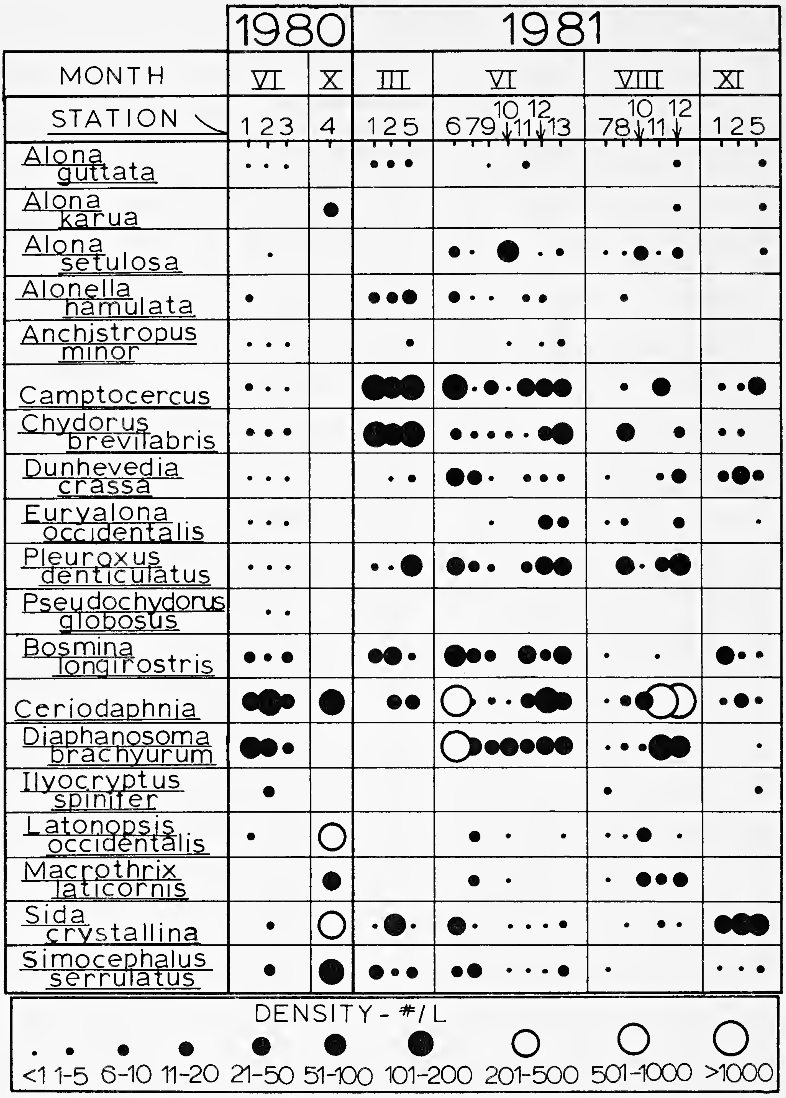

FIGURE 2. Average density (number/liter) by station and date for littoral cladoceran species found in hydrilla beds in Lake Conroe.

Spatial Variation in Relation to Hydrilla Beds

In littoral areas unprotected from wave action, hydrilla often becomes concentrated in a mat parallel to and separated from the shore by an unvegetated zone of varying width. Morris (1982) routinely collected samples of microcrustacea from the water overlying these exposed areas in addition to the usual weed-bed samples. Exemplary data for station 11 (on the west shore of the island at the lower end

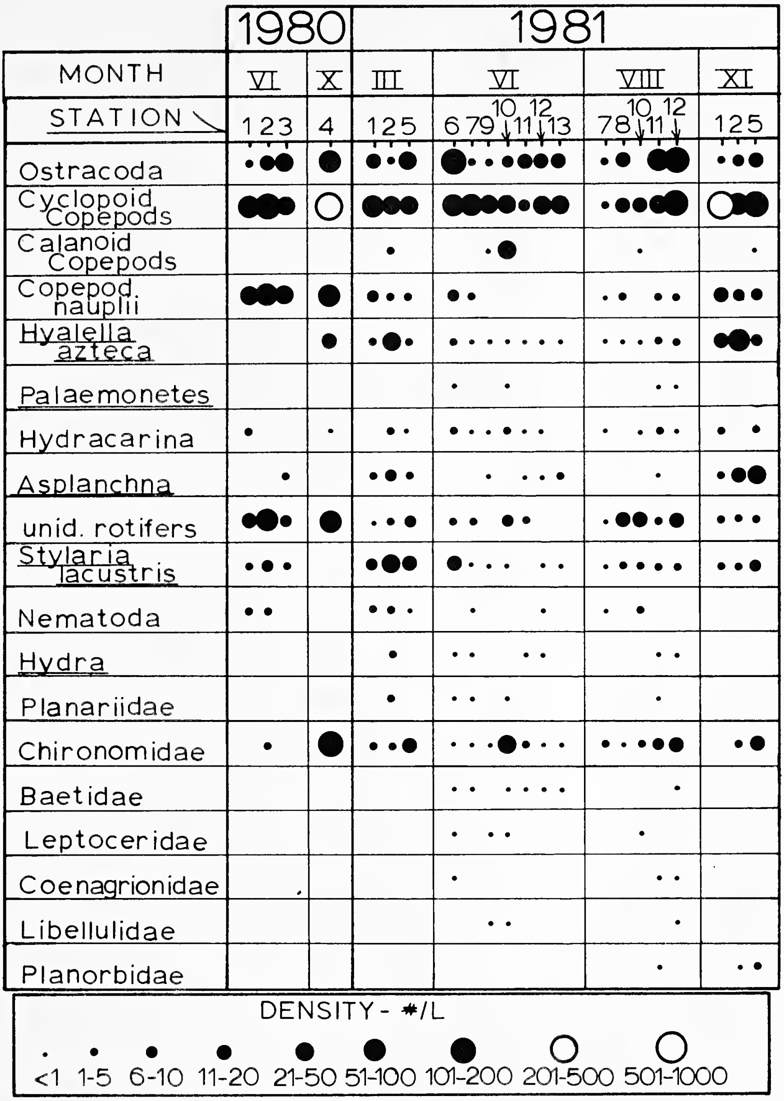

FIGURE 3. Average density (number/liter) by station and date for ostracods, cyclopoid and calanoid copepods, *Hyalella azteca* (Amphipoda) and non-microcrustacean organisms found in hydrilla beds in Lake Conroe.

of the reservoir) show how littoral microcrustacean densities varied in this heterogeneous habitat (Fig. 4). These data suggest that the horizontal distribution of microcrustaceans within the littoral zone is directly related to the location of dense accumulations of submerged plants. The unvegetated areas where waves strike the shore are apparently not a favorable habitat for littoral microcrustacea.

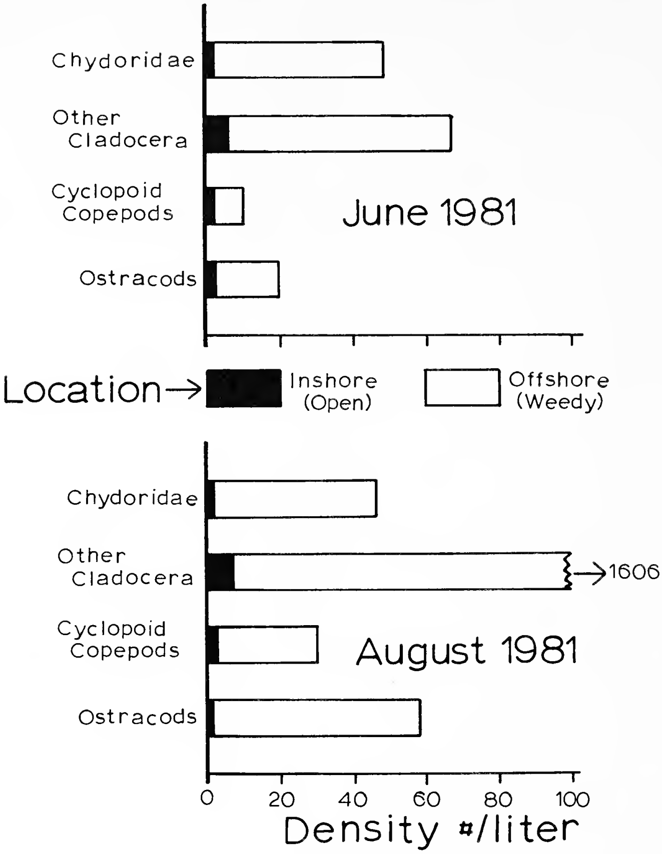

FIGURE 4. Average density (number/liter) of major microcrustacean groups found in inshore (open) and offshore (weed bed) areas of the littoral region on the west side of the island near the lower end of Lake Conroe (station 11).

Predation by dense schools of littoral planktivorous fish may also limit microcrustacean population densities in the inshore areas. Catch data during the summer of 1981 indicated that silversides were very abundant at this station and fed primarily on microcrustaceans (Morris 1982).

Hydrilla usually does not form a homogeneous mass throughout the water column, but rather tends to form mats with maximum density near the surface; growth below the 1-2 m depth is consequently reduced, due to self-shading. In June, 1980, we collected samples with the pump at 1-m intervals through dense hydrilla mats to a depth of 3 m. The intake hose was lowered slowly through each meter, filling buckets with water from each depth. Data for chydorid cladocerans (Fig. 5) indicate that their vertical distribution was correlated with the

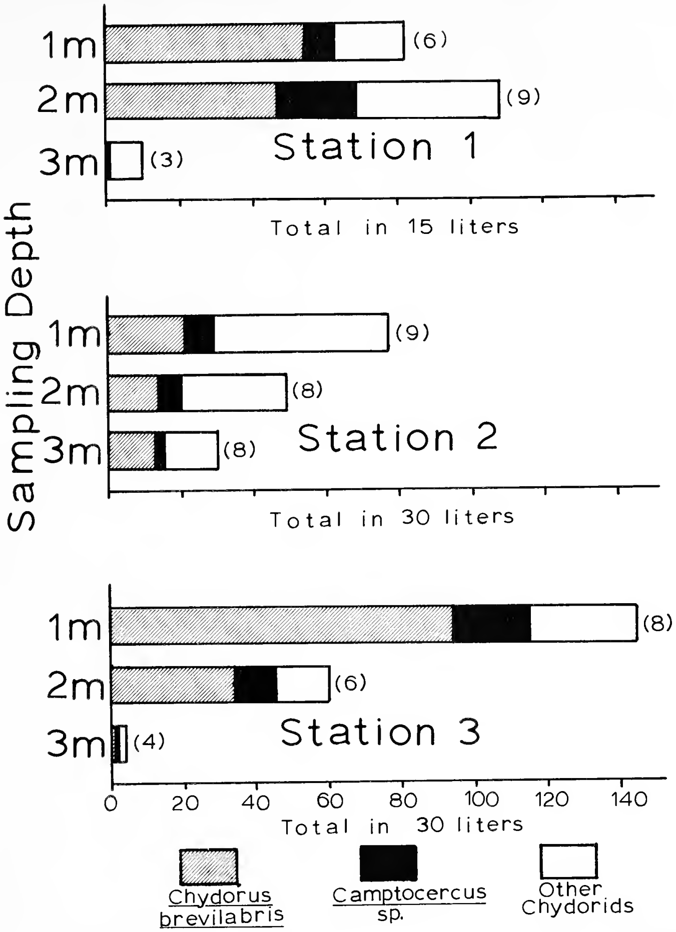

FIGURE 5. Total number of chydorid cladocerans and number of species of Chydoridae (numbers in parentheses) found in samples collected at one-meter intervals in the water column through dense hydrilla mats in Lake Conroe during June 1980.

depth-distribution of hydrilla. The chydorids were more abundant near the surface, where the densest growth of hydrilla occurred. The close relationship of chydorid distribution to the distribution of submerged macrophytes has been well documented (Smyly 1957; Pennak 1966; Fryer 1968; Quade 1969; Whiteside 1974; Whiteside et al. 1978). The densities of eponic algae (upon which the chydorids feed) were probably greatest in the upper part of the hydrilla mat, so the observed distribution of chydorids may have been correlated with food abundance. Fairchild (1981) found that the density of chydorids correlated with the density of epiphytic diatoms on the stems of submerged macrophytes.

We measured profiles of temperature and dissolved oxygen within hydrilla beds on a few occasions during the study and found evidence that shading effects and lack of mixing may influence physicochemical conditions in these areas. Oxygen concentrations near the bottom were often near 0 mg/liter, even in bright sunlight, and surface temperatures in hydrilla mats were always several degrees higher than surface temperatures in adjacent open water areas. We also observed considerable time-of-day variation in oxygen-temperature profiles. Dense and diverse populations of littoral microcrustacea persist in the hydrilla beds of Lake Conroe, despite extreme fluctuations in temperature and dissolved oxygen.

ACKNOWLEDGMENTS

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BENTONITES: POTENTIAL KEY BEDS IN THE MARLBROOK FORMATION (CAMPANIAN), ELLIS COUNTY, TEXAS

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ABSTRACT

Volcanic materials occur at many levels within the Upper Cretaceous Series of northeastern Texas. Three closely spaced, yellowish-orange-weathering bentonites, recently discovered in the upper part of the Taylor Group (Campanian), provide additional evidence of late Cretaceous volcanism in Texas. These bentonites occur 2.2 m, 2.8 m, and 3.8 m, respectively, above the Wolfe City-Marlbrook contact near Bristol, Ellis County, Texas. The use of these and other bentonites as chronostratigraphic markers could facilitate correlations within the lithologically complex Taylor Group.

INTRODUCTION

The term "bentonite" was proposed by Knight (1898) for a clay in the Benton Shale (Cretaceous) of eastern Wyoming that had soap-like characteristics. Subsequent workers (e.g. Hewitt 1917 and Wherry 1917) established that bentonites commonly formed by *in situ* alteration of volcanic ash. The most definitive characteristic of bentonites is their large content of the clay material smectite (Grim and Güven 1978).

Volcanic materials are present at many levels in the Upper Cretaceous Series of northeastern Texas. In this region, bentonites occur in the lower Eagle Ford Shale (Powell 1970), lower Austin Chalk (Williams 1957; Seewald 1960), middle Austin Chalk (Norton 1965; Allen 1975), Lower Taylor Marl (Ozan Formation; Beall 1964), basal Pecan Gap Chalk (Ellisor and Teagle 1934), and Upper Taylor Marl (Marlbrook Formation; Beall 1964).

Brown and Pierce (1962) tentatively correlated a bentonite layer in the lower Eagle Ford Shale from Dallas, southward to Waco. Also,

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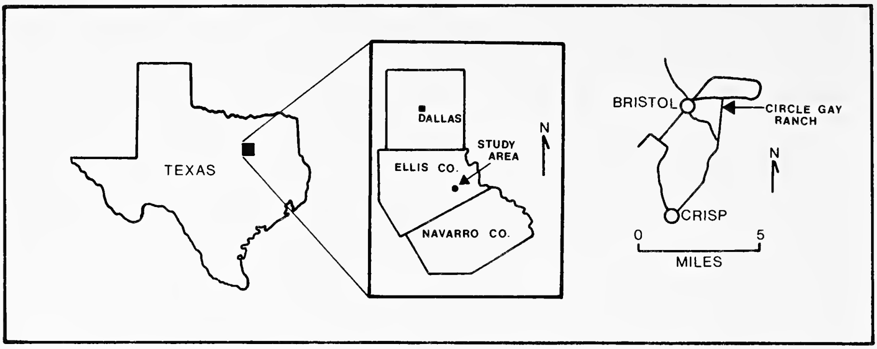

FIGURE 1. Map showing bentonite locality near Bristol in Ellis County, Texas.

some previous workers have used bentonite in the lower Austin Chalk for local correlations near Dallas (Herrin 1957; Williams 1957; Herrin and Robertson 1961; Norton 1965). However, the majority of these bentonites previously have received only cursory attention and have rarely been used for stratigraphic correlation outside of Dallas County.

The purpose of this paper is to describe the stratigraphic position and X-ray diffraction (XRD) characteristics of three newly-discovered bentonite layers in the upper part of the Taylor Group (Campanian), Ellis County, Texas; also we recommend the use of these bentonites as chronostratigraphic markers.

STRATIGRAPHY

The Taylor Group (Campanian) is disconformably underlain by the Austin Group and disconformably overlain by the Navarro Group. In northeastern Texas, the Taylor Group consists of four formations; from oldest to youngest, these are Ozan, Wolfe City, Pecan Gap, and Marlbrook. Many local facies complicate the regional stratigraphy and make correlations within the Taylor Group difficult.

The study site is along a road ditch 100 yards (91 m) south of the intersection of Slate Rock Road and Andrews Road, near the entrance to the Circle Gay Ranch, about 1.5 miles (2.5 km) east of Bristol, Ellis County, Texas (Fig. 1). There, the Taylor Group is represented by a fine-grained, bioturbated, glauconitic, and locally phosphatic quartz arenite that grades upward into a grayish yellow calcareous claystone. According to Richardson (1972), the sandy lithofacies exposed here is the upper member of the Wolfe City Formation and the superjacent claystone is the Marlbrook Formation. The bentonites occur 2.2 m, 2.8 m, and 3.8 m above the Wolfe City-Marlbrook contact (Fig. 2).

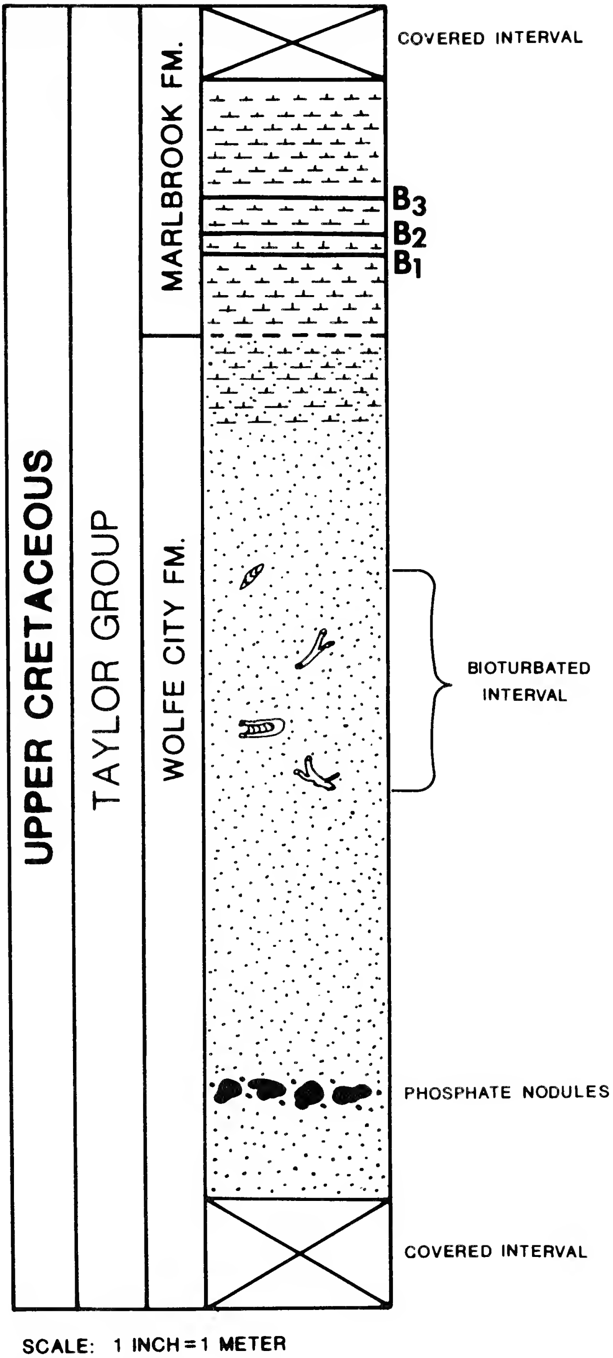

FIGURE 2. Lithologic column of Upper Cretaceous Taylor Group east of Bristol, Texas, showing stratigraphic position of three bentonites in the Marlbrook Formation.

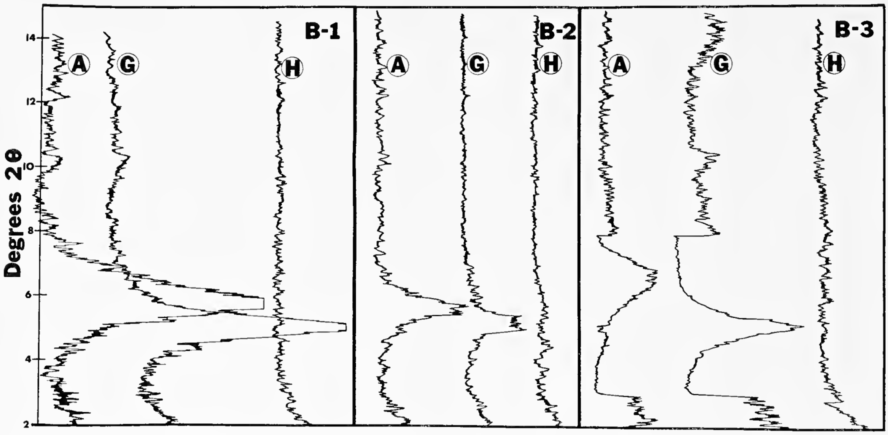

FIGURE 3. X-ray diffraction patterns of three Marlbrook bentonites, Ellis County, Texas. A—air dried sample; G—glycolated sample; H—heated sample (after glycolation). Horizontal axis represents relative intensity.

MARLBROOK BENTONITES

Samples of three distinctive clay layers, tentatively identified as "bentonites" in the field, were analyzed using standard XRD techniques (e.g. Carroll 1970). Accordingly, oriented mounts of the particles, which were less than 2 μm in diameter, were prepared on glass slides and scanned from 2° to 30° 2θ with copper K-alpha (CuKα) radiation. Three XRD patterns were derived from each sample: air-dried, glycolated (samples were allowed to stand overnight in a chamber saturated with ethylene glycol) and heat-treated (300 C for 1 h). The results are presented in Figure 3.

The lower dark yellowish orange "bentonite" (Sample B-1) occurred 2.2 m above the Wolfe City-Marlbrook contact and had a thickness of 1.0 cm. Its XRD pattern (air-dried sample) consisted of a sharp peak at 5.72° 2θ, indicating an (001) *d*-spacing of 15.49 Å. A poorly developed peak at 12.10° 2θ (7.30 Å) was also apparent. Treatment with ethylene glycol increased the original (001) *d*-spacing from 15.49 Å to 17.67 Å (5.00 2θ). Subsequent heating shifted the 17.67 Å peak to 10.16 Å (8.79 2θ). The 7.30 Å peak was not affected by glycolation or heating.

The medial dark yellowish orange "bentonite" (Sample B-2) was about 0.5 cm thick and occurred 2.8 m above the Wolfe City-Marlbrook contact. An XRD pattern of the air-dried sample was characterized by a relatively broad (001) peak with *d*-spacings ranging from 15.24 Å (5.80° 2θ) to 16.07 Å (5.50° 2θ). After glycolation the average (001) *d*-spacing increased to 16.99 Å (5.10° 2θ); this peak shifted to 8.90° 2θ (9.94 Å) after heat treatment.

The upper grayish orange to dark yellowish orange "bentonite" (Sample B-3) occurred 3.8 m above the Wolfe City-Marlbrook contact and was 0.8 cm thick. The air-dried sample had a broad peak with (001) *d*-spacings ranging from 12.81 Å (6.91° 2θ) to 13.57 Å (6.54° 2θ). Following glycolation a relatively sharp peak appeared at 5.20° 2θ (16.99 Å). After heating, the 16.99 Å shifted to 9.72 Å (9.10° 2θ).

DISCUSSION

The XRD data indicated that our clay samples were composed principally of smectite. Therefore, following the terminology of Grim and Güven (1978), we interpreted the three Marlbrook clay layers as true bentonites.

The well-defined (001) peaks exhibited by sample B-1 indicated that it is a well-crystallized, pure smectite. The 7.30 Å (001) peak revealed that accessory kaolinite was present in sample B-1. Samples B-2 and B-3 were characterized by somewhat broader (001) peaks, suggesting that they were smectites interlayered with minor amounts of another clay.

In addition to an increase in their original 13 to 16 Å (001) *d*-spacing caused by glycolation and the subsequent decrease in (001) *d*-spacing to about 9 to 10 Å upon heating, smectite XRD patterns may exhibit a characteristic integral series of high-order peaks (Carroll 1970, p. 26). The apparent absence of higher-order peaks in Marlbrook XRD patterns (Fig. 3) is most probably a result of incompletely oriented mounts, which is an inherent limitation of clay sample-preparation on glass slides. Cation substitution in smectites can also account for the failure of XRD recognition of integral peak series. Furthermore, relatively high levels of background radiation may obscure low-intensity, higher-order peaks of XRD patterns.

The commonest mode of origin for bentonites is *in situ* devitrification and attendant chemical alteration of volcanic ash or tuff in subaqueous environments. Nevertheless, some clays designated on the basis of composition as "bentonites" have formed by other processes (Wolf 1959; Grim and Güven 1978). Unequivocal establishment of a bentonite's origin from alteration of volcanic material requires that it exhibit relict textures of volcanic precursor (e.g., Carozzi 1972, p. 137) or contain unaltered volcanic grains such as euhedral biotite (Weaver 1963). Pseudohexagonal biotite is a common accessory constituent of the Marlbrook and many other Upper Cretaceous formations in northeast Texas; its presence strongly supports a volcanic origin for bentonites within the Upper Cretaceous Series of Texas. Indeed, Grim and Güven (1978, p. 127) have concluded that Cretaceous bentonites in Texas are classic examples of altered volcanic deposits. Numerous centers of Cretaceous volcanism have been identified in southeastern Texas (e.g., Ewing and Caran 1982).

The three clays discussed herein are not the only bentonite layers that have been identified within the Marlbrook Formation. Beall (1964, p. 22) reported the presence of two bentonites in the Upper Taylor Marl (Marlbrook Formation) near Dawson, Navarro County, Texas. Presently, we are unable to confirm that Marlbrook bentonites in Ellis County, Texas, correlate with those in Navarro County, Texas. Chemical analyses (e.g., Yen and Goodwin 1976; Huff 1983) and precise radiometric dating (e.g., Baadsgaard and Lerbekmo 1982) of individual bentonites could significantly aid regional correlations.

A comprehensive depositional model for the Taylor Group is presently lacking; generalized interpretations suggest regressive conditions (e.g., Beall 1964). More specific depositional reconstructions must await the establishment of detailed correlations. Because each bentonite represents a single ashfall, it records an essentially instantaneous geological event and consequently may be used as a synchronous datum. If such a datum can be accurately identified and traced throughout an area of interest, an excellent time-line is established. Thus, Marlbrook and other bentonites are potential sources of valuable chronostratigraphic data which could diminish correlation problems within the lithologically complex Upper Cretaceous Series of northeastern Texas. Downdip from the field area many Upper Cretaceous formations are prolific hydrocarbon producers. Detailed chronostratigraphic data are essential to the development of subsurface models for future petroleum exploration.

CONCLUSIONS

The common presence of tuffaceous and bentonite layers in the Taylor Group indicates that Campanian deposition in northeastern Texas was punctuated by numerous volcanic events. Three previously unreported bentonites in an outcrop of the Marlbrook Formation, near Bristol, Ellis County, Texas, provide additional evidence of late Cretaceous volcanism in this area. These bentonites occur 2.2 m, 2.8 m, and 3.8 m, respectively, above the Wolfe City-Marlbrook contact.

The chronostratigraphic significance of Campanian bentonites in northeastern Texas has been largely overlooked. These bentonites could be used as key beds to solve numerous surface and subsurface correlation problems within the lithologically complex Taylor Group. Such a refined time framework would greatly aid in deciphering the depositional history of individual rock units and thereby provide a chronostratigraphic framework for future academic studies and practical endeavors. Many additional studies are necessary to establish the areal extent of individual Campanian bentonites in northeastern Texas.

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PETROLOGY AND GEOCHEMISTRY OF THE PRECAMBRIAN MUNDY BRECCIA, FRANKLIN MOUNTAINS, TEXAS[1]

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ABSTRACT

The Precambrian Mundy Breccia is an unsorted and unstratified epiclastic volcanic breccia (rock consisting of angular fragments) composed entirely of angular to subrounded basalt clasts. Basalt clasts range in size from granule to boulder in an open to close-packed framework. The matrix consists of silt and sand-sized basalt fragments along with finer-grained quartz, muscovite, biotite, actinolite, chlorite, albite, microline, epidote and magnetite. The relative distribution and amount of matrix is highly variable, both vertically and laterally, throughout the entire unit. Deposition of the Mundy Breccia onto the Castner Marble resulted in brecciation and folding of the semi-consolidated carbonate strata.

Although the Mundy Breccia has been contact-metamorphosed to the albite-epidote hornfels facies, original textures and structures are very well preserved, as seen in outcrops and thin sections. Petrographically, the basalt clasts exhibit a relict intersertal texture, and more rarely an amygdaloidal texture.

Variations in major element chemistry of Mundy Breccia basalts indicate element mobility due to contact metamorphism from granites of the Precambrian Red Bluff Granite Complex. Alkali metasomatism is prominent in the Mundy Breccia near the intrusive granites in the north part of the map area where former minerals in the basalts have been converted to a mixture of biotite, K-feldspar and muscovite. Correlation plots of alteration-resistant element pairs TiO_2-P_2O_5 for the least texturally altered basalt clasts indicate a tholeiitic composition.

The Mundy Breccia uncomformably overlies two basalt dikes that were the feeder vents for either a lava flow or sill. The Mundy Breccia basalt clasts were subsequently eroded from the flow (or sill) to form the breccia. *Key words*: Mundy Breccia, Precambrian geology, Franklin Mountains, petrology, geochemistry.

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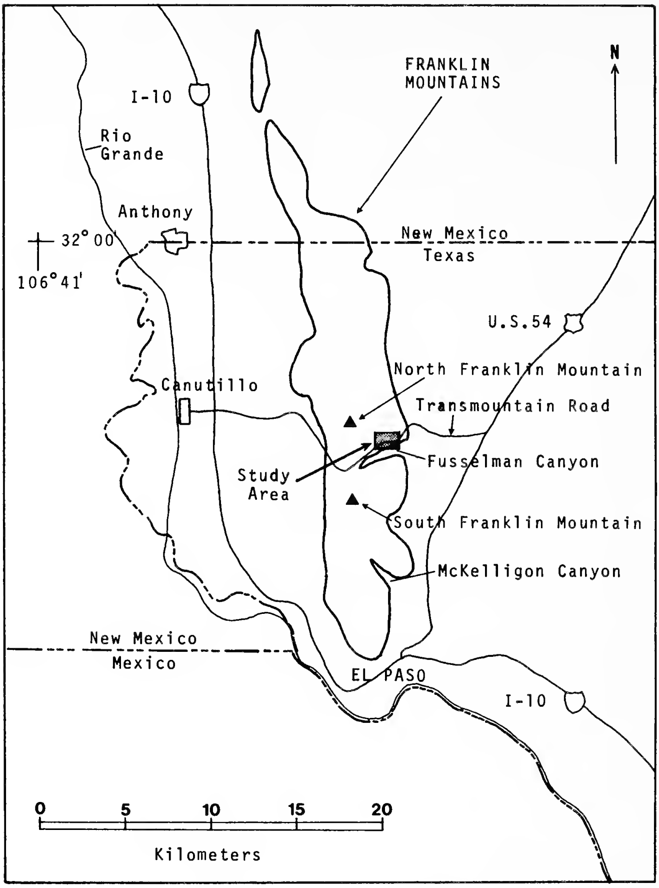

FIGURE 1. Location map of study area of the Mundy Breccia, Franklin Mountains, Texas.

INTRODUCTION

In this paper, "breccia" is defined as a coarse-grained rock composed of angular fragments cemented in a finer-grained groundmass. The Precambrian Mundy Breccia occurs on the east side of the Franklin Mountains (Fig. 1) at four isolated outcrops, two of which are mapped in Figure 2. The third outcrop is located 9 km north of the map area, and the fourth is located 2 km south of the map area. The best exposures are located adjacent to and north of the Transmountain Road in Fusselman Canyon (Fig. 2). Rock samples and all other data were collected from this outcrop because of availability of unweathered rock samples and exposure of a complete stratigraphic section. The other outcrops were examined but not sampled because they are intensely weathered and partly covered by alluvium.

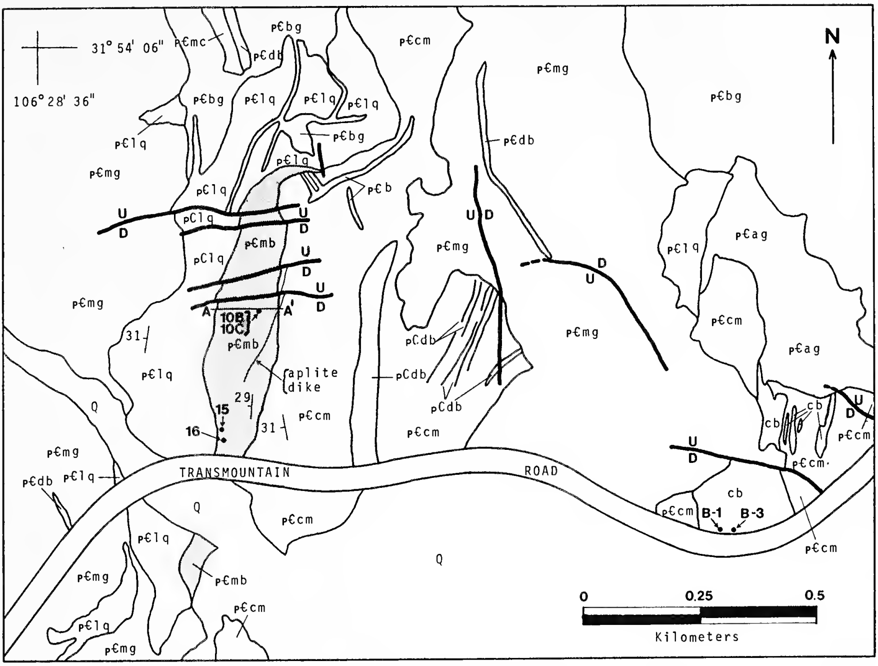

FIGURE 2. Simplified geologic map of Mundy Breccia and other Precambrian rocks, Franklin Mountains, Texas. Q = Quaternary alluvium; pCdb = Precambrian diabase dike; pCbg = Precambrian biotite granite of the Red Bluff Granite Complex; pCag = Precambrian porphyritic alkali granite of the Red Bluff Granite Complex; pCmg = Precambrian microgranite; pClq = Precambrian Lanoria quartzite; pCmb = Precambrian Mundy Breccia; pCcm = Precambrian Castner Marble; cb = columnar basalt member of the Castner Marble; A - A′ represents location of measured section. Aplite dike is 2 meters thick. Thick solid lines represent faults with D on downthrown side and U on upthrown side. Samples 10B, 10C, 15 and 16 are metabasalts from the Mundy Breccia. Samples B-1 and B-2 are columnar basalts from a concordant unit within the Castner Marble. Geologic map modified after Ray (1982).

The Mundy Breccia has never been studied in any detail. Previous workers described only briefly the petrology and petrography of the breccia, but they suggested possible origins: volcanic agglomerate (Harbour 1960, 1972), weathered basalt lava flow or sill (Harbour 1960, 1972), basalt flow breccia (McAnulty 1967), and surface or submarine flow breccia (Denison and Hetherington 1969). Contact metamorphism of all Precambrian sedimentary and volcanic rocks in the Franklin Mountains resulted in mineralogical alteration with virtually no change in original textures and structures. Heat derived from intrusive granites of the Red Bluff Granite Complex (Ray 1982) metamorphosed all Precambrian stratigraphic units with the highest grade metamorphic rocks seen at and near the intrusive margins, to the lowest grade metamorphic rocks seen well away from the granite contacts (Harbour 1960, 1972; McAnulty 1967; Dye 1970; Hoffer 1976; Denison and Hetherington 1969; Thomann 1980, 1981). There are very few Precambrian mafic units in West Texas that clearly exhibit original textures and structures as seen in outcrops and thin sections of the Mundy Breccia. Thus a study of the Mundy Breccia can provide important information not only for metamorphic conditions but also for nature and composition of framework clasts, kind of flow and depositional environment. This paper describes the stratigraphy, structure, petrology and geochemistry of the Mundy Breccia.

GEOLOGIC SETTING

The Franklin Mountains are a north-trending, fault-block range near the southeastern edge of the Basin and Range Province of the southwestern United States. Most of the range consists of Precambrian and Paleozoic rocks that strike north and dip generally 20° to 30° west.

The Mundy Breccia is one of four Precambrian stratigraphic units exposed in the Franklin Mountains which include, from oldest to youngest, the Castner Marble (Hoffer 1976), Mundy Breccia (Harbour 1960, 1972), Lanoria Quartzite (Richardson 1909), and Thunderbird Group (Thomann 1980, 1981). The Castner Marble is interpreted as a near-shore, shallow water (subtidal to intertidal) marine carbonate shelf deposit (Hoffer 1976). The Lanoria Quartzite represents a regressive sequence onto the Castner Marble and Mundy Breccia, but the depositional environment is unknown for the quartzite. The Thunderbird Group consists of three formations: a basal conglomerate, trachyte lavas interbedded with tuffaceous sandstone, and a thick upper unit composed of rhyolite ash-flow tuffs (Thomann 1980, 1981). The Precambrian Red Bluff Granite Complex (Ray 1982) partly to completely engulfs all older Precambrian formations, including the Mundy Breccia (Harbour 1960, 1972). Only a small portion of the granite complex is shown in the eastern and northern portion of the map in Figure 2. Alteration and recrystallization of all Precambrian stratigraphic units, including the Mundy Breccia, were due primarily to heat derived from the emplacement of epizonal (high-crystal level) granite plutons. This thermal metamorphism resulted in the development of high-temperature-equilibrium mineral assemblages of the hornblende hornfels facies at and near the intrusive contacts (Harbour 1960, 1972; McAnulty 1968; Hoffer 1976; Ray 1982) to lower-temperature-equilibrium mineral assemblages of the albite-epidote hornfels facies at much greater distances from the intrusive contacts (Harbour 1960; McAnulty 1968; Dye 1970; Thomann 1980, 1981). Distinctive skarn zones (calcium-iron-magnesium-bearing silicates) also developed along contacts between contrasting sedimentary layers (shale-dolomite) and sedimentary-volcanic layers (dolomite-basalt) due to thermal metamorphism (McAnulty 1967; Hoffer 1976). Metasomatism by hydrothermal solution occurred at and near intrusive granite contacts and along aplite and pegmatite dike contacts. This metasomatism also produced distinctive skarn zones especially along Castner Marble-granite contacts (Hoffer 1976).

Radiometric Rb/Sr ages of the granites are 950 million years (Denison and Hetherington 1969). The youngest Precambrian rocks are basalt and diabase dikes that cross-cut all pre-existing rocks, but the exact ages of these dikes are unknown (Harbour 1972).

STRATIGRAPHY AND STRUCTURE

The Mundy Breccia varies in thickness from zero to 64.0 m (Fig. 3), and trends approximately north-south with an average dip of 27° west. The breccia lies uncomformably on the Castner Marble along a contact marked by a 3- to 20-cm skarn zone. This zone, as mentioned previously, formed as a result of thermal metamorphism from intrusive granites. The chemical reactions that occurred between the basalt and marble resulted in the formation of an equilibrium mineral assemblage of primarily calc-silicates (Hoffer 1976). The source of fluids that resulted in formation of several hydrous calc-silicates in the zone came from connate (trapped fluids) within the Castner Marble (Hoffer 1976).

The breccia filled in channels and also produced depressions by differential loading as it flowed onto the semi-consolidated carbonate sediments. Evidence of disrupted bedding in the upper portion of the Castner Marble includes load casts, intraformational breccias, imbricate structures and folds. Along strike, the upper contact of the Mundy Breccia with the Lanoria Quartzite is sharp and uniform. The upper contact is a surface of erosion, and thus the original thickness of the breccia is not known.

The joint pattern of the Mundy Breccia generally coincides with the overall northwest-trending regional fracture pattern for Precambrian rocks in the Franklin Mountains (Ray 1982). Some of the joints are filled with epidote, and some with fine-grained actinolite. The breccia is cut by numerous east-trending faults. Only the major ones are shown in Figure 2.

Framework of the Mundy Breccia consists almost entirely of angular to subrounded basalt clasts ranging in size from granule to boulder. The fabric varies considerably, both vertically and laterally, from a clast-supported framework with little matrix to a very open framework with clasts supported by matrix. There is no evidence of superposed mudflows. The divisions shown in Figure 3 represent major textural

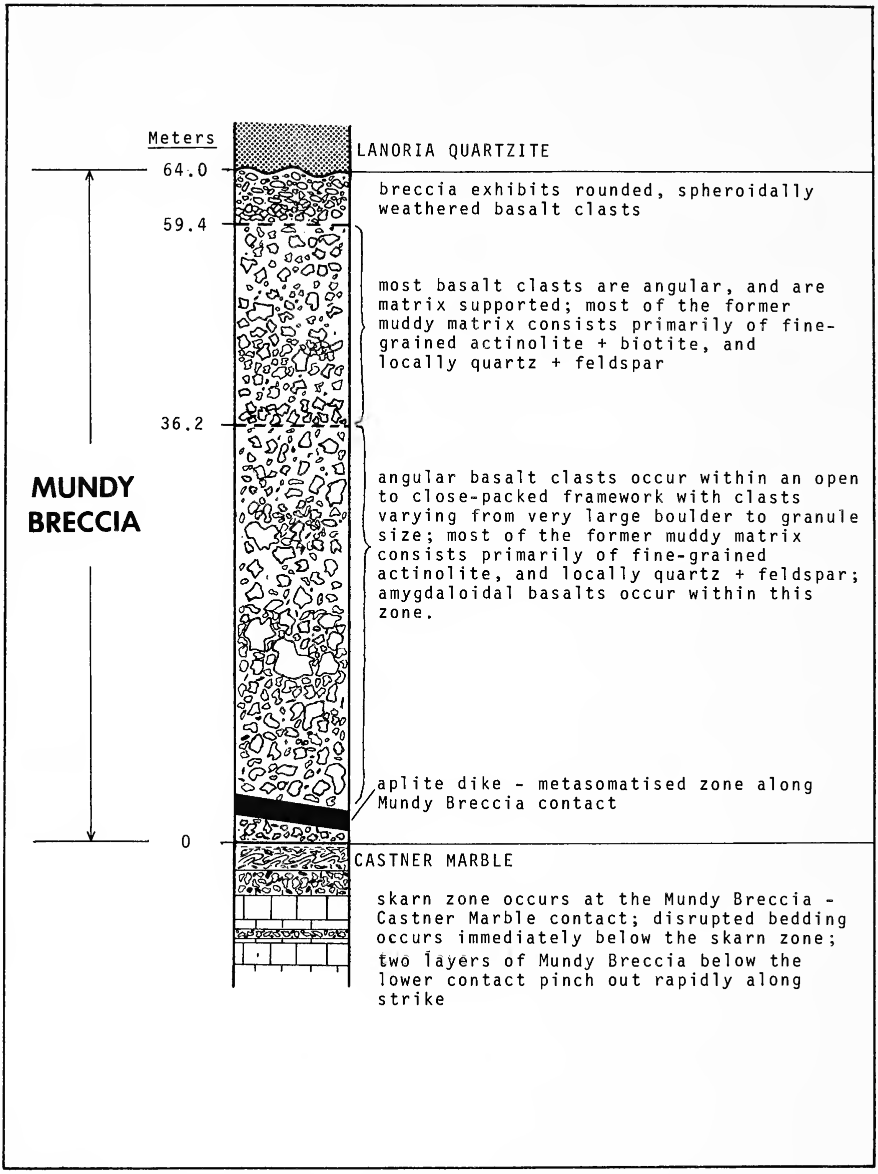

FIGURE 3. Stratigraphic column of the Mundy Breccia. See Figure 2 for location of measured section. The basalts vary from black (N-1) to dark gray (N-3), whereas most of the matrix varies from black (N-1) to medium dark gray (N-4). Matrix that contains a high proportion of quartz, muscovite, and feldspar varies from white (N-9) to greenish-gray (10GY5/2) to dark greenish-gray (5G4/1).

features as seen along the measured type section and do not represent different strata.

The breccia is unsorted and unstratified. The upper 4.5 m of the Mundy Breccia was weathered prior to deposition of the Lanoria Quartzite as shown by spheroidally weathered clasts in various stages of decomposition. The intensity of weathering diminishes gradually beneath the quartzite-breccia contact; the lower basalt fragments retain their original angular to subrounded shapes. The contact at the 59.4 m mark on the stratigraphic column (Fig. 3) therefore represents only the approximate boundary separating weathered from unweathered Mundy Breccia. The two layers of Mundy Breccia beneath the Castner Marble (Fig. 3) were emplaced as a result of disruption and uplifting of blocks of semi-consolidated limestone (now Castner Marble) when the breccia flowed onto the limestone. These layers pinch out very rapidly along strike, and this structural feature is seen only at the type section.

Hoffer (1976) recognized two basalt dikes that lie uncomformably beneath the Mundy Breccia (pers. comm. from R. L. Hoffer, Univ. of Texas, El Paso, TX 79968). Thus, the basalt from the dikes represents the source rock for clasts in the Mundy Breccia.

Denison and Hetherington (1969) interpreted the Mundy Breccia as a mudflow breccia but they, as well as the authors, could not determine if the breccia was a surface or submarine flow. The Mundy Breccia has characteristics of a mudflow breccia that includes granule to boulder-sized fragments derived from weathering and erosion of a basalt. The Mundy Breccia is an epiclastic volcanic breccia according to Fisher's (1961) classification.

PETROGRAPHY

Basalt clasts in the Mundy Breccia are predominantly aphanitic; a few are amygdaloidal (mineral-filled vesicles). Thin sections reveal metamorphic mineralogy in the basalts with well preserved relict intersertal (glassy) textures seen in only a few samples (Fig. 4). The very fine-grained, almost irresolvable nature of much of the groundmass in the clasts and matrix prevents an accurate point-count determination of percent metamorphic minerals. However, the following presentation of minerals in the basalt clasts and the matrix is generally in order of decreasing abundance.

Cobble and boulder-size clasts exhibit the best preserved relict intersertal (and/or amygdaloidal) textures. In these basalts, plagioclase crystals retain their original lath shapes, although they altered to albite and/or sericite. Microphenocrysts now composed of fine-grained actinolite, and less commonly sericite, are pseudomorphic after olivine

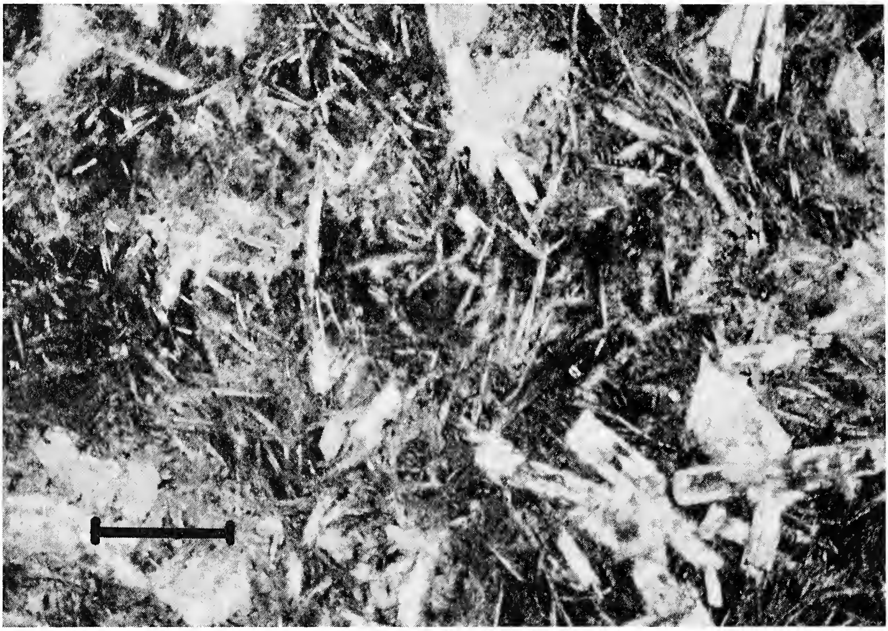

FIGURE 4. Photomicrograph of metabasalt from the Mundy Breccia exhibiting well preserved intersertal texture. Lath-shape albite crystals occur in a very fine-grained groundmass of feldspar, sericite, magnetite, actinolite, biotite, and trace amounts of epidote and chlorite. Bar scale = 0.5 mm.

and pyroxene. Former glass (tachylite?) altered to a very fine-grained aggregate of feldspar (albite?), sericite, magnetite, actinolite, biotite and trace amounts of epidote and chlorite. In some samples, fine-grained magnetite is so abundant that extensive portions of a thin section are opaque to transmitted light. Those basalts with the rarer amygdaloidal texture have vesicles filled with very fine-grained muscovite, biotite, and somewhat coarser-grained quartz. The well preserved textures and the relatively low concentrations of olivine and pyroxene (as shown by pseudomorphs) suggest these rocks are petrographically tholeiitic olivine basalts. The rest of the basalts show a wide range of textural variations from those with some traces of former relict igneous textures (i.e. lath shapes of former plagioclase) to those so thoroughly recrystallized that no evidence of former textures remains. The relative amounts of metamorphic minerals vary considerably from one sample to the next throughout the breccia. Generally, in the intensely recrystallized and usually coarser-grained metabasalts, the predominant replacement minerals are actinolite, biotite, epidote and/or clinozoisite.

Matrix minerals in the Mundy Breccia include actinolite, biotite, epidote, magnetite, albite, chlorite, clinozoisite, muscovite, quartz, microcline, and some zoned tourmaline. Small patches, streaks, lenses, or fracture fillings of actinolite, biotite, epidote, quartz and magnetite are coarse enough to identify in some hand specimens by the unaided eye or hand lens. Locally, some portions of the matrix are composed predominantly of quartz with muscovite, biotite, albite, actinolite, microcline and magnetite in subordinate amounts. However, there is no uniformity in the distribution of mineral assemblages found throughout the matrix in the Mundy Breccia.

The mineralogy and texture of the spheroidally weathered basalt in the upper 4.5 m of the breccia are similar to the underlying metabasalts. Although original minerals are no longer present, relict textures of the weathered rinds are well preserved with a typical clast showing various stages of decomposition from the core of the unweathered clast to the outermost weathered rind. The rinds vary in thickness from a few millimeters up to a centimeter and consist of fine-grained actinolite, biotite, albite and magnetite.

Near the biotite granite and dikes in the northern part of the area (Fig. 2), the Mundy Breccia has been texturally and mineralogically altered by alkali metasomatism. Alteration of basalts involved conversion of plagioclase laths to microcline, and replacement of groundmass by muscovite, biotite, and microcline. No evidence of intersertal or amygdaloidal texturess is seen in these rocks.

A 20-cm thick baked zone along an aplite-Mundy Breccia contact in the southern portion of the area (Figs. 2 and 3) consists of framework and matrix replaced by biotite, garnet, some albite and quartz, and trace amounts of tourmaline. The skarn zone at the contact of the Mundy Breccia with the Çastner Marble consists mostly of massive garnet (grossularite-andradite?) and scapolite with minor amounts of calcite, biotite, magnetite, diopside (?) and actinolite. Isolated, euhedral garnets attain sizes up to 5 cm.

Equilibrium mineral assemblages (Fig. 5) indicate the Mundy Breccia has been metamorphosed to at least the albite-epidote hornfels facies. This mineral assemblage corresponds to low-grade metamorphism for mafic rocks (Winkler 1979, p. 173). Total pressure at the time of metamorphism was at least 0.3 kb based on Harbour's (1972) estimates of the stratigraphic thickness of Precambrian rocks overlying the Mundy Breccia.

GEOCHEMISTRY

Analytical Techniques

Basalts that exhibit well preserved original texture as seen in thin section were chosen for chemical analyses. A large number of basalt samples was collected in the field, but few exhibited original textures.

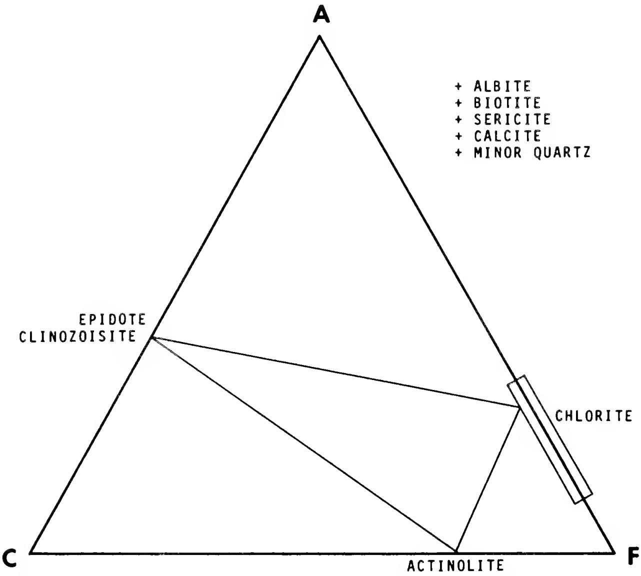

FIGURE 5. A-C-F variations diagram of coexisting metamorphic mineral assemblage in metabasalts of the Mundy Breccia.

The four samples listed in Table 1 are the least texturally altered basalts collected from the field area.

Major element analyses were performed by x-ray fluorescence. Analyses in Table 1 do not total 100% because H_2O, CO_2, and trace elements were not determined. C.I.P.W. normative data presented in Figures 6 and 7 may be obtained from the senior author upon request.

TABLE 1. Major oxide data for Mundy Breccia basalts and columnar basalts. (See Figure 2 for sample locations). FeO determined by wet chemical methods.

	Mundy Basalt Samples				Columnar Basalt Samples	
Oxide	16	10B	10C	15	B-1	B-3
SiO_2	46.82	46.11	45.43	46.65	45.81	46.19
TiO_2	1.34	1.67	1.56	1.12	2.86	3.94
Al_2O_3	15.52	12.79	13.20	12.09	14.16	14.32
Fe_2O_3	2.84	3.17	3.06	2.62	4.36	5.44
FeO*	8.65	10.61	9.82	10.78	10.45	11.59
MnO	0.19	0.10	0.16	0.21	0.22	0.22
MgO	10.30	16.39	18.84	12.09	6.40	5.70
CaO	8.81	4.91	3.52	10.72	7.79	8.0
Na_2O	2.38	3.21	1.64	1.74	3.03	3.01
K_2O	0.25	0.58	1.33	0.20	1.84	0.17
P_2O_5	0.13	0.06	0.07	0.19	0.52	0.48
Total	97.23	99.60	98.63	98.41	97.44	99.06

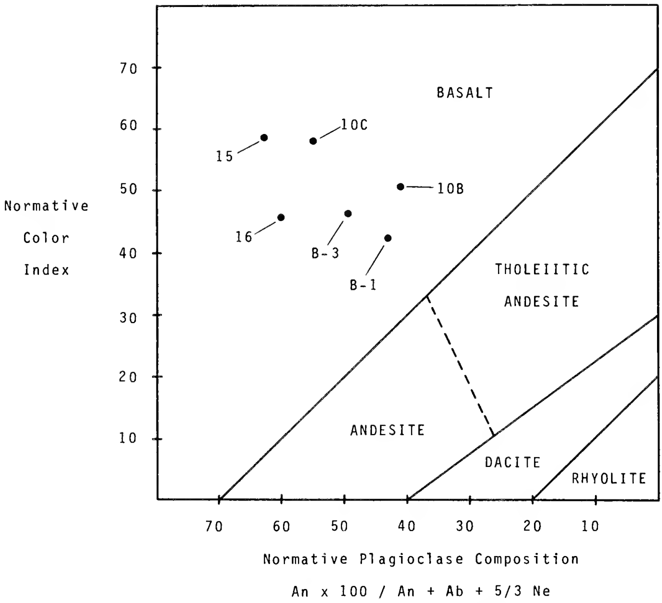

FIGURE 6. Normative color index versus normative plagioclase composition diagram for mafic rocks from Franklin Mountains, Texas. See Figure 2 for sample locations. B-1 and B-2 are columnar basalts from a concordant unit within the Castner Marble. Normative color index = 01 + Opx + Cpx + Mt + Il + Hm + Ap after Irvine and Baragar (1971).

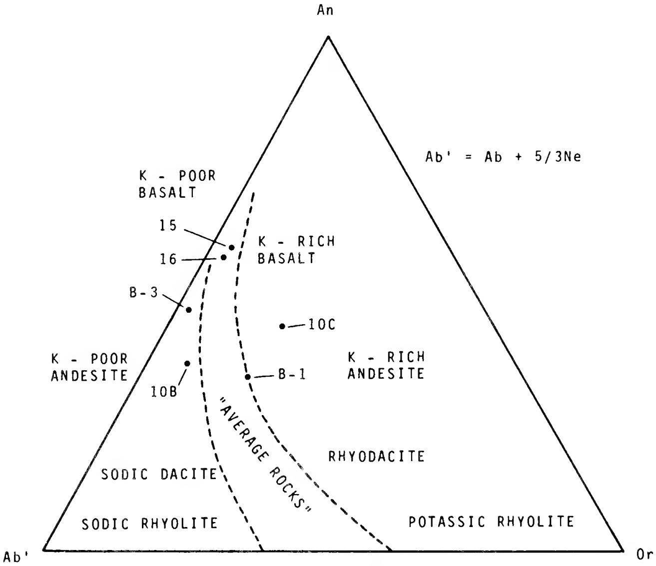

FIGURE 7. An-Ab′-Or variation diagram. See Figure 2 for sample locations. After Irvine and Baragar (1971).

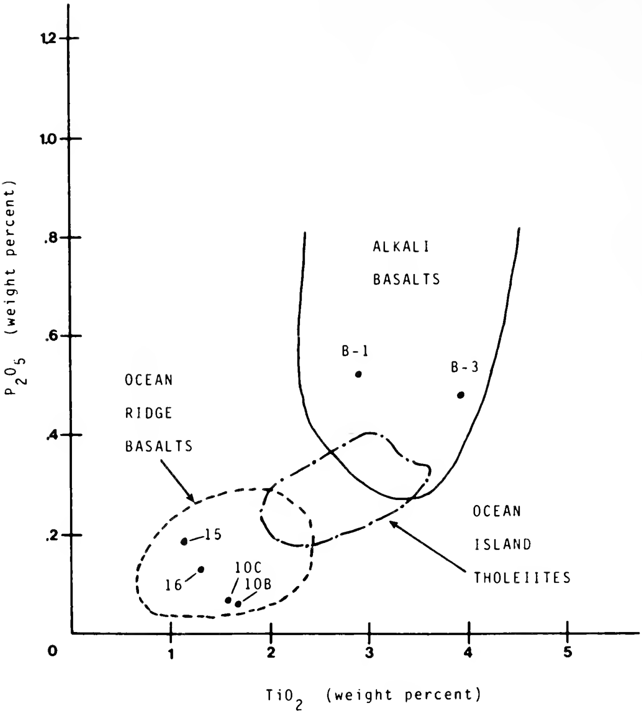

FIGURE 8. Correlation plot of alteration-resistant element pairs P_2O_5 (weight %) versus TiO_2 (weight %) for Mundy Breccia basalts (10B, 10C, 15, 16) and columnar basalts (B-1, B-3). See Figure 2 for sample locations. Figure from Ridley et al. (1974).

In Figures 6 and 7, chemical classifications of individual basalt clasts in the Mundy Breccia are based on methods of Irvine and Baragar (1971). Plots on the variations diagrams of Figures 6 and 7 are values based on recalculation on analyses to 100% for comparison. Correlation plots of alteration-resistant element pairs TiO_2 vs P_2O_5 in Figure 8 represent actual weight-percent values.

Chemistry

Inspection of the four analyses of basalt clasts in the Mundy Breccia (Table 1) shows large variations in the concentrations of Al_2O_3, MgO, CaO, Na_2O, and K_2O. These variations are larger than would be expected from a single-source basalt, and are consistent with significant element mobility and redistribution during deuteric to metamorphic alteration. Major element mobility is shown by (1) wide range in the alkalis and calcium; (2) presence of normative corundum in one sample [Gelinas et al. (1982) have shown that a peraluminous character of metavolcanic rocks indicates intense calcium leaching]; (3)

low and erratic normative diopside, which also indicates calcium mobility; and, (4) wide scatter of plots in Figures 6 and 7.

All of the samples shown in Figure 6 plot on the basalt field even though major element mobility altered the original basalt chemistry. This suggests that perhaps the least texturally altered baslats behaved almost as a closed system, at least on the scale of hand-specimen size basalts. The variation of K-poor to K-rich basalt types in Figure 7 further demonstrates alkali and calcium redistribution. Chemical classifications of the basalts therefore cannot be based on Si, Na, K, Ca, Al since the basalts have undergone alteration that changed the primary concentration of these elements.

Plots of P_2O_5 versus TiO_2 content provide reliable criteria for basalt classification and comparison since these elements are largely unaffected by deuteric alteration and low-grade metamorphism (Ridley et al. 1974). All samples from Table 1 plot in the ocean-ridge basalt (tholeiite) field of Figure 8. This is not to suggest that the Mundy Breccia basalts are mid-oceanic ridge basalts, but they apparently are chemically tholeiitic nonetheless.

PETROGRAPHIC AND CHEMICAL COMPARISONS WITH NEARBY COLUMNAR BASALT

A contact-metamorphosed columnar basalt is exposed along the easternmost cut of the Transmountain Road in the Franklin Mountains (Fig. 2). This basalt superficially resembles the basalt in the Mundy Breccia, and Harbour (1960, 1972) referred to it and other units in the Castner Marble as diabase. He suggested that these units are the intrusive equivalents of the Mundy Breccia.

Both the Castner Marble and columnar basalt comprise a roof pendant that is completely engulfed by the several granite phases of the Red Bluff Granite Complex. Numerous granite dikes additionally cross-cut the marble and basalt in the roof pendant. The columnar basalt is concordant to layering within the Castner Marble and exhibits well preserved 4- to 5-sided columns with 0.5-cm to 2-cm wide joint spaces filled with biotite, a little feldspar, and rare andalusite and sillimanite. The columns are oriented perpendicular to stratification in the overlying Castner Marble, and the upper basalt contact with the Castner is sharp.

In thin section, the metabasalt exhibits a well preserved, intergranular subophitic texture unlike the Mundy Breccia basalt. Plagioclase laths altered to oligoclase and/or sericite (?), and pyroxene altered to hornblende, biotite, and magnetite.

Chemical comparisons of the columnar basalts (Table 1) with the Mundy Breccia basalts show differences in TiO_2, P_2O_5, total iron, and especially MgO. Chemical classification of these columnar basalts cannot be made on the basis of major elements due to element mobility (for example K_2O) during contact metamorphism. However, plots of alteration-resistant elements P_2O_5-TiO_2 (Fig. 8) show that the columnar basalts are alkalic compared to the tholeiitic basalts of the Mundy Breccia. Thus, due to chemical dissimilarities, the columnar basalt is not related to the Mundy Breccia basalts.

CONCLUSION

The source of the tholeiitic olivine basalt that occurs as clasts in the Mundy Breccia is from two basalt dikes that lie uncomformably below the breccia. However, it is not possible to tell if the breccia formed from erosion of a lava flow or shallowly emplaced sill. The intersertal and amygdaloidal textures are common in lava flows as well as high-level synvolcanic sills and dikes (Best 1982). The lack of sorting and stratification in the Mundy Breccia indicates that the breccia moved as a thick, viscous mudflow capable of carrying clay to boulder-size clasts. There is no evidence to indicate if the Mundy Breccia is a single- or multiple-flow unit, or whether the breccia travelled as a surface or subsurface flow. Deposition of the breccia onto carbonate sediments resulted in disruption of layering, folding, and development of intraformational breccias. The breccia was subsequently exposed to weathering for some length of time as shown by spheroidally weathered clasts at various stages of decomposition in the upper portion of the volcanic mudflow breccia. In addition to weathered, sand-size and smaller basalt particles, the matrix was probably a mud composed of minerals such as clay and Fe-oxides derived from weathering of the basalt. Locally, quartz, perhaps a result of later silicification, was abundant enough to cement the framework and matrix. Deposition of sediments of the Lanoria Quartzite, and sediments and volcanic rocks of the Thunderbird Group on top of the Mundy Breccia was followed by a period of plutonic igneous activity with intrusion of several phases of the Red Bluff Granite Complex. Emplacement of the high-level granite batholith resulted in stopping of roof rocks, and contact metamorphism of all pre-existing rocks. The breccia was metamorphosed to at least the albite-epidote hornfels facies with skarn zones developed along the Mundy Breccia-Castner Marble, and granite-Castner Marble contacts.

ACKNOWLEDGEMENTS

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RANGE EXTENSION FOR THE WHIPTAIL LIZARD *CNEMIDOPHORUS LAREDOENSIS* (TEIIDAE)

by HUGH K. McCRYSTAL[1], ROBERT H. DEAN[1],
and JAMES R. DIXON

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ABSTRACT

Cnemidophorus laredoensis is recorded from Starr and Zapata counties, Texas, for the first time.

The unisexual whiptail lizard *Cnemidophorus laredoensis* was described in 1973, from specimens collected at Chacon Creek (type locality), Webb Co., Texas, and at an additional site 1.6 km S of Chacon Creek (McKinney et al. 1973). Subsequent papers by Bickham et al. (1976) on karyology and by Wright et al. (1983) on mitochondrial DNA of *C. laredoensis* did not identify additional localities. The latter study, however, predicted a more widespread distribution of the new species based on its habitat associations and the distribution of the parental forms.

On 14 May 1982 we collected three *C. laredoensis* (TCWC 61097-099) in Zapata Co., Texas, at a roadside park adjacent to the Rio Grande along Texas Highway 83, 5.3 km N of the junction with FM 3169. This is 53 km S of the type locality of *C. laredoensis.* In August 1983 we returned to the same roadside park and collected six additional specimens (TCWC 61630-635). Differences in color pattern enabled easy distinction of *C. laredoensis* from *C. gularis,* which also occurred in the park. Karyotypic and electrophoretic patterns of specimens TCWC 61630-635 were typical of *C. laredoensis* from the type locality.

In July 1983, H.K.M. informed J.M. Walker (University of Arkansas, Fayetteville) of our discovery of *C. laredoensis* in Zapata Co. In August 1984, at a presentation during a national meeting, Walker confirmed that he too had collected *C. laredoensis* there.

On 26 August 1983 we collected one *C. laredoensis* (TCWC 61629) 11 km N Roma-Los Saenz, Starr Co., Texas, some 135 km S of the type locality of *C. laredoensis.* Additionally, in April 1984, our associates K. King and D. Kizirian (pers. comm.) observed *C.*

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laredoensis 8.25 km W of Roma-Los Saenz on the Santa Margarita Ranch.

We thank Ken King and David Kirizian for sharing their observations with us. Research reported in this note was supported (in part) by the Texas Agricultural Experiment Station, Project 1678.

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GRAFT INCOMPATIBILITY IS NOT REDUCED BY TREATMENT WITH PLANT GROWTH REGULATORS

by RANDY MOORE

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ABSTRACT

To determine if exogenous plant growth regulators could be used to overcome graft incompatibility, I applied gibberellic acid, indoleacetic acid (IAA), kinetin, and IAA plus kinetin to scions of incompatible heterografts between (1) *Sedum telephoides* and *Solanum pennellii*, and (2) *Lycopersicon esculentum* and *Brassica oleraceae*. Tensile strengths of treated grafts were not significantly different from those of untreated controls. Thus, the lack of vascular redifferentiation which characterizes graft incompatibility in these systems seems not to be due to the absence of morphogens believed responsible for vascular redifferentiation. *Key words*: grafting, indoleacetic acid, kinetin, gibberellic acid, *Brassica oleraceae, Lycopersicon esculentum, Sedum telephoides, Solanum pennellii.*

INTRODUCTION

Several studies have suggested that plant growth regulators are involved in graft formation between compatible tissues (Kruyt 1847; Muller-Stoll 1938; Shimomura and Fuzihara 1977, 1978; Parkinson and Yeoman 1982). Auxins may promote graft formation by (1) stimulating the production of callus cells at the graft interface (Kruyt 1847; Muller-Stoll 1938) and (2) promoting vascular redifferentiation across the graft interface (Shimomura and Fuzihara 1977, 1978; Parkinson and Yeoman 1982). Application of indoleacetic acid (IAA) is indispensable for the formation of a successful graft between cultured internodes (Parkinson and Yeoman 1982).

The absence of vascular redifferentiation is typical of incompatible grafts (Yeoman et al. 1978; Moore 1981, 1983a; Moore and Walker 1981a). This lack of vascular redifferentiation in incompatible grafts may be due to the absence of the normal morphogens responsible for procambial development (Moore and Walker 1981a). Since (1) auxin is necessary for vascular redifferentiation (Sachs 1968; Jacobs 1979), (2) the application of auxins promotes graft formation by stimulating vascular redifferentiation (Shimomura and Fuzihara 1977, 1978; Parkinson and Yeoman 1982), and (3) chemical treatments have been used to overcome graft incompatibility (Gur 1972), I decided to

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investigate whether the application of plant growth regulators could be used to overcome graft incompatibility. Two incompatible grafts were examined: heterografts between (1) *Sedum telephoides* and *Solanum pennellii* (eggplant), and (2) *Lycopersicon esculentum* (tomato) and *Brassica oleraceae* (broccoli). Details regarding graft development in these systems have been presented elsewhere (Moore and Walker 1981a, b; Moore 1982, 1983b; Moore and Walker 1983; Moore 1984a, b).

MATERIALS AND METHODS

Incompatible heterografts between (1) *Sedum telephoides* and *Solanum pennellii*, and (2) *Lycopersicon esculentum* and *Brassica oleraceae* were used in this study. Plant growth conditions and grafting procedures were similar to those described previously (Moore and Walker 1981a). Immediately after grafting, the scion apex was severed approximately 1 cm above the grat interface and various plant growth regulators (in lanolin or distilled water) were applied (see Table 1 for treatments). Dosing was repeated every 2 to 3 days. Controls included untreated grafts (i.e., grafts with intact scion apices) and those to which only lanolin or distilled water was applied. Three weeks after grafting, tensile strengths of the graft unions were determined according to methods described by Moore (1983b). Each treatment and control was replicated at least 4 times. The significance of differences in mean tensile strengths was assessed using Student's *t*-test (Snedecor and Cochran 1976) at $\alpha=0.01$.

RESULTS

Tensile strengths of grafts treated with growth regulators were not significantly different ($P>0.01$) from those of controls (Table 1).

DISCUSSION

This is the first study to investigate the effects of plant growth regulators on graft incompatibility. Two systems with differing incompatibility responses were examined: (1) the *Sedum/Solanum* heterograft, characterized by extensive cellular necrosis (Moore and Walker 1981a), and (2) the *Lycopersicon/Brassica* heterograft, in which cellular necrosis is much less pronounced (Moore 1984a). Since cellular interdigitation and vascular redifferentiation are absent in both of these grafts (Moore and Walker 1981a; Moore 1984a), their tensile strengths never exceed approximately 20 g breaking weight (BW)/mm^2 graft area. In contrast, the presence of cellular interdigitation and vascular redifferentiation in compatible grafts results in tensile

TABLE 1. The effect of plant growth regulators on the tensile strength of incompatible heterografts between (1) *Sedum telephoides* and *Solanum pennellii*, and (2) *Lycopersicon esculentum* and *Brassica oleracease*. Tensile strengths are reported as the force in g/mm^2 graft area required to separate the graft partners, stock/scion.

	Tensile Strength (Mean ± Standard Error) of Graft			
Treatment	*Sedum/ Solanum*	*Solanum/ Sedum*	*Lycopersicon/ Brassica*	*Brassica/ Lycopersicon*
Untreated	9 ± 5	11 ± 5	8 ± 5	13 ± 5
Lanolin/Water	14 ± 4	9 ± 4	10 ± 6	16 ± 6
Gibberellic Acid, 0.5 mg/l	13 ± 8	10 ± 7	8 ± 4	11 ± 4
Indoleacetic Acid (IAA)				
0.01 mg/l	9 ± 5	10 ± 7	8 ± 4	11 ± 4
0.10 mg/l	17 ± 8	19 ± 8	14 ± 7	16 ± 9
1.0 mg/l	18 ± 6	14 ± 4	8 ± 4	14 ± 6
Kinetin, 0.1 mg/l	12 ± 4	8 ± 5	13 ± 3	9 ± 6
IAA (0.10 mg/l) plus Kinetin (0.10 mg/l)	12 ± 7	20 ± 7	18 ± 6	12 ± 3

strengths as high as 150 to 200 g BW/mm^2 graft area (McGarry and Moore 1984). More comprehensive discussions of the use of tensile strength as a diagnostic tool for studying graft development are presented elsewhere (Lindsay et al. 1974; Yeoman and Brown 1976; Moore 1983b).

The application of IAA, kinetin, gibberellic acid, and IAA plus kinetin at concentrations known to stimulate vascular redifferentiation and graft development (Parkinson and Yeoman 1982) did not significantly increase the tensile strengths of incompatible grafts over those of controls (Table 1). That is, application of these growth regulators did not overcome graft incompatibility in the two systems investigated in this study. These data indicate that the mere presence of morphogens necessary for vascular redifferentiation does not ensure that vascular redifferentiation will occur. Furthermore, since the morphogens believed to be responsible for directing vascular redifferentiation are released from severed strands of vascular tissue (LaMotte and Jacobs 1963), there is no reason to believe that the absence of vascular redifferentiation in untreated heterografts is due to the absence of these morphogens. A possible explanation for the lack of vascular redifferentiation in incompatible heterografts is that callus cells at the graft interface are somehow rendered incompetent to respond to the morphogens which normally direct vascular redifferentiation.

ACKNOWLEDGEMENTS

The author thanks Steve Ransom for his capable technical assistance. This research was supported by a grant from the University Research

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EFFECT OF TEMPERATURE ON THE CELLULOLYTIC ACTIVITIES OF TWO SOIL FUNGI

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ABSTRACT

Viscometrically assayed cellulolytic activities of fluids from *Chaetomium globosum* and *Fusarium oxysporum* were stable at temperatures of 10 to 45 C. Coefficients of cellulolytic rate for both fungi increased to the upper limit of stability (45 C) and declined at higher temperatures. Arrhenius plots of the ln rate vs. 1/T indicated cellulase activation energies of 7,292 cal and 9,696 cal for *C. globosum* and *F. oxysporum*, respectively.

INTRODUCTION

Several methods have been developed for the study and measurement of cellulolytic activities of fungi and other microorganisms. Perhaps the most extensively used of these methods involves the measurement of reducing sugars resulting from the action of cell-free filtrates obtained from liquid cultures of the microorganism, on various cellulosic substrates such as carboxymethyl cellulose, filter paper, and fibrous or powdered cellulose (Reese and Mandels 1963; Mandels and Weber 1969). This method equates cellulolytic activity with the production of glucose as inferred from the amount of reducing sugars produced in the reaction mixture after a given time of incubation at constant temperature (Miller 1959; Miller et al. 1960).

Other methods used to measure cellulase activity are based on viscometric techniques (Almin and Eriksson 1967; Almin et al. 1967; Hulme 1971; Ortega and Baca 1983) or on the kinetics of the isolated enzyme (Day 1982).

Here, we present a viscometric analysis of temperature effects on the cellulolytic activities of two soil fungi, *Chaetomium globosum* and *Fusarium oxysporum*, and estimate their cellulase activation energies.

MATERIALS AND METHODS

Isolates of *Chaetomium globosum* (CN 8311-1) and *Fusarium oxysporum* (CN 12351-4) were cultivated in a mineral-salts-enriched liquid medium described before (Ortega and Baca 1983). Seven-day-old

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TABLE 1. Decline in the viscosity of sodium carboxymethyl cellulose at 25 C due to the cellulase activities of two fungi. Cs indicates centistokes.

Chaetomium globosum			*Fusarium oxysporum*		
Time (min)	Eflux (sec)	Nsp (Cs)	Time (min)	Efflux (sec)	Nsp (Cs)
0.00	384	67.09	0.00	347	60.52
0.98	291	50.60	1.02	320	55.74
6.29	236	40.84	6.86	281	48.82
10.86	202	34.82	12.01	253	43.86
14.49	180	30.91	16.71	230	39.78
17.94	163	27.90	20.97	212	36.59
21.13	150	25.60	24.98	199	34.28
24.07	140	23.82	28.70	187	32.16
26.83	131	22.23	32.26	178	30.56
29.46	124	20.99	35.68	170	29.14
31.92	118	19.92	38.96	163	27.90
34.31	112	18.96	42.14	155	26.48
36.49	108	18.15	45.19	149	25.42

cultures of the test fungi grown on solid medium were used as sources of inoculum. Each culture flask was inoculated (Ortega 1980) by aseptically transferring four 5 mm inoculum disks carrying hyphae and spores. All cultures were incubated at 25 C. A 6000 g supernatant aseptically collected from ten-day-old cultures was frozen for subsequent analysis of enzyme activity.

Samples of the culture-fluid supernatant were assayed for carboxymethyl cellulase (CM cellulase, EC.3.2.1.4.) viscometrically as described before (Ortega 1980; Ortega and Baca 1983). The test solution consisted of 7.0 g of sodium carboxymethyl cellulose (CMC, type 7HF with a D.S. of 0.7, by Hercules, Inc.) dissolved in 1000 ml of 0.05 M sodium citrate buffer with a pH of 5.0. The reaction mixture consisted of 9 ml of CMC test solution and 1 ml of the culture-fluid supernatant appropriately diluted (50%) to produce maximum reaction rates (Vmax; Williams and Williams 1973).

The rate coefficient of the reaction was determined by fitting the data obtained from the viscosity tests to an exponential model (Ortega and Baca 1983) of the form

$$Nsp = a \cdot e^{(bt)}$$

where Nsp is the specific viscosity of the substrate, a is the intercept, b is the rate coefficient and t is the incubation time in minutes.

The effect of temperature on the reaction was determined from a series of assays made over the temperature range of 10 to 80 C in increments of 5 degrees. At each temperature, 2 to 3 replicate tests were

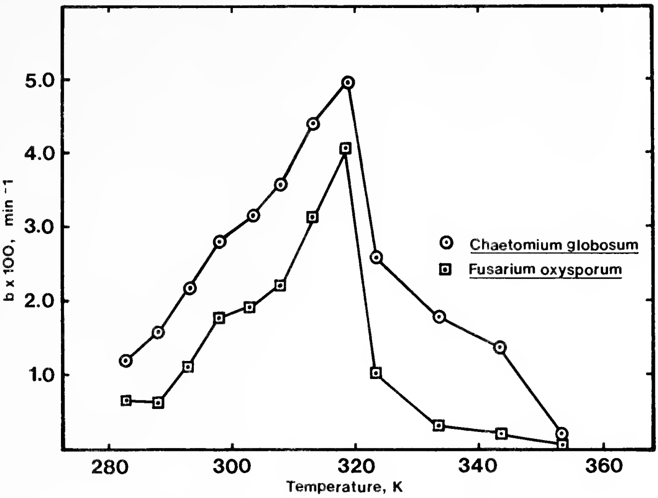

FIGURE 1. Effect of temperature on the reaction rate coefficient for cellulase activities of *Chaetomium globosum* and *Fusarium oxysporum.*

made. The energy of activation for cellulase activity of the test fungi was determined from Arrhenius plots (Williams and Williams 1973) of the data.

Extracellular protein in the culture-fluid supernatant was determined by the method of Bradford (1976), using crystallized bovine albumin (US Biochemical Corp.) as standard.

RESULTS AND DISCUSSION

At 25 C (298 K), the reaction mixture from *C. globosum* caused a reduction in substrate viscosity of 16.49 centistokes during the first minute of incubation; in contrast, the reaction mixture from *F. oxysporum* caused a first-minute reduction of only 4.78 centistokes at 25 C (Table 1). The exponential rate coefficient b was 0.028 min^{-1} for *C. globosum* and 0.017 min^{-1} for *F. oxysporum.* This difference between the two fungi in apparent cellulase activity may have been partly attributable to differences in the relative richness of their culture fluids: protein level of the *C. globosum* supernatant (22 μg/ml) was almost twice that of the *F. oxysporum* supernatant (13 μg/ml).

In the assays at all temperatures, coefficients of correlation with the exponential model of viscosity change were higher than 0.95. At each temperature, the reaction rate constant (b) for *C. globosum* was higher than the value for *F. oxysporum* (Fig. 1). The values of the reaction rate constant determined in the assays of the fluids of both test fungi increased when the temperature of incubation was incremented up to 318 T (45 C); further increments of the incubation temperature reduced

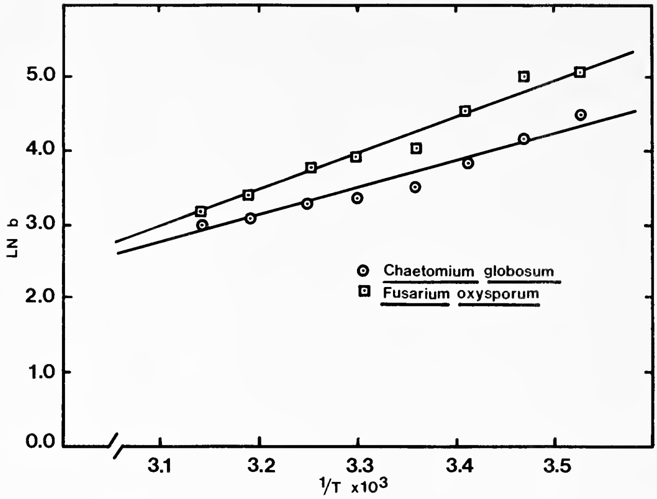

FIGURE 2. Arrhenius plots of the cellulase activities of *Chaetomium globosum* and *Fusarium oxysporum* inferred from viscometric assay. LN b = natural logarithm of the exponential rate coefficient; T = absolute temperature in degrees Kelvin. The equation for the regression line of *Chaetomium globosum* is LN b = −8.61 + 3670/T (r^2 = 0.97). The equation for the regression line of *Fusarium oxysporum* is LN b = −12.12 + 4880/T (r^2 = 0.96).

drastically the rate of the reaction (Fig. 1). These results indicate that the cellulases of both test fungi are stable at temperatures of 10 to 45 C (283 to 318 K) and that higher temperatures reduce cellulase activity.

Similar results were obtained by Mandels and Weber (1969) for the cellulases of *Trichoderma viride* and Hagerdal et al. (1979) for the cellulolytic enzyme system of *Thermoactinomyces* sp.

The energy of activation (Ea) for the cellulase activity of the test fungi was estimated by linear regression of Arrhenius plots (ln b vs. 1/T; Fig. 2). Activation energies were obtained from the slopes of the lines which represent Ea/R, where R = 1.9869 cal per degree C per mole. Energies of activation were 7,292 cal and 9,696 for *C. globosum* and *F. oxysporum*, respectively. Since enzymes increase the rate of a reaction by lowering the activation energy, it can be inferred that the cellulase activity of *C. globosum* was higher than that of *F. oxysporum*.

Measurement of the decline in substrate viscosity as an indicator of enzyme activity is a simple procedure which yields activity of the enzyme as a percentage of the maximal reduction in the viscosity of the substrate. The determination of enzyme activity by this method may be dependent on the quantity of enzyme and other experimental variables.

The energy of activation of the reaction as an indicator of enzyme activity requires temperature-dependent studies of the reaction rate constant. However, this indicator of enzyme activity is independent of the amount of enzyme and other experimental variables. Furthermore, the required reaction rate constants for the measurement of the activation energy can be expressed and measured in terms of an experimental variable (in this case, viscosity) which is proportional to the concentration of the substrate. Therefore, the activation energy of the reactions studied in this work can be utilized as a relative measure of enzyme activity.

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Notice of Publication

PROTECTION OF TEXAS NATURAL DIVERSITY: AN INTRODUCTION FOR NATURAL RESOURCE PLANNERS AND MANAGERS

Edited by
E. Glenn Carls and James Neal

Contents

Copies of this publication are available at no charge from *Bulletin Room, Ag. Communications, Texas A&M University, College Station, Texas 77843.*

Erratum

In the paper

> Young, K. 1984. *Hysteroceras* Hyatt [Cretaceous (Albian) ammonoid] in Texas and the Angola connection. Texas Journal of Science 36(2&3):185-195,

Figure 3 (p. 189) was reduced photographically to 76.5% of the original size without corresponding adjustment of the multipliers given in the figure caption. Each of the multipliers can be corrected by multiplying it by 0.765. For example, specimen A is shown $1.5 \times 0.765 = 1.15$ times its actual size, not 1.5 times its actual size.

We apologize to subscribers and to Dr. Young for this error in production of his paper. Please amend your copy of TJS 36(2&3) to accommodate the correction.

INDEX TO VOLUME XXXVI (1984), THE TEXAS JOURNAL OF SCIENCE

by CHARLOTTE A. NEILL

Medical Sciences Library

and L. JOSEPH FOLSE

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PREFACE

This index has separate subject and author sections.

The subject index is patterned after that currently used in the Proceedings of the National Academy of Sciences: The key word or phrase is followed by the complete title and initial page number of each relevant article. However, when the key word(s) comprises the name of a biological or chemical taxon mentioned primarily in the context of a survey, the relevant article is identified only by initial page number. In the latter case, biological species are indexed only to the generic level, except that common names of species are used in cases where corresponding scientific names did not appear in the article.

Index terms were chosen both from titles and texts. Key words supplied by authors also were used. Index terms were alphabetized by a computer program that disregarded conformational prefixes, numerals, and hyphenated Greek letters.

The author index includes the names of all authors of each article. Each name is followed by the number of the first page of that author's article.

C.A.N. did the indexing; L.J.F. developed the microcomputer programs (in Pascal) that assimilated the key-word information and produced the index.

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REVIEWERS

The persons listed below have reviewed manuscripts for the Texas Journal of Science within the past year. The Academy is very grateful for their help.

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Map of Lake Conroe, TX

from Bettoli et al., pp. 221-233.
(Also, see related papers, pp. 235-257.)

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